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CK-12 Earth Science Concepts

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CHAPTER 1

Principles of Science

Chapter Outline

Introduction

Science is Different from Other Ways of Understanding the World

If someone asks you "what is science?" you might say that it's a bunch of facts and explanations. But that's only part of the story. Science is a knowledge base. But science is also a way of learning about the world.

1.1 Scientific Explanations and Interpretations

- Identify and define facts, explanations, and opinions.

"It used to be, everyone was entitled to their own opinion, but not their own facts. But that's not the case anymore." Stephen Colbert, AV Club Interview, January 2006

Can you tell a fact from an opinion? Can you tell when an idea follows logically from a fact? Basing ideas on facts is essential to good science. **Science** is a set of facts, and it is also a set of explanations that are based on those facts. Science relies on facts to explain the natural world.

Facts, Observations, Opinions

Scientists usually begin an investigation with facts. A **fact** is a bit of information that is true. Facts come from data collected from observations or from experiments that have already been run. **Data** is factual information that is not subject to opinion or bias.

What is a fact? Look at the following list and identify if the statement is a fact (from observation or prior experiments), an opinion, or a combination.

FIGURE 1.1
Can you be sure from the photo that Susan has a cold?

1. Susan has long hair.
2. Susan is sneezing and has itchy eyes. She is not well. She has a cold.
3. Colds are caused by viruses.
4. Echinacea is an herb that prevents colds.
5. Bill Gates is the smartest man in the United States.
6. People born under the astrological sign Leo are fiery, self-assured, and charming.
7. Average global temperature has been rising at least since 1960.

An Analysis

The following is an analysis of the statements above:

1. This is a fact made from observation.
2. The first part is from observations. The second is a fact drawn from the prior observations. The third is an opinion, since she might actually have allergies or the flu. Tests could be done to see what is causing her illness.

3. This is a fact. Many, many scientific experiments have shown that colds are caused by viruses.
4. While that sounds like a fact, the scientific evidence is mixed. One reputable study published in 2007 showed a decrease of 58%, but several other studies have shown no beneficial effect.
5. Bill Gates is the wealthiest man in the United States; that's a fact. But there's no evidence that he's also the smartest man, and chances are he's not. This is an opinion.
6. This sounds like a fact, but it is not. It is easy to test. Gather together a large number of subjects, each with a friend. Have the friends fill out a questionnaire describing the subject. Match the traits against the person's astrological sign to see if the astrological predictions fit. Are Leos actually more fiery, self assured, and charming? Tests like this have not supported the claims of astrologers, yet astrologers have not modified their opinions.
7. This is a fact. The graph below shows the temperature anomaly since 1880. There's no doubt that temperature has risen overall since 1880 and especially since the late 1970s.

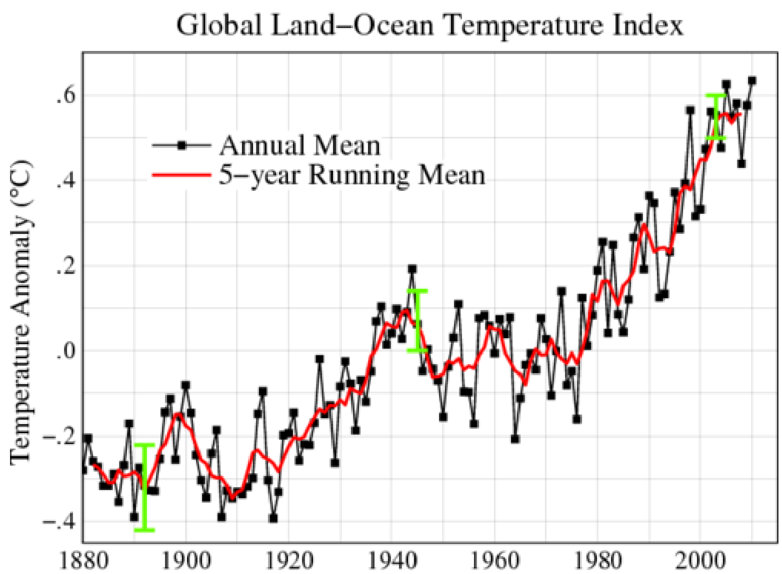


FIGURE 1.2

Global Average Annual Temperatures are Rising. This graph shows temperature anomaly relative to the 1951-1980 average (the average is made to be 0). The green bars show uncertainty.

Vocabulary

- **data**: Facts that have been uncovered scientifically by systematic observations or experiments.
- **fact**: A bit of information that is true.
- **science**: Knowledge about the natural world gathered systematically.

Summary

- Facts are true. Data, gathered correctly, are facts.
- Some statements that appear to be facts are not.
- All scientific explanations and interpretations are based on facts.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=zcavPAFiG14

MEDIA

Click image to the left for more content.

1. What is science?
2. What is evidence?
3. List the steps of the scientific method (procedure).
4. What happens if a hypothesis is determined to be wrong?
5. Why is peer review important?
6. What is a theory?
7. Why might a theory be modified?
8. Explain the importance of the scientific method.

Review

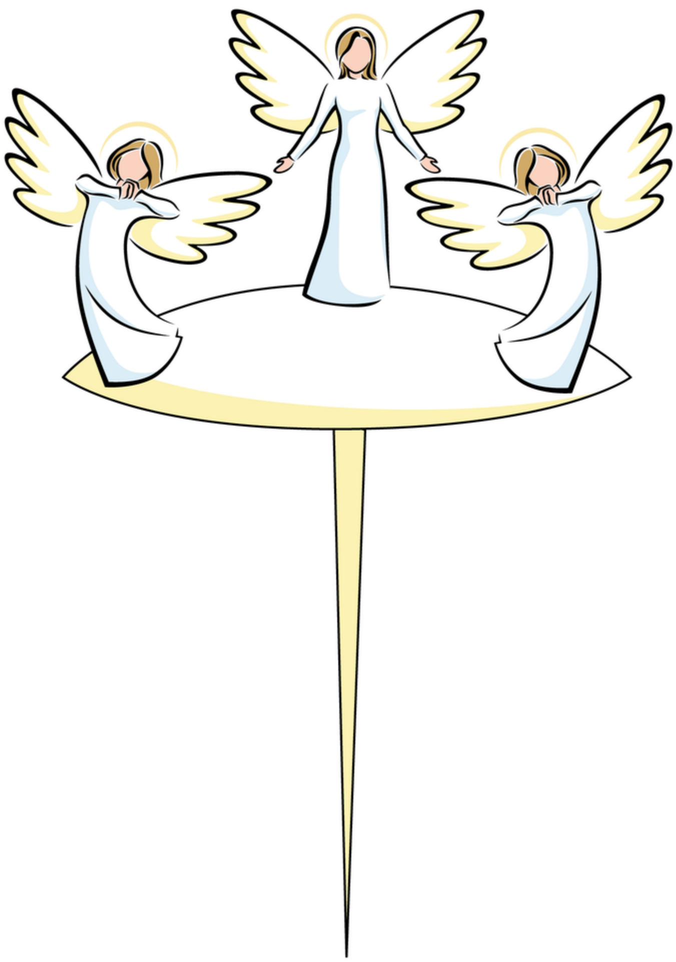
1. Just because something appears in print doesn't mean it's true. Many stories circulate around the internet and appear to be true but are not. Take a look at http://www.snopes.com to see some interesting true and false tales. Think of something that you think is true, but may not be, and look it up. Here's one: a tooth placed in Coca-Cola will dissolve overnight.

2. Neuroscientists have shown that people are more likely to believe a statement if they have heard it before, whether it's true or not. Look in a newspaper or watch television news and find three statements that are not actually true but that the person saying them is hoping will be believed. Is this effective?

3. What is the relationship between observations and facts? What is the relationship between facts and opinions?

1.2 Scientific Method

- Explain how scientific questions are answered using scientific method.



How many angels can dance on the head of a pin?

This is a question that has been pondered over the centuries. Can it be answered using scientific method? Is it a scientific question?

The Goal of Science

The goal of science is to answer questions about the natural world. Scientific questions must be testable. Which of these two questions is a good scientific question and which is not?

- What is the age of our planet Earth?

- How many angels can dance on the head of a pin?

The first is a good scientific question that can be answered by radiometrically dating rocks among other techniques. The second cannot be answered using data, so it is not a scientific question.

Scientific Method

Scientists use the **scientific method** to answer questions. The scientific method is a series of steps that help to investigate a question.

Often, students learn that the scientific method is a linear process that goes like this:

- Ask a question. The question is based on one or more observations or on data from a previous experiment.
- Do some background research.
- Create a hypothesis.
- Do experiments or make observations to test the hypothesis.
- Gather the data.
- Formulate a conclusion.

The process doesn't always go in a straight line. A scientist might ask a question, then do some background research and discover that the question needed to be asked a different way, or that a different question should be asked.

A flow chart of how science works that is much more accurate than the simple list above is found here: http://undsci.berkeley.edu/lessons/pdfs/complex_flow_handout.pdf.

Ask A Question

Now, let's ask a scientific question. Remember that it must be testable.

We learned above that average global temperature has been rising since record keeping began in 1880. We know that carbon dioxide is a **greenhouse gas**. Greenhouse gases trap heat in the atmosphere. This leads us to a question:

Question: Is the amount of carbon dioxide in Earth's atmosphere changing?

This is a good scientific question because it is testable.

How has carbon dioxide in the atmosphere changed over those 50-plus years? About how much has atmospheric CO_2 risen between 1958 and 2011 in parts per million?

Answer a Question

So we've answered the question using data from research that has already been done. If scientists had not been monitoring CO_2 levels over the years, we'd have had to start these measurements now.

Because this question can be answered with data, it is testable.

Vocabulary

- **greenhouse gas**: Gases such as carbon dioxide and methane that absorb and hold heat from the sun's infrared radiation in the atmosphere.
- **scientific method**: A means of investigating a testable question using empirical information gathered from experiments, experience, or observations.

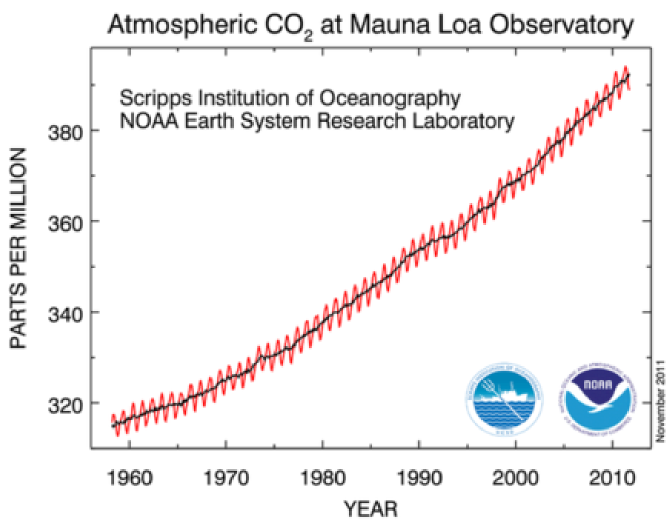


FIGURE 1.3
Atmospheric carbon dioxide has been increasing at Mauna Loa Observatory in Hawaii since 1958. The small ups and downs of the red line are seasonal variations. The black line is the annual average.

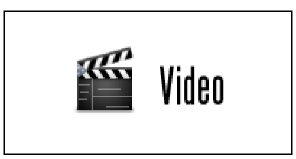
Summary

- Scientists use scientific method to answer questions about the natural world.
- First, scientists ask a question that they want to answer.
- Background research is essential for better understanding the question and being able to move to the next step.

Practice

Use this resource to answer the questions that follow.

http://www.schooltube.com/video/f52dc16d06d58ede92d5/writing-scientific-questions



MEDIA
Click image to the left for more content.

1. What is the first rule of writing science questions?
2. What is rule number 2?
3. What type of questions should NOT be used?
4. What is rule number 3?
5. Write a good scientific question using the three rules.

Review

1. What features does a question need to have to be a good science question?
2. Create a list of three questions that are good science questions. Create a list of three questions that are not science questions.

3. Look at the graph of atmospheric CO_2 over time above. As close as you can determine, how much as the atmospheric CO_2 content risen since 1958?

1.3 Development of Hypotheses

- Describe the characteristics of a good hypothesis.

What is a hypothesis?

An educated guess? Is that what you learned a hypothesis is? Lots of people have learned that, but it's not exactly right. So what is a hypothesis? There are two hypotheses listed below to address a question about carbon dioxide in the atmosphere. Check out what those hypotheses are and what to do with them next.

Asking a New Question

Before we develop some hypotheses, let's find a new question that we want to answer. What we just learned – that atmospheric CO_2 has been increasing since 1958 — leads us to ask this question: why is atmospheric CO_2 increasing?

Possible Answers for the Question

We do some background research to find the possible sources of carbon dioxide into the atmosphere. We discover two things:

- Carbon dioxide is released into the atmosphere by volcanoes when they erupt.
- Carbon dioxide is released when fossil fuels are burned.

A **hypothesis** is a reasonable explanation to explain a small range of phenomena. A hypothesis is limited in scope, explaining a single event or a fact. A hypothesis must be **testable** and **falsifiable**. We must be able to test it and it must be possible to show that it is wrong.

From these two facts we can create two hypotheses. We will have **multiple working hypotheses**. We can test each of these hypotheses.

Hypothesis 1

Atmospheric CO_2 has increased over the past five decades, because the amount of CO_2 gas released by volcanoes has increased.

Hypothesis 2

The increase in atmospheric CO_2 is due to the increase in the amount of fossil fuels that are being burned.

Usually, testing a hypothesis requires making observations or performing experiments. In this case, we will look into the scientific literature to see if we can support or refute either or both of these hypotheses.

Vocabulary

- **falsifiable**: Able to be proven false by an observation or experiment and therefore testable.
- **hypothesis**: A good working explanation for a problem that can be tested.
- **multiple working hypotheses**: Two or more hypotheses that can be tested simultaneously or in sequence.
- **testable**: Able to be evaluated critically, usually using data.

Summary

- A hypothesis is a reasonable explanation to explain a phenomenon.
- A scientific hypothesis must be testable and falsifiable.
- Often, scientists as individuals or as a group test more than one hypothesis at a time to explain a phenomenon. This is called multiple working hypotheses.

Practice

Use this resource to answer the questions that follow.

http://www.teachertube.com/viewVideo.php?video_id=195822#38;title=Hypothesis_Machine

MEDIA

Click image to the left for more content.

1. Review: What is the purpose of the scientific method?
2. What is your task?
3. Create a hypothesis that explains how the machine works.
4. Examine your hypothesis. What questions do you have?
5. Revise your hypothesis and explain how you might test it.

Review

1. How is defining hypothesis as "a reasonable explanation" different from defining it as "an educated guess"?
2. If a hypothesis is shown to be wrong, is the question the scientists are trying to answer a bad question?
3. Why would scientists have multiple working hypotheses rather than just dealing with one hypothesis until it is shown to be right or is thrown out?

1.4 Testing Hypotheses

- Identify and explain the steps required to test a hypothesis.

How can I show that my hypothesis is wrong?

Many young scientists learn that a good scientist tries to disprove her hypothesis. This is the best way to be sure that your hypothesis is getting a rigorous test. Why do you think established scientists tell students this? Why is it a good idea?

Testing Hypothesis 1

How do you test a hypothesis? In this example, we will look into the scientific literature to find data in studies that were done using scientific method.

To test Hypothesis 1 from the concept "Development of Hypotheses," we need to see if the amount of CO_2 gas released by volcanoes over the past several decades has increased.

There are two ways volcanoes could account for the increase in CO_2:

- There has been an increase in volcanic eruptions in that time.
- The CO_2 content of volcanic gases has increased over time globally.

To test the first, we look to the scientific literature and find this graph:

We see that the number of volcanic eruptions is about constant. We also learn from the scientific literature that volcanic gas compositions have not changed over time. Different types of volcanoes have different gas compositions, but overall the gases are the same. Another journal article states that major volcanic eruptions for the past 30 years have caused short-term cooling, not warming!

Hypothesis 1 is wrong! Volcanic activity is not able to account for the rise in atmospheric CO_2. Remember that science is falsifiable. We can discard Hypothesis 1.

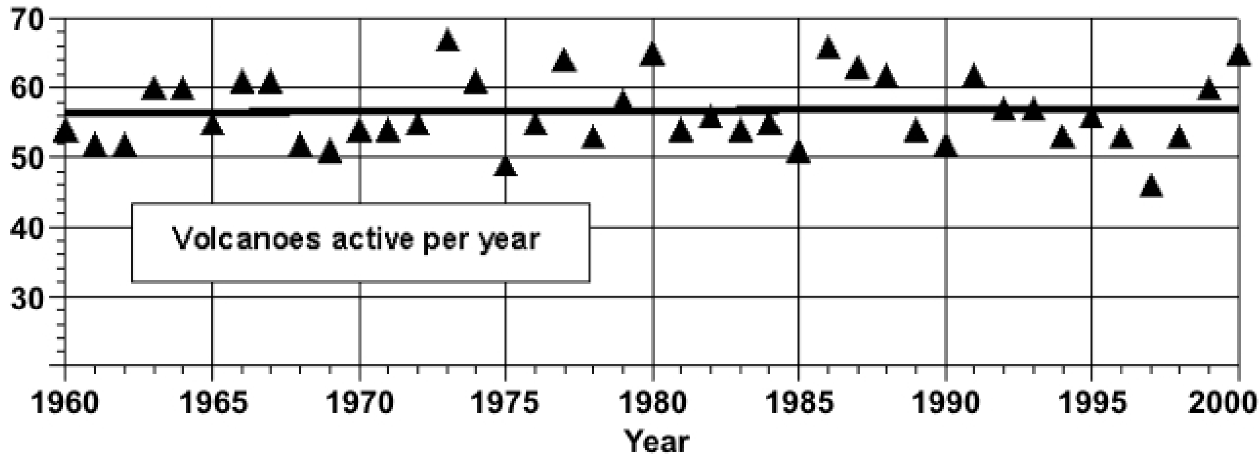


FIGURE 1.4
Number of active volcanoes since 1960.

Testing Hypothesis 2

Hypothesis 2 states that the increase in atmospheric CO_2 is due to the increase in the amount of fossil fuels that are being burned. We look into the scientific literature and find this graph.

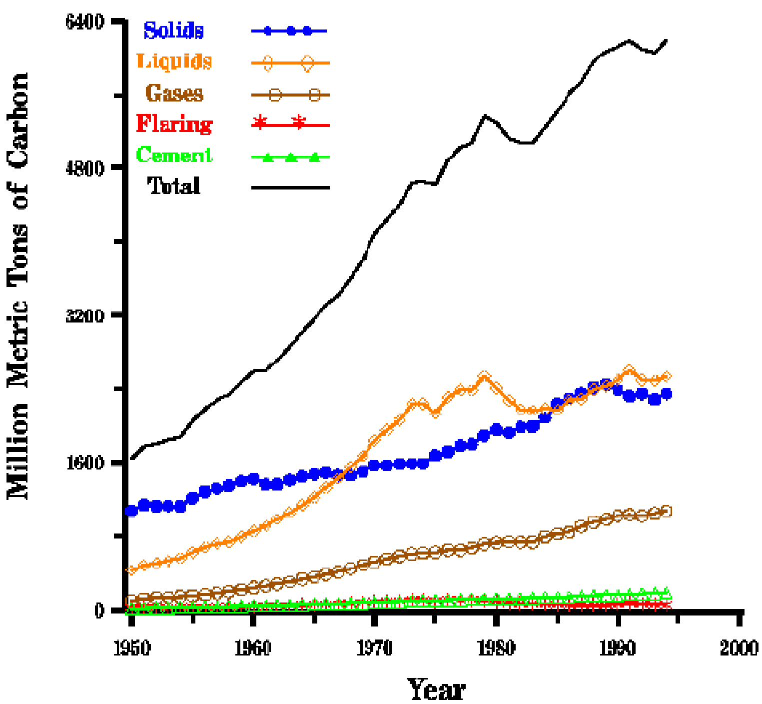


FIGURE 1.5
Global carbon dioxide emissions from fossil fuel consumption and cement production. The black line represents all emission types combined, and colored lines show emissions from individual fossil fuels.

Fossil fuels have added an increasing amount of carbon dioxide to the atmosphere since the beginning of the Industrial Revolution in the mid 19th century. Hypothesis 2 is true!

Summary

- Science is falsifiable. An incorrect hypothesis is discarded.
- Carbon dioxide levels in the atmosphere are increasing due to fossil fuel burning.

Practice

Use this resource to answer the questions that follow.

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

Note: the term theory is used inaccurately in the video.

MEDIA

Click image to the left for more content.

1. How are they using the word theory in this video? What word would be more accurate for them to use in this context?

2. What is the hypothesis they are testing?

3. How do they test the hypothesis?

4. What were their results?

5. Is their hypothesis absolutely certainly correct? If you say, that they don't know yet, what can they do to further narrow down whether the hypothesis is correct?

Review

1. Think of at least one other hypothesis for why atmospheric carbon dioxide has been rising for the past several decades. How would you test that hypothesis?
2. If your hypothesis is shown to be true, does that mean that hypothesis 2, which states that the increase in atmospheric CO_2 is due to fossil fuel burning, is wrong?
3. How did having multiple working hypotheses help this investigation along?

1.5 Correlation and Causation

- Distinguish between correlation and causation.

Sugar consumption up. Global temperatures up. Is one causing the other?

Is the rise in sugar consumption in America causing average global temperature to rise? Are rising temperatures causing people to eat more sugar? Both of these factors are rising but are they related by correlation, causation, or both?

Correlation

We made a few discoveries in the previous sections:

- Average global temperature has been rising for the past several decades.
- Atmospheric carbon dioxide levels have been rising for the past several decades.
- Carbon dioxide emissions into the atmosphere from fossil fuel burning have been rising for the past several decades.

We see a correlation. A **correlation** is the mutual relationship between two or more things. CO_2 emissions from fossil fuel burning, atmospheric CO_2 levels, and average global temperatures are all rising. They exhibit **positive correlation** because they are all going in the same direction. If one factor rises while another sinks they have **negative correlation**.

Causation

But correlation does not necessarily indicate causation. To explain the difference, let's look at an example. Sugar consumption in the United States has also been rising for decades. This is positively correlated with rising average global temperatures.

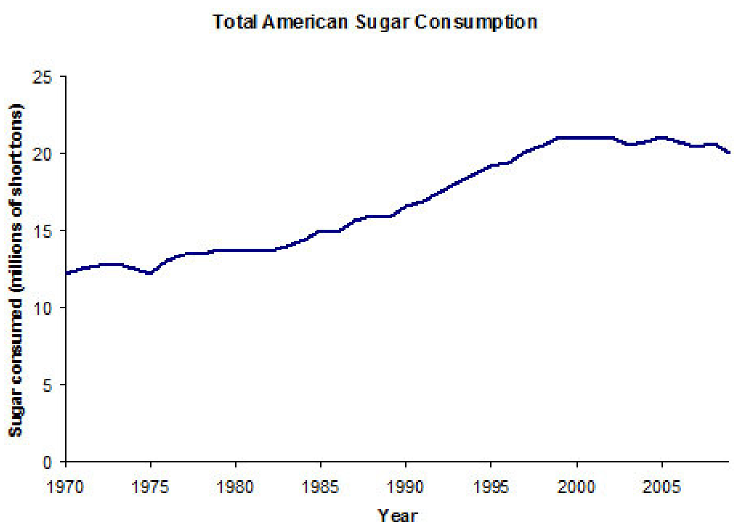


FIGURE 1.6
American consumption of caloric sweeteners (sugar), 1970-2009.

Is the rise in sugar consumption causing the rise in global temperatures or vice versa? While this isn't impossible; it's extremely unlikely. There's no **mechanism** for one to increase the other. Here there is correlation, not causation.

Causation refers to the factor that is producing the effect. To establish causation we need to know how one would cause the other.

Here is a brief outline of the way an increase in CO_2 can increase global temperatures. Climate change science is dealt with extensively in the "Climate Change" concepts.

- Greenhouse gases in the atmosphere trap heat. This is natural and good.
- CO_2 is a greenhouse gas.
- The more greenhouse gases there are in the atmosphere, the more heat can be trapped.
- The more heat that's trapped, the warmer average global temperatures are.

Because carbon dioxide is a greenhouse gas, increased atmospheric CO_2 causes average global temperatures to rise. We found one cause for rising global temperatures. There are also others.

Vocabulary

- **causation**: The relationship between an event and another event in which one event caused the other event.
- **correlation**: A mutual relationship between two or more things.
- **mechanism**: The process by which something takes place.

- **negative correlation**: A mutual relationship between two or more things in which one changes in one direction and the other changes in the opposite direction.
- **positive correlation**: A mutual relationship between two or more things in which both change in the same direction.

Summary

- Correlation is a comparison of two factors within a population. Correlation does not imply causation.
- If one factor is responsible for the change in another factor, there is causation.
- Establishing causation requires a mechanism to show how one factor can influence the other.
- Burning fossil fuels releases CO_2 into the atmosphere. That CO_2 traps heat, which causes global temperatures to rise.

Practice

Use these resources to answer the questions that follow.

Correlation vs. Causality: Freakonomics Movie (http://www.youtube.com/watch?v=lbODqslc4Tg)

MEDIA
Click image to the left for more content.

1. Why did people fear polio?

2. Why did people think there was a correlation between ice cream and polio?

Correlation vs. Causality: Continued (http://www.youtube.com/watch?v=t8ADnyw5ou8)

MEDIA
Click image to the left for more content.

3. Why are there more police in Washington DC than in Denver? Where is there more crime? Do police cause crime? Then why are there more police in Washington DC?

4. Explain why people often confuse correlation and causation.

Review

1. Compare and contrast correlation and causation.

2. Sugar consumption has been rising in the U.S. for decades. Can you think of something this might be positively correlated with? Can you think of something this might be negatively correlated with?

3. Name at least two factors that are changing as a result of the increase in sugar consumption in the U.S. Is this correlation or causation?

1.6 Observations and Experiments

- Explain how observations and experiments are used to answer scientific questions.

How do you test a hypothesis?

When you test a hypothesis, you must make observations or perform experiments. We could test the two hypotheses in the concept "Correlation and Causation" using the scientific literature because scientists who came before us collected that data using scientific method. If the question was new we would need to do the testing ourselves. How might you do the testing yourself?

Testing Hypotheses

If we were doing a scientific investigation we need to gather the information to test the hypotheses ourselves. We would do this by making observations or running experiments.

Observations

Observations of Earth's surface may be made from the land surface or from space. Many important observations are made by orbiting satellites, which have a bird's eye view of how the planet is changing.

Often, observation is used to collect data when it is not possible for practical or ethical reasons to perform experiments. Scientists may send devices to make observations for them when it is too dangerous or impractical for them to make the observations directly. They may use microscopes to explore tiny objects or telescopes to learn about the universe.

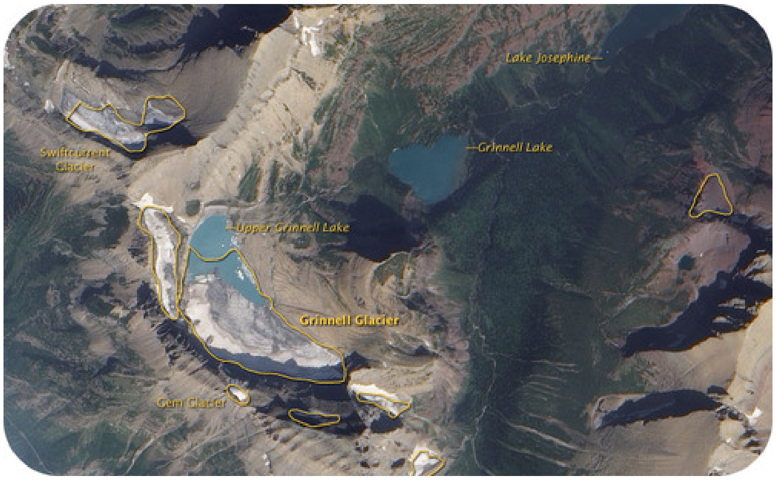


FIGURE 1.7
This satellite image shows how the extent of glaciers in Glacier National Park has changed in recent years.

FIGURE 1.8
Artist's concept of the Juno orbiter circling Jupiter. The mission is ongoing.

Experiments

Answering some questions requires **experiments**. An experiment is a test that may be performed in the field or in a laboratory. An experiment must always done under controlled conditions. The goal of an experiment is to verify or falsify a hypothesis.

In an experiment, it is important to change only one factor. All other factors must be kept the same.

- **Independent variable**: The factor that will be manipulated.
- **Dependent variable**: The factors that depend on the independent variable.

An experiment must have a **control group**. The control group is not subjected to the independent variable. For example, if you want to test if Vitamin C prevents colds, you must divide your sample group up so that some receive Vitamin C and some do not. Those who do not receive the Vitamin C are the control group.

Experimental Error

Scientists often make many measurements during experiments. As in just about every human endeavor, errors are unavoidable. In a scientific experiment, this is called **experimental error**. **Systematic errors** are part of the experimental setup, so that the numbers are always skewed in one direction. For example, a scale may always measure one-half of an ounce high. **Random errors** occur because a measurement is not made precisely. For example, a stopwatch may be stopped too soon or too late. To correct for this, many measurements are taken and then averaged. Experiments always have a margin of error associated with them.

In an experiment, if a result is inconsistent with the results from other samples and many tests have been done, it is likely that a mistake was made in that experiment. The inconsistent data point can be thrown out.

Vocabulary

- **control group**: A group in a scientific experiment in which the factor being tested, the independent variable, is not applied; used as a basis for comparison.
- **dependent variable**: The variable in an experiment that is being measured as the independent variable is changed.
- **experiment**: A trial made under controlled conditions to test the validity of a hypothesis.
- **experimental error**: Errors that are made due to problems with the experimenter.
- **independent variable**: The variable in an experiment that is controlled and changed by the researcher.
- **random error**: A mistake made by the person performing the experiment or from an event that occurs for no apparent reason.
- **systematic error**: Errors that are due to some problem in the system so that the results are always skewed in one direction.

Summary

- Testing a hypothesis requires data. Data can be gathered by observations or by experiments.
- Observations can be done simply by looking at and measuring a phenomenon, or by using advanced technology.
- Experiments must be well-designed. They must be done under controlled conditions and with the manipulation of only one variable.
- Guidelines must be followed when dealing with possible experimental errors.

Practice

Use these resources to answer the questions that follow.

http://www.slideshare.net/cmsdsquires/inference-and-observation-activity-presentation

MEDIA

Click image to the left for more content.

1. What is an observation?

2. What is an inference?

3. For each slideshow picture, list an observation. Now, for each picture list an inference. How can you tell the difference?

Go to the following website: http://www.sciencekids.co.nz/gamesactivities/rockssoils.html

Conduct the experiments to find the following answers:

4. Which rock floats?
5. Which rocks are permeable?
6. Which rocks can be split?
7. Which rocks wear well?
8. How did you do experiments to find the answers to the questions?

Review

1. Under what circumstances would a scientist test a hypothesis using observations?
2. Under what circumstances would a scientist test a hypothesis using experiments?
3. What is the difference between an independent and a dependent variable in an experiment?

1.7 Development of Theories

- Define the terms theory and law as they are used in science.

Do you have a theory about this couple?

"My theory on why she doesn't want to go out with him any more is that he won't let her see her friends." While that might be why she doesn't want to go out with him, the idea is not a theory. In common speech, the word theory is often misused. It is sometimes misused when referring to scientific ideas as well. What would be a better word to use?

Theory

Scientists seek evidence that supports or refutes a hypothesis. If there is no significant evidence to refute the hypothesis and there is an enormous amount of evidence to support it, the idea is accepted. It may become a theory.

A scientific **theory** is strongly supported by many different lines of evidence. A theory has no major inconsistencies. A theory must be constantly tested and revised. A theory provides a model of reality that is simpler than the phenomenon itself. Scientists can use a theory to offer reliable explanations and make accurate predictions.

A theory can be revised or thrown out if conflicting data is discovered. However, a longstanding theory that has lots of evidence to back it up is less likely to be overthrown than a newer theory. But science does not prove anything beyond a shadow of a doubt.

Laws

Many people think that any idea that is completely accepted in science is a law. In science, a **law** is something that always applies under the same conditions. If you hold something above the ground and let go it will fall. This phenomenon is recognized by the law of gravity. A law explains a simpler phenomenon or set of phenomena than does a theory. But a theory tells you why something happens and a law only tells you that it happens.

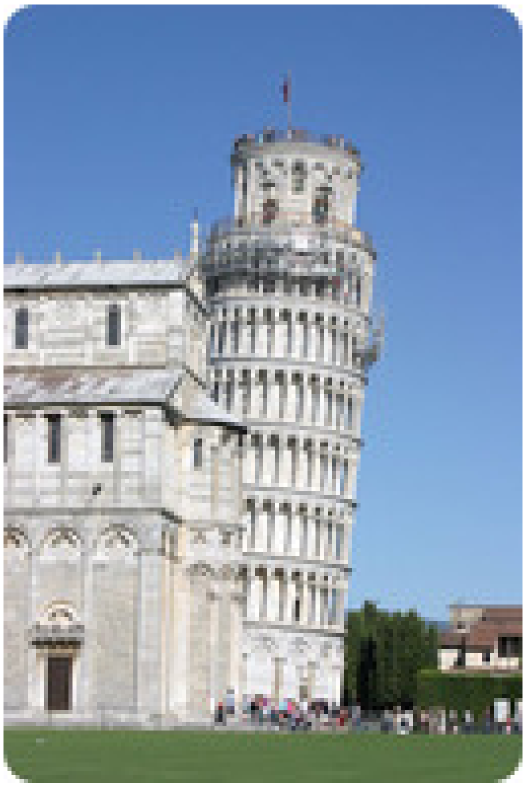


FIGURE 1.9
The Leaning Tower of Pisa in Italy only appears to defy gravity.

Amazingly, scientific laws may have exceptions. Even the law of gravity does not always hold! If water is in an enclosed space between a hillside and a glacier, the weight of the glacier at the bottom of the hill may force the water to flow uphill – against gravity! That doesn't mean that gravity is not a law. A law always applies under the right circumstances.

Vocabulary

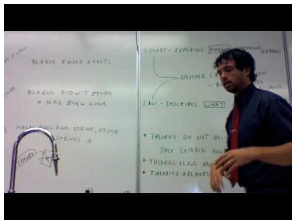
- **law**: An explanation that always applies under the same circumstances.
- **theory**: A hypothesis or group of hypotheses that have been repeatedly tested that have no significant evidence against them. A theory is testable and falsifiable.

Summary

- In science, a theory is an explanation of a much more complex phenomenon than a law describes. A theory tells why something happens.
- A theory can be used to predict future events.
- A law describes something that always happens under the same set of circumstances, but not why it happens. But even laws do not always hold.

Practice

Use this resource to answer the questions that follow.



MEDIA
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1. What is a theory?
2. What is a law?
3. What is the purpose of a theory?
4. What is the purpose of a law?
5. Does a theory ever become a law?
6. If a theory gets more evidence to support it, what does it become?
7. There is a law of gravity? Is there a theory of gravity? How are these different?

Review

1. Compare and contrast hypothesis, theory, and law.
2. Can a theory become a law or a law become a theory? Can a hypothesis become a law or a theory?
3. Which of these, if any, is more important in science: hypothesis, theory, or law?

1.8 Evolution, Plate Tectonics, and Climate Change

- Describe the three essential theories of Earth science: the theory of evolution, the theory of plate tectonics, and the theory of climate change.

How do you know this isn't what the world is like?

The natural world wouldn't make much sense without the theories scientists have developed to explain the things that happen or that we observe. Without science, we might think that the world was on the back of an elephant that rested on a tortoise (an inquisitive person would then wonder what the tortoise is resting on). With science, we have theories. Some are essential for earth science.

Three Essential Theories

Scientific theories are sometimes thrown out when the data shows them to be wrong. Before plate tectonics theory was accepted, people thought that fossil organisms had spread around using land bridges. Although a land bridge across the Atlantic seemed a bit far-fetched, there was no better idea. Most scientists were relieved when they could toss that theory out.

But some theories account for so many phenomena and are so broadly supported by so many lines of evidence that they are unlikely ever to be disproved. Additional scientific evidence may reveal problems and scientists may need to modify the theories. But there is so much evidence to support them and nothing major to refute them that they have become essential to their fields of science.

The Theory of Evolution

Darwin's theory of **evolution** has been under attack ever since Darwin proposed it. But nearly all biologists accept the theory and recognize that everything they learn about life on Earth supports the theory. Evolution is seen in the fossil record, in the developmental paths of organisms, in the geographic distribution of organisms, and in the genetic codes of living organisms. Evolution has a mechanism, called **natural selection**. People often refer to natural selection as "the survival of the fittest." With natural selection, the organism that is best adapted to its environment will be most likely to survive and produce offspring, thus spreading its genes to the next generation.

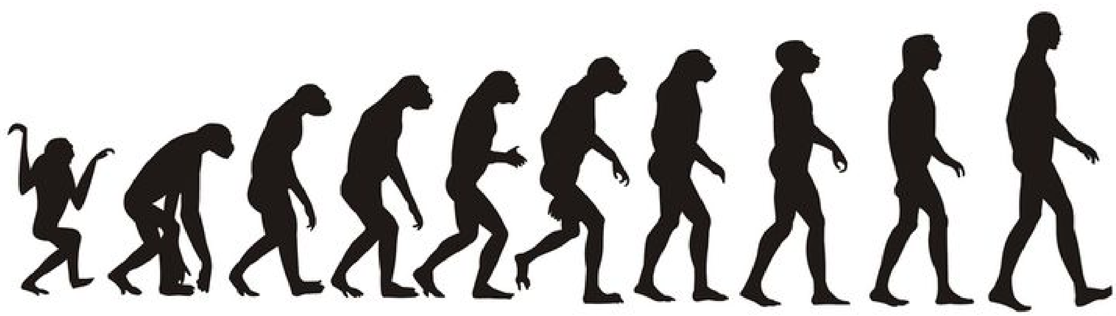


FIGURE 1.10
The theory of evolution maintains that modern humans evolved from ape-like ancestors.

The Theory of Plate Tectonics

The theory of plate tectonics is the most important theory in much of earth science. Plate tectonics explains why much geological activity happens where it does, why many natural resources are found where they are, and can be used to determine what was happening long ago in Earth's history. The theory of plate tectonics will be explored in detail in later concepts.

The Theory That Climate is Changing Due to Human Activities

The theory of climate change is a much newer theory than the previous two. We know that average global temperatures are rising. We even know why: Carbon dioxide is released into the atmosphere when fossil fuels are burned.

Carbon dioxide is a greenhouse gas. In the atmosphere, greenhouse gases trap heat. This is like putting an extra blanket over Earth. Since more heat is being trapped, global temperature is rising.

There is very little information that contradicts the theory that climate is changing due in large part to human activities. Unless some major discrepancy is discovered about how the atmosphere works, the theory is very likely to stand. So far, the evidence that is being collected supports the idea and global warming can be used to predict future events, which are already taking place. This idea will be explored in detail in later concepts.

Vocabulary

- **evolution**: Change through time. The change in the genetic makeup of a population of organisms over time such that a new species is often the result.
- **natural selection**: The mechanism for evolution. Natural processes favor some traits over others in a population causing those traits to be more common in subsequent generations. This results in change to a new species or subspecies.

Summary

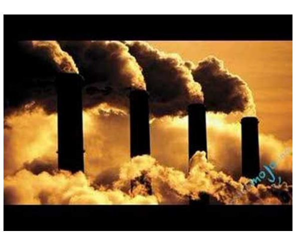
- Since scientific ideas must be testable and falsifiable, theories are sometimes tested and shown to be wrong.
- Many theories have held up against most tests over many decades. These theories may need to be modified but they are solid at their core.
- Three essential theories for Earth Science are the theory of evolution, the theory of plate tectonics, and the theory that human activities are altering Earth's climate.

Practice

Use these resource to answer the questions that follow. Note that plate tectonics will be described in great detail in coming concepts.

MEDIA
Click image to the left for more content.

1. Briefly explain the theory of evolution.
2. Why is the evolution by natural selection called the unifying theory of biology?
3. How have scientists tested this theory so that it is so widely accepted?
4. Is it likely that scientists will unearth something that will show the theory of evolution to be false?
5. How does the process of evolution differ from the theory of evolution?



MEDIA
Click image to the left for more content.

(http://www.youtube.com/watch?v=CmRyJaBPvD0)

6. Briefly explain the theory of climate change as mentioned here.

7. What evidence is there for this theory?

8. Most people, including scientists, do not call this a theory. Why not? Do you think it should be called a theory? Would calling it a theory saddle it with the same air of uncertainty that follows the theory of evolution?

Review

1. Scientists are reluctant to say that any theory is absolutely true. Why do you think that is?

2. What reasons do people have outside science to think that a theory is incorrect? Are these valid scientific arguments?

3. What are the three essential theories in Earth science as stated here?

1.9 Scientific Community

- Explain how the scientific community self-regulates and supports research.

How does science monitor itself?

Computer hackers stole files and emails from the Climate Research Unit's server. These messages were alleged to show that scientists had a conspiracy to promote the idea of global warming. Government and scientific bodies investigated the charges and found no evidence of a conspiracy. Science is done with a great deal of quality control and nearly all allegations of scientific misconduct are found to be false.

Sharing Results

A hypothesis will not be fully accepted unless it is supported by the work of many scientists. Although a study may take place in a single laboratory, a scientist must present her work to the community of scientists in her field.

Initially, she may present her data and conclusions at a scientific conference where she will talk with many other scientists. Later, she will write a paper to be published in a scientific journal. After she submits the paper, several scientists will review the paper – a process called **peer review** – to suggest further investigations or changes in interpretation to make the paper stronger. The scientists will then recommend or deny the paper for publication. Once it is published, other scientists incorporate the results into their own research. If they cannot replicate her results, her work will be thrown out!

Scientific ideas are advanced after many papers on a topic are published.

Scientific Integrity

There scientific community controls the quality and type of research that is done by project funding. Most scientific research is expensive, so scientists must write a proposal to a funding agency, such as the National Science Foun-

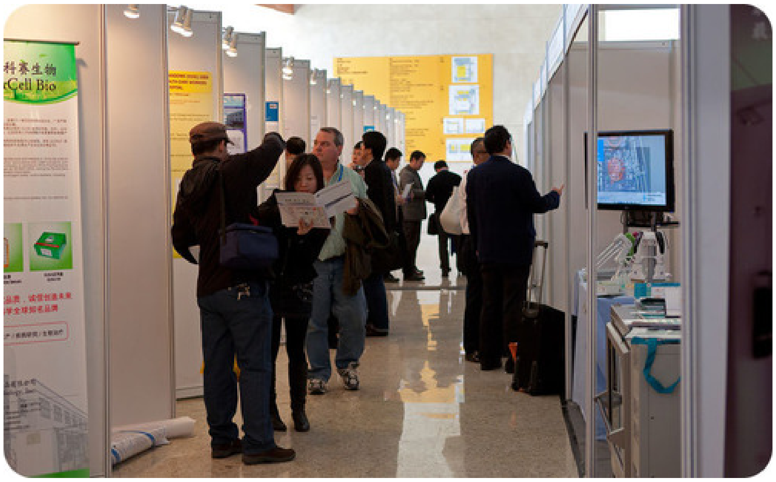


FIGURE 1.11
Participants share their results at a scientific conference.

dation or the National Aeronautics and Space Administration (NASA), to pay for equipment, supplies, and salaries. Scientific proposals are reviewed by other scientists in the field and are evaluated for funding. In many fields, the funding rate is low and the money goes only to the most worthy research projects.

The scientific community monitors scientific integrity. During their training, students learn how to conduct good scientific experiments. They learn not to fake, hide, or selectively report data, and they learn how to fairly evaluate data and the work of other scientists. Scientists who do not have scientific integrity are strongly condemned by the scientific community.

Nothing is perfect, but considering all the scientific research that is done, there are few incidences of scientific dishonesty. Yet when they do occur, they are often reported with great vehemence by the media. Often this causes the public to mistrust scientists in ways that are unwarranted.

Vocabulary

- **peer review**: Evaluation of work by qualified people in a field before the work is published.

Summary

- If science is done well, other scientists who replicate the same work will get the same results.
- Scientists peer review a scientific paper before it is published to be sure the work was done using the scientific method.
- There are lots of controls in science, including oversight of the projects that get funded.
- The checks and balances assure that nearly all scientists operate with a great deal of integrity.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Why aren't scientists infallible? How are scientists different from theologians or other experts?
2. What is peer review?
3. What is the importance of peer review?
4. What makes a person a scientist?
5. For something to be science it must be reviewed by people who understand the topic scientifically and be published in a peer reviewed journal. Why?

Review

1. How does peer review work keep quality control high in scientific research?
2. What happens if a scientist's results cannot be replicated by other scientists?
3. What procedures are present in science to insure scientific integrity?

1.10 Scientific Models

- Explain why scientists use models.
- Explain the importance and uses of scientific models.

Why do scientists need models?

What does it mean when the newspaper reports the results of a scientist's most recent climate modelling? Scientists work with models when the system they are interested in studying is too complex, too remote, or too difficult to deal with as a whole. Models are necessary in science, but it must always be remembered that they are models.

Models are Useful Tools

Scientific models are useful tools in science. Earth's climate is extremely complex, with many factors that are dependent on one another. Such a system is impossible for scientists to work with as a whole. To deal with such complexity, scientists may create models to represent the system that they are interested in studying.

Scientists must validate their ideas by testing. A model can be manipulated and adjusted far more easily than a real system. Models help scientists understand, analyze, and make predictions about systems that would be impossible to study as a whole. If a scientist wants to understand how rising CO_2 levels will affect climate, it will be easier to model a smaller portion of that system. For example, he may model how higher levels of CO_2 affect plant growth and the effect that will have on climate.

Models can be Used to Make Predictions

How can scientists know if a model designed to predict the future is likely to be accurate, since it may not be possible to wait long enough to see if the prediction comes true? One way is to run the model using a time in the past as the starting point see if the model can accurately predict the present. A model that can successfully predict the present is more likely to be accurate when predicting the future.

Many models are created on computers because only computers can handle and manipulate such enormous amounts of data. For example, climate models are very useful for trying to determine what types of changes we can expect as the composition of the atmosphere changes. A reasonably accurate climate model would be impossible on anything other than the most powerful computers.

Models Have Limitations

Since models are simpler than real objects or systems, they have limitations. A model deals with only a portion of a system. It may not predict the behavior of the real system very accurately. But the more computing power that goes into the model and the care with which the scientists construct the model can increase the chances that a model will be accurate.

Types of Models

- Physical models are smaller and simpler representations of the thing being studied. A globe or a map is a physical model of a portion or all of Earth.
- Conceptual models tie together many ideas to explain a phenomenon or event.
- Mathematical models are sets of equations that take into account many factors to represent a phenomenon. Mathematical models are usually done on computers.

Vocabulary

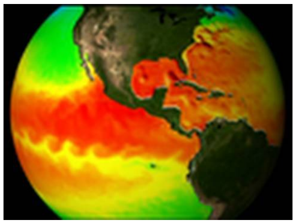
- **scientific model**: A simple representation of a more complex system.

Summary

- A model is a representation of a more complex system. Models can be manipulated far more easily than the system they represent.
- Models can be used to make predictions.
- Models may be physical, conceptual, or mathematical.

Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What is a model?
2. How do scientists create models?
3. How are models checked for accuracy?
4. How did Dr. Hansen check his model?
5. What are the challenges associated with modeling?

Review

1. If models have limitations, why do scientists use them?
2. What are some types of scientific models that you can name?
3. Imagine you make a model to predict an earthquake in a particular location. What factors would you need to include? How accurately do you think your model might predict that earthquake?

Summary

Science is different from other types of information because scientists follow rigorous methods to learn about the world. A scientific idea must be testable and falsifiable. Ideas that are not supported by observations and data are revised or thrown out. The distinction between science and other ways of understanding the world is important because scientific information has been obtained with much more rigor than ideas that are the result of opinion, gut feelings, or faith. Scientists use the scientific method to answer questions about the natural world. The scientific method is not linear but takes on this basic structure: Ask a question, do background research, propose a hypothesis, test the hypothesis using data from observations and experiments, continue testing the hypothesis if it holds up or find a new hypothesis if it does not, eventually create a theory. A theory is an explanation of a complicated set of phenomena that fits virtually all of the available data. The theories of evolution, plate tectonics, and climate change are crucial to understanding earth science.

1.11 References

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CHAPTER 2

Studying Earth Science

Chapter Outline

Introduction

Why do people study Earth science?

A lot of people are attracted to Earth science because they love to be outdoors. These people wonder how the magnificent rock formations that they see, like here in Yosemite in California, were formed. They want to study the processes that create and modify landforms. Some people want to go deeper, to learn about what drives the surface processes and other features of the planet; for example, why does Earth have a magnetic field? These people are interested in learning about the layers of material that lie beneath the surface, the mantle and the core. Since more than 70% of Earth is covered with oceans, it's not surprising that many people wonder what lies within and at the bottom of the seas. Although scientists say that we know more about the far side of the moon than we do about the deep oceans, we know an awful lot considering how hostile the ocean environment is for humans. Some people look up and wonder what lies beyond our skies. These people are interested in applying what we know about Earth to our more distant surroundings. They want to understand our near neighbors, the planets and satellites of our Solar System, and objects that lie far beyond.

2.1 Branches of Earth Science

- Identify and define the major branches of Earth Science.

If science is the study of the natural world, what could be more obvious than to study the land, sky, water, and space surrounding us?

Earth scientists seek to understand the beautiful sphere on which we live. Earth is a very large, complex system or set of systems, so most Earth scientists specialize in studying one aspect of the planet. Since all of the branches of Earth science are connected, these researchers work together to answer complicated questions. The major branches of Earth science are described below.

Geology

Geology is the study of the Earth's solid material and structures and the processes that create them. Some ideas geologists might consider include how rocks and landforms are created or the composition of rocks, minerals, or various landforms. Geologists consider how natural processes create and destroy materials on Earth, and how humans can use Earth materials as resources, among other topics.

FIGURE 2.1
Geologists study rocks in the field to learn what they can from them.

Oceanography

Oceanography is the study of everything in the ocean environment, which covers about 70% of the Earth's surface. Recent technology has allowed people and probes to venture to the deepest parts of the ocean, but much of the ocean remains unexplored. Marine geologists learn about the rocks and geologic processes of the ocean basins.

Climatology and Meteorology

Meteorology includes the study of weather patterns, clouds, hurricanes, and tornadoes. Using modern technology such as radars and satellites, meteorologists are getting more accurate at forecasting the weather all the time.

Climatology is the study of the whole atmosphere, taking a long-range view. Climatologists can help us better understand how and why climate changes (**Figure** 2.2).

FIGURE 2.2
Carbon dioxide released into the atmosphere is causing the global climate to change.

Environmental Science

Environmental scientists study the effects people have on their environment, including the landscape, atmosphere, water, and living things. Climate change is part of climatology or environmental science.

Astronomy

Astronomy is the study of outer space and the physical bodies beyond the Earth. Astronomers use telescopes to see things far beyond what the human eye can see. Astronomers help to design spacecraft that travel into space and send back information about faraway places or satellites (**Figure** 2.3).

FIGURE 2.3
The Hubble Space Telescope.

Summary

- The study of Earth science includes many different fields, including geology, meteorology, oceanography, and astronomy.
- Each type of Earth scientist investigates the processes and materials of the Earth and beyond as a system.
- Geology, climatology, meteorology, environmental science, and oceanography are important branches of Earth science.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What do Earth scientists study?

2. What tools do geoscientists use?

3. Do all Earth scientists study Earth's past?

4. What is fundamental about the study of Earth science?

5. Why is it important for people to study Earth science?

6. Why is Earth science called a combined science?

Review

1. What type of Earth scientist would be interested in understanding volcanic eruptions on the seafloor?

2. If it were to snow in Phoenix in July, which type of Earth scientist would be most surprised?

3. If people have been studying the natural world for centuries or even millennia, why are scientists learning so much about Earth science now?

2.2 Field Trips

Does this look like fun?

For many geologists, a day hiking in beautiful country to learn more about the interesting geology is about as good as it gets!

Field Work

Many Earth scientists collect data in the field. The data may be from observations or measurements. The scientists may create a geological map of the area, write detailed descriptions, or collect samples to analyze in the lab. Or a combination of all of these! Many Earth science laboratories contain high-tech equipment to reveal the chemistry or age of a rock sample. Field work is done to look for resources, for environmental cleanup, or for any number of other reasons. One common reason is just to understand the region better.

Field Trips

To really understand geology and some of the other branches of Earth science, it's best to go out in the field! Some of the concepts presented here focus on regions where geologically interesting features can be seen. In these cases, a location is presented and the phenomena of interest described. It's just like we're going on a field trip! These field trips are great because they don't involve long drives in a car, expensive airplane trips, or a passport! We can do things that are difficult or impossible to do on an ordinary field trip. We can go to any single location on Earth, we can hop along a latitude line, visit the bottom of the ocean, or look to different areas for a specific phenomenon.

Of course, we won't be enjoying the fresh air, exercise, camaraderie, or thrill of discovery in the same way we would on a real field trip, but, hey, you can't have everything! What follows is a brief synopsis of some of the places we'll be visiting. Where possible, we've tried to visit locations in the western United States, an area that may be familiar to you.

California

FIGURE 2.4

In the satellite image above, it is possible to identify the major geographic features of California.

- The Coast Range runs the length of the state along the Pacific coast. A tremendous amount of rain falls in the northern part of the range, so the region is heavily forested. Further south, rainfall and vegetation are more sparse.
- The Central Valley, made up of the Sacramento and San Joaquin river valleys, runs through about half of the central part of the state is located inland from the Coast Range. The collection of river sediments and the abundance of water has made the Central Valley one of the most important agricultural regions in the world.
- The Sierra Nevada Mountain range lies east of the Central Valley. In the winter the mountains are covered by snow, but in this image there is little to no snow and the bare rocks of the high peaks are showing, particularly in the southern portion of the range. Yosemite National Park lies within the Sierra Nevada.
- East of the Sierra Nevada and into the state of Nevada, the climate is very arid. Death Valley, the driest spot in the United States is found there.

- Mt Shasta, at the north end of the Sierra Nevada, is the southernmost remaining volcanic cone in the Cascades Range.

Nevada

East of the image of California is Nevada. Very different from California, Nevada is extremely arid. The Basin and Range province, which consists of a set of mountains and valleys, is best displayed in the state. You can see the ranges as dark brown rocky regions and the valleys as lighter brown. The ranges have been described as worms crawling northward across the state, which is what they look like in this image.

Pacific Northwest

FIGURE 2.5
North of California along the Pacific Coast is Oregon, Washington and then British Columbia in Canada. This region is similar to California in having a coastal range, a central valley (at least in part of Oregon) and very arid lands east of the high Cascades mountains.

The Cascades are volcanoes that begin with Lassen in California, run through Oregon and Washington, and continue into British Columbia. Some of them are easily spotted on this image as white spots in the midst of the green forests of the Cascades range.

FIGURE 2.6
The closeup image of Mount Hood taken by an astronaut on the International Space Station shows one of the most distinctive of the Cascades composite volcanoes. Solidified lava makes up the summit of the mountain and glaciers are found on both the north and south sides of the peak. Mount Hood is the northernmost Cascade volcano in Oregon and is just south of Mt. St. Helens.

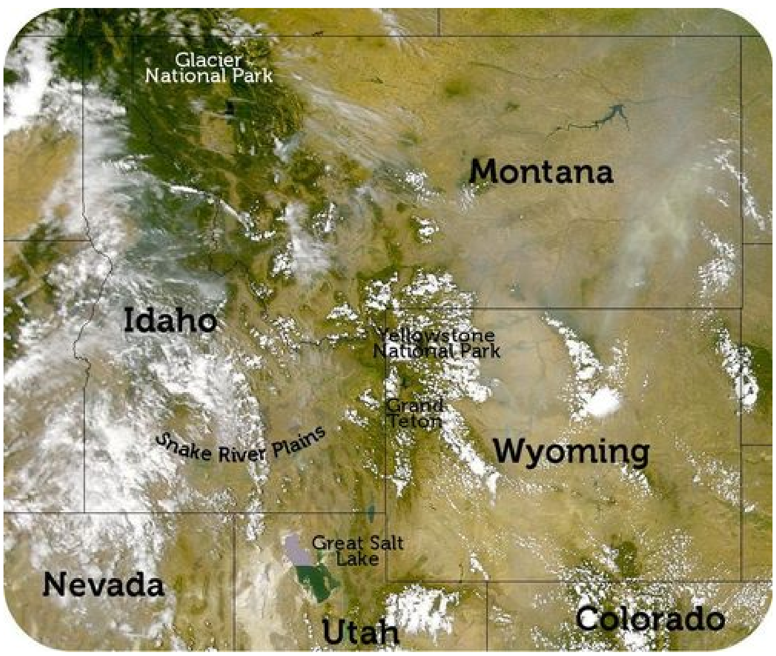


FIGURE 2.7
This image shows the states of Idaho, Montana, Wyoming, with a little of Utah and a few others. The northern part of Idaho and northwestern Montana is mountainous and forested. Arid lands lie to the east.

Idaho, Montana, Wyoming

Glacier National Park

Glacier National Park in the northwestern part of Montana reaches to the Canadian border. North of the border the park becomes the Canadian Waterton Lakes National Park. Although Glacier National Park was established in 1910 to preserve the wild lands and wildlife, the glaciers have been reduced by a reduction in precipitation and higher summer temperatures. On glaciers, snowfields, or just rock, Glacier National Park is a fantastic place to see glacial features, beautiful scenery, and wildlife.

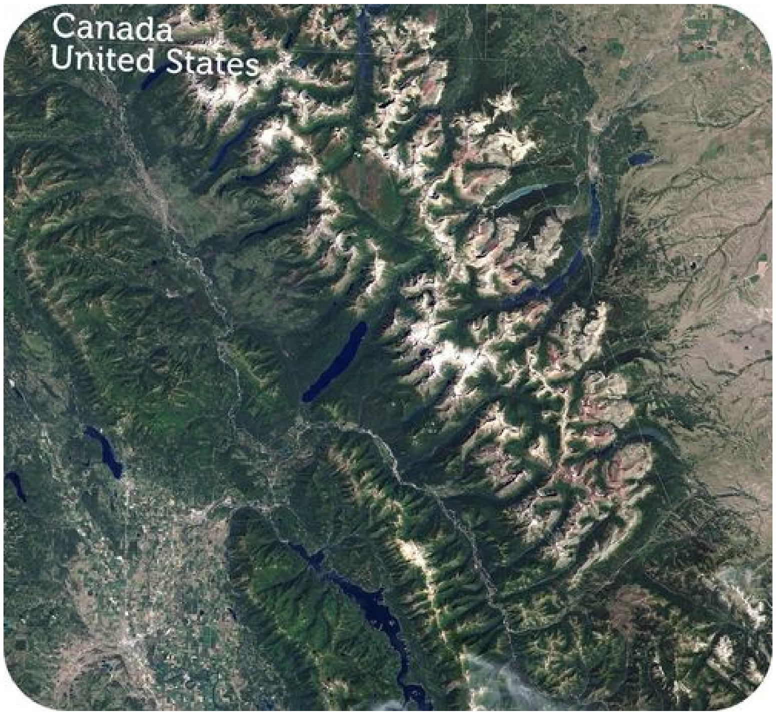


FIGURE 2.8
This satellite image of GNP in summer shows snow-capped peaks and glacial valleys, many of which are now lakes.

FIGURE 2.9
Naturalists enjoy the hike to Iceberg Lake in Glacier National Park.

Yellowstone National Park

Yellowstone National Park is in the northwestern corner of Wyoming. Although Yellowstone is best known for its incredible geysers, the park also has gorgeous mountain scenery and fantastic wildlife, including herds of amazing bison. The best known feature is Old Faithful, a geyser that's not the highest, largest, or most beautiful, but is the most reliable.

FIGURE 2.10
Grand Prismatic Spring is one of the spectacular features of Yellowstone National Park.

FIGURE 2.11
Bison are just some of the amazing creatures that roam around Yellowstone.

Southwest

The Southwestern United States is a great place to study geology. The region is so arid that in most locations rocks and structures are easily seen. In several concepts we will visit parts of the Southwest to view geology in the field.

Grand Canyon

Geologists say that the Grand Canyon has "layer cake geology" because the rock strata are so easy to see. Sedimentary rocks are like a book that tells of the environment in which they formed. Rock units can be traced across large expanses. Looking down into the Grand Canyon, you get a sense of the vastness of space and of time.

FIGURE 2.12
The Southwest is home to mountains, canyons, valleys, and flat lands. Many features discussed in the Earth Science concepts can be seen in the Southwest.

FIGURE 2.13
From the rim, the Grand Canyon gives a sense of the vastness of geologic time and the immensity of the planet.

Hawaiian Islands

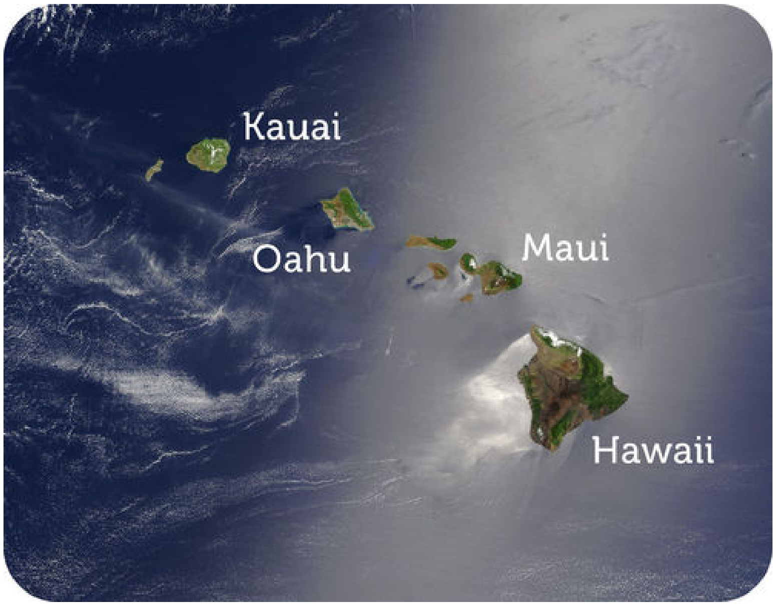


FIGURE 2.14
The Hawaiian Islands from space.

The Hawaiian Islands are in the central Pacific Ocean, a land of sun, exotic life, and volcanoes. The islands increase in age from the Big Island of Hawaii at the southeast end of the chain through Maui, Kahoolawe, Lanai, Molokai, Oahu, Kauai, and Niihau Islands through the northwest. Kilauea volcano on Hawaii has been erupting almost continuously since 1983 and eruptions are also going on at an underwater volcano called Loihi seamount. Hawaii is a fantastic place to see volcanic eruptions and features.

Summary

- Earth scientists learn about many aspects of their disciplines by going out into the field.
- Field trips are an important part of the education of a geology student.
- The western United States is a great place to see examples of many types of geological phenomena.

Practice

Use this resources to answer the questions that follow.

Yosemite Nature Notes- Rockfall

http://www.youtube.com/watch?v=H0YhlqP1BgE

MEDIA
Click image to the left for more content.

1. What are run out zones?

2. What evidence is there for long term rockfalls having occurred?

3. How was Yosemite Valley created?

4. How did the rockfall in 2008 change the slope?

5. How can you determine the age of the boulder from a rockfall?

6. Why are they monitoring the mountains?

Our Changing Planet: Glacier National Park

http://www.nrmsc.usgs.gov/research/video/ccme_umac_meltinggp

7. What is happening to the glaciers in Glacier National Park?

8. How many glaciers are there in the park?

9. When do scientists predict that the glaciers will disappear?

FYI: Yellowstone Super Volcano

http://www.youtube.com/watch?v=Ap_YUwdiy8I

MEDIA

Click image to the left for more content.

10. How large is Yellowstone?

11. What is Yellowstone?

12. How often has Yellowstone erupted in the past? What does this mean?

13. What heats the geysers and super volcano of Yellowstone?

Grand Canyon

http://www.nps.gov/grca/photosmultimedia/fly-through.htm

14. How long did it take for the Grand Canyon to be formed?

15. What river runs through the Grand Canyon?

16. What is the youngest rock in the canyon?

17. What is found in the sandstone? What is this evidence of?

19. What is Vulcan's Throne?

20. Why are the faults important?

21. What is the evidence for long-term human habitation along the canyon?

22. Where does the Grand Canyon end?

How the Earth was Made: Hawaii

http://www.youtube.com/watch?v=66UdZWZgfWY

MEDIA

Click image to the left for more content.

23. How many islands make up Hawaii?
24. How long has Kīlauea been continuously erupting?
25. Explain how Hawaii formed.
26. What is Hawaii?

Review

1. How does the geography of Oregon parallel the geography of California?
2. Where are the arid lands in the western United States and why are they important for understanding geology?
3. How do the satellite images of the western United States give you a sense of space and time?

2.3 Principle of Uniformitarianism

- Explain how scientists use knowledge of Earth in the present to understand Earth's history.

What does this mean: "the present is the key to the past"?

How can what you see in this photo help you to figure out what happened in Earth's history? You can see the molten lava and what it looks like when it cools. If you see that type of rock in an outcrop you can assume that it formed from molten lava. This reveals the best tool for understanding Earth history that Earth scientists have. They use what they know about materials and processes in the present to figure out what happened in the past.

Ask a Question – Earth History

The outcrop in the image below is at Checkerboard Mesa in Zion National Park, Utah. It has a very interesting pattern on it. As a geology student you may ask: how did this rock form?

If you poke at the rock and analyze its chemistry you will see that it's made of sand. In fact, the rock formation is called the Navajo sandstone. But knowing that the rock is sandstone doesn't tell you how it formed. It would be hard to design an experiment to show how this rock formed. But we can make observations now and apply them to this rock that formed long ago.

Uniformitarianism

James Hutton came up with this idea in the late 1700s. The present is the key to the past. He called this the **principle of uniformitarianism**. It is that if we can understand a geological process now and we find evidence of that same process in the past, then we can assume that the process operated the same way in the past.

FIGURE 2.15
Checkerboard Mesa in Zion National Park, Utah.

Let's go back to that outcrop. What would cause sandstone to have layers that cross each other, a feature called cross-bedding?

Answer a Question – Earth History

In this photo of the Mesquite sand dune in Death Valley National Park, California, we see that wind can cause cross-bedding in sand. Cross-bedding is due to changes in wind direction. There are also ripples caused by the wind waving over the surface of the dune.

FIGURE 2.16
The Mesquite sand dune in Death Valley National Park, California.

This doesn't look exactly like the outcrop of Navajo sandstone, but if you could cut a cross-section into the face of the dune it would look very similar.

Since we can observe wind forming sand dunes with these patterns now, we have a good explanation for how the Navajo sandstone formed. The Navajo sandstone is a rock formed from ancient sand dunes in which wind direction changed from time to time.

This is just one example of how geologists use observations they make today to unravel what happened in Earth's past. Rocks formed from volcanoes, oceans, rivers, and many other features are deciphered by looking at the geological work those features do today.

Vocabulary

- **principle of uniformitarianism**: Processes that happen today happened in the past with the same results; the present is the key to the past.

Summary

- You may need to apply what you know about the present to determine what happened in the past.
- The idea that the present is the key to the past was recognized by James Hutton in the late 1700s.
- If you see something forming by a process today and then find the end results of that process in the rock record, you can assume that the the process operated the same way in the past.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. How does a geologist use observations about how and where ripple marks are found to understand ripple marks in a rock?

2. What do the colors of the rocks tell us?

3. Explain, briefly, the principal of uniformitarianism.

4. Why are the principles discussed in this video important for Earth science?

Review

1. What does an Earth scientist often need to answer a question about something that happened in Earth's distant past?

2. James Hutton is sometimes called the father of geology. Why does he merit that title?

3. If you found a layer of ancient lava rock within a sandstone outcrop, what could you say about that lava rock using the principle of uniformitarianism?

2.4 Location and Direction

- Identify and define latitude and longitude.
- Use latitude and longitude to find a location.

If you found this feature while out in the field, could you find it again?

If you're going to make observations of Earth systems, you're going to need to know the location where you are so you can mark it on a map. If you find a rock filled with gold, you'll want to be able to find the location again! You may need to tell someone when your truck gets stuck when you're in the field so you'll need a direction to give them.

The photo above is of Old Faithful Geyser in Yellowstone National Park. Let's explore just a few of the ways we can pinpoint the location of this famous geological icon.

Location

How would you find Old Faithful? One way is by using latitude and longitude. Any **location** on Earth's surface — or on a map — can be described using these coordinates. Latitude and longitude are expressed as degrees that are divided into 60 minutes. Each minute is divided into 60 seconds.

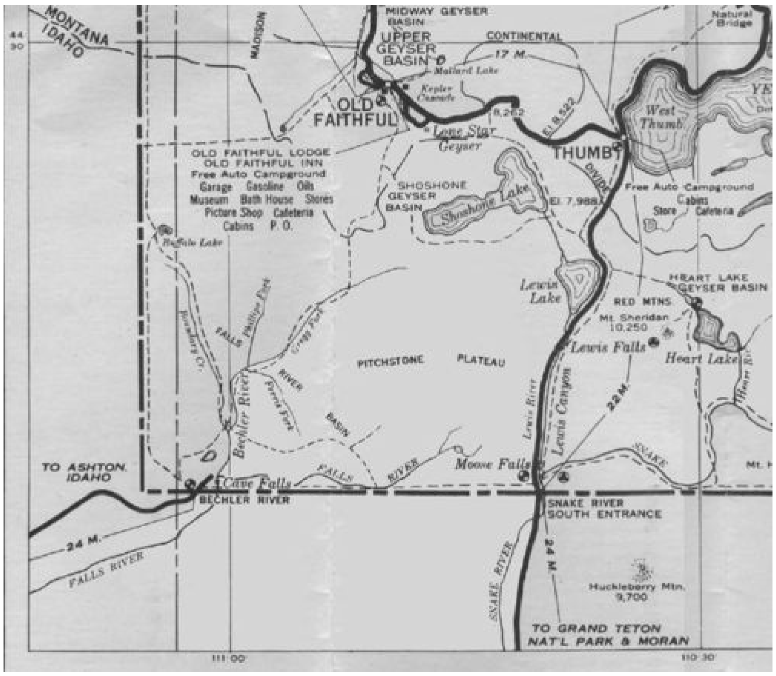


FIGURE 2.17

Latitude

A look on a reliable website shows us that Old Faithful Geyser is located at N44^{o}N 27' 43". What does this mean?

Latitude tells the distance north or south of the Equator. Latitude lines start at the Equator and circle around the planet. The North Pole is 90^{o}N, with 90 degree lines in the Northern Hemisphere. Old Faithful is at 44 degrees, 27 minutes and 43 seconds north of the equator. That's just about exactly half way between the Equator and the North Pole!

Longitude

The latitude mentioned above does not locate Old Faithful exactly, since a circle could be drawn that latitude north of the Equator. To locate Old Faithful we need another point – longitude. At Old Faithful the longitude is W110^{o}49'57".

Longitude lines are circles that go around the Earth from north to south, like the sections of an orange. Longitude is measured perpendicular to the Equator. The Prime Meridian is 0^o longitude and passes through Greenwich, England. The International Date Line is the 180^o meridian. Old Faithful is in the Western Hemisphere, between the Prime Meridian in the east and the International Date Line in the west.

Elevation

An accurate location must take into account the third dimension. **Elevation** is the height above or below sea level. **Sea level** is the average height of the ocean's surface or the midpoint between high and low tide. Sea level is the same all around Earth.

Old Faithful is higher above sea level than most locations at 7,349 ft (2240 m). Of course, the highest point on Earth, Mount Everest, is much higher at 29,029 ft (8848 m).

Global Positioning System

Satellites continually orbit Earth and can be used to indicate location. A **global positioning system** receiver detects radio signals from at least four nearby GPS satellites. The receiver measures the time it takes for radio signals to travel from a satellite and then calculates its distance from the satellite using the speed of radio signals. By calculating distances from each of the four satellites the receiver can triangulate to determine its location. You can use a GPS meter to tell you how to get to Old Faithful.

Direction

Direction is important if you want to go between two places. **Directions** are expressed as north (N), east (E), south (S), and west (W), with gradations in between. The most common way to describe direction in relation to the Earth's surface is with a **compass**, a device with a floating needle that is actually a small magnet. The compass needle aligns itself with the Earth's magnetic north pole. Since the magnetic north pole is 11.5 degrees offset from its geographic north pole on the axis of rotation, you must correct for this discrepancy.

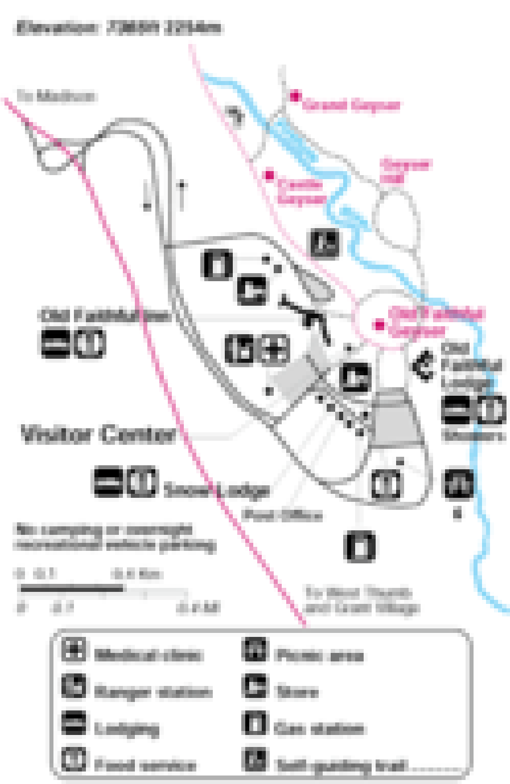


FIGURE 2.18
Map of the Visitor Center at Old Faithful, Yellowstone National Park, Wyoming.

Without using a compass, we can say that to get to Old Faithful, you enter Yellowstone National Park at the South

Entrance, drive north-northeast to West Thumb, and then drive west-northwest to Old Faithful.

Vocabulary

- **compass**: Hand-held device with a magnetic needle used to find magnetic north.
- **direction**: The location of something relative to something else.
- **elevation**: Height of a feature measured relative to sea level.
- **equator**: A line connecting all the points equal distance between the North and South Poles. The zero degree line.
- **global positioning system (GPS)**: A system of satellites designed to give location information that can be picked up by special devices that use triangulation.
- **latitude**: The location of a place between the north and south pole relative to the equator.
- **location**: Where an object is on Earth, best described in three dimensions.
- **longitude**: The location of a place relative to the Prime Meridian, which runs north-south through Greenwich, England.
- **sea level**: The average height of the ocean; the midpoint between high and low tide.

Summary

- Latitude is the distance north or south of the equator and is expressed as a number between 0 and 90 degrees north or south.
- Longitude is the distance east or west of the Prime Meridian and is expressed as a number between 0 and 180 degrees east or west.
- Elevation is the height above sea level.
- Direction is expressed as north, south, east, or west, or some gradation between them.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What are lines of latitude?

2. How far apart are the lines of latitude, in degrees, in miles?

3. What are the latitudes of the Equator, the Tropic of Cancer, and the Tropic of Capricorn? What are the characteristics of the regions found between the Tropic of Cancer and Tropic of Capricorn?

4. Where are the Arctic and Antarctic circle? What are the characteristics of the regions that are found poleward of these circles?

5. What are lines of longitude?

6. Where do the meridians meet?

7. What is the Prime Meridian? Where is it located?

8. How are longitude and latitude measured?

Practice your skills at identifying latitude and longitude at the following website -**Latitude and Longitude Map Match Game** at KidsGeo.com. The game is simple to start but becomes more challenging (and fun!) as you progress through the levels. Can you get to level 10? http://www.kidsgeo.com/geography-games/latitude-longitude-map-game.php

Review

1. Where would a feature at S44^{o}N 27' 43"be located?
2. How else might you describe where Old Faithful is?
3. Define latitude and longitude.

2.5 Maps

- Identify and define types of maps common in Earth science.
- Use maps to find information about a location.

How much information can be put on one map?

What a confusing map! It shows the locations of important features, including Old Faithful, trails, development, trees, streams, and hillsides. But it has all those squiggly lines! Look carefully and try to notice some features about the lines. For example, they don't cross. Every fifth one is darker. What is this map trying to tell you?

Topographic Maps

Topographic maps represent the locations of geographical features, such as hills and valleys. Topographic maps use contour lines to show different elevations. A **contour line** is a line of equal elevation. If you walk along a contour line you will not go uphill or downhill. Topographic maps are also called contour maps. The rules of topographic maps are:

- Each line connects all points of a specific elevation.
- Contour lines never cross since a single point can only have one elevation.
- Every fifth contour line is bolded and labeled.
- Adjacent contour lines are separated by a constant difference in elevation (such as 20 ft or 100 ft). The difference in elevation is the **contour interval**, which is indicated in the map legend.
- Scales indicate horizontal distance and are also found on the map legend.

While this image isn't exactly the same view as the map at the top of this lesson, it is easy to see the main features. Hills, forests, development, and trees are all seen around Old Faithful.

FIGURE 2.19
Old Faithful erupting, Yellowstone National Park.

Bathymetric Maps

A **bathymetric map** is like a topographic map with the contour lines representing depth below sea level, rather than height above. Numbers are low near sea level and become higher with depth.

Kilauea is the youngest volcano found above sea level in Hawaii. On the flank of Kilauea is an even younger volcano called Loihi. The bathymetric map pictured shows the form of Loihi **Figure** 2.20.

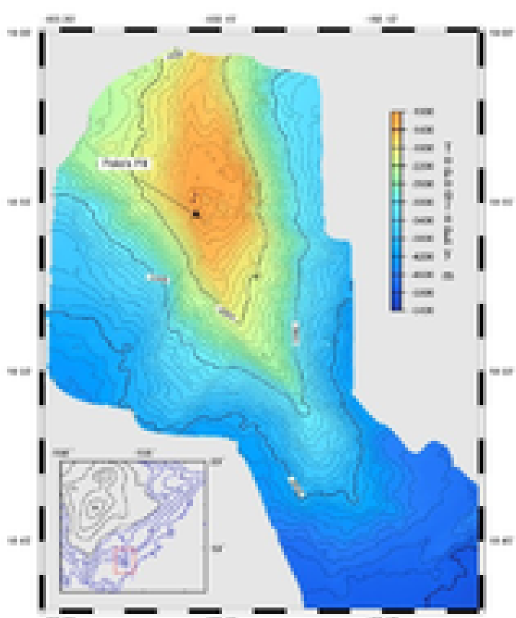


FIGURE 2.20
Loihi volcano growing on the flank of Kilauea volcano in Hawaii. Black lines in the inset show the land surface above sea level and blue lines show the topography below sea level.

Geologic Maps

A **geologic map** shows the geological features of a region. Rock units are color-coded and identified in a key. Faults and folds are also shown on geologic maps. The geology is superimposed on a topographic map to give a more

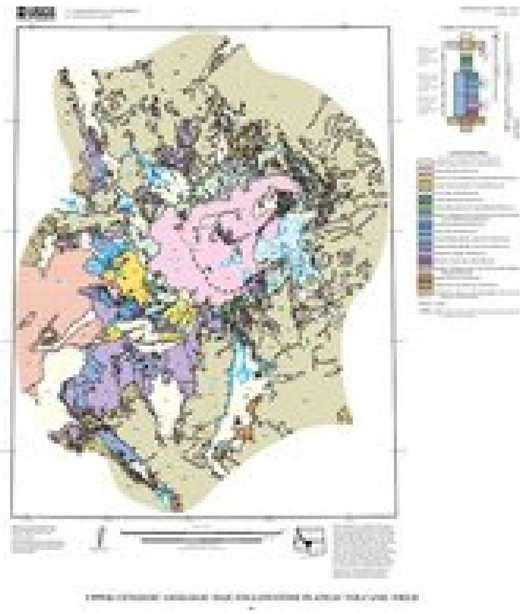


FIGURE 2.21
A geologic map of the region around Old Faithful, Yellowstone National Park.

complete view of the geology of the region.

Vocabulary

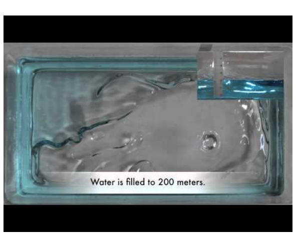
- **bathymetric map**: A topographic map that shows depth below sea level to indicate geographic features. These maps are created from the measurement of ocean depths using echo sounders.
- **contour interval**: The constant difference in elevation between two contour lines on a topographic map.
- **contour line**: A line on a topographic map to show elevation.
- **geologic map**: A map showing the geologic features, such as rock units and structures, of a region.
- **topographic map**: A map that shows elevations above sea level to indicate geographic feature.

Summary

- Earth scientists regularly use topographic, bathymetric, and geologic maps.
- Topographic maps reveal the shape of a landscape. Elevations indicate height above sea level.
- Bathymetric maps are like topographic maps of features found below the water. Elevations indicate depth below sea level.
- Geologic maps show rock units and geologic features like faults and folds.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is sea level?

2. How far apart are topographic lines?

3. What do the contour lines represent?

4. How do you know that there's a crater at the top of the volcano rather than a peak?

5. What is the purpose of a topographic map?

Review

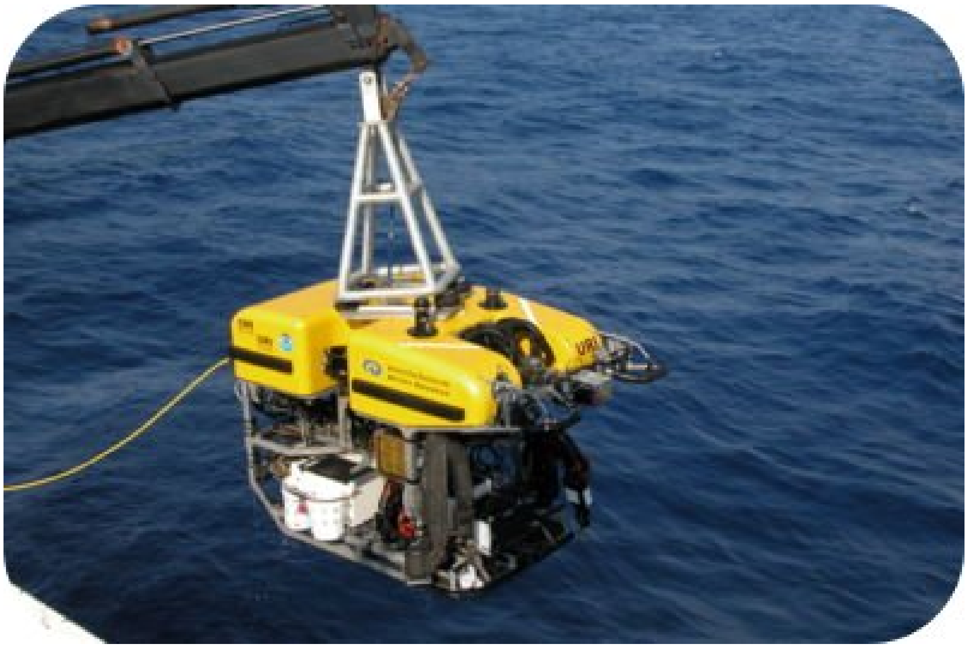
1. What will a hill look like on a topographic map? How will a basin look different from a hill?

2. How will a steep slope look different from a shallow slope?

3. What would a geologic map of the Grand Canyon look like? Remember that the Grand Canyon has many layers of rocks exposed like a layer cake.

2.6 Seafloor

- Describe ways scientists learn about the deep ocean.



Is it true that we know more about the dark side of the Moon than we do about the oceans?

It's true! Why do you think so? The oceans are deep, dark, frigid, and under extraordinarily high pressure at all but the surface. It's hard to imagine an environment that's less hospitable to human life! Yet, as you will see, we know quite a bit about the oceans and this is due mostly to technology. Rovers, like the one pictured, allow scientists to go to places that are too inhospitable or dangerous for human life.

Studying the Seafloor

Scuba divers can only dive to about 40 meters, and they cannot stay down there for very long. Although this is good for researching the organisms and ecosystems very near a coast, most oceanic research requires accessing greater depths.

Seafloor Bathymetry

How do scientists create bathymetric maps like the one of Loihi volcano in Hawaii shown in "Concept Studying Earth Science V: Maps"? Early explorers mapped a small amount of the seafloor by painstakingly dropping a line over the side of a ship to measure the depth at one tiny spot at a time. Then, during World War II, battleships and submarines carried **echo sounders** to locate enemy submarines (**Figure** 2.22). Echo sounders produce sound waves that travel outward in all directions, bounce off the nearest object, and then return to the ship. By knowing the speed of sound in seawater, scientists calculate the distance to the object based on the time it takes for the wave to make a round trip.

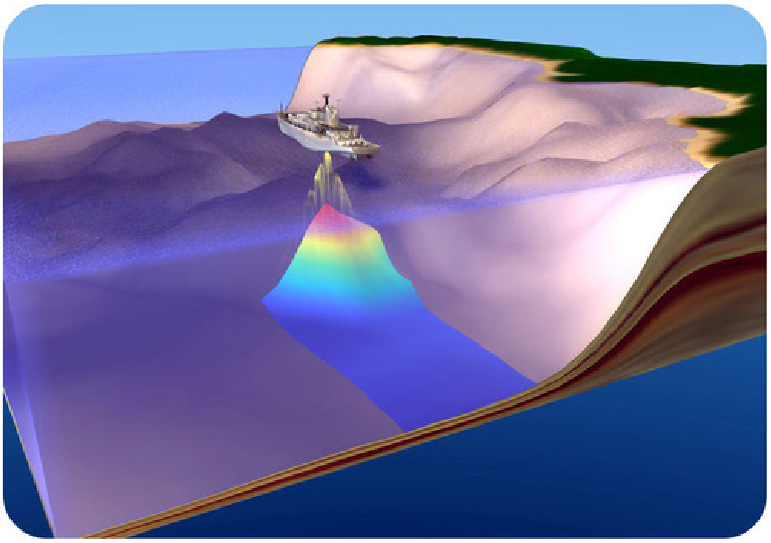


FIGURE 2.22
This echo sounder has many beams and creates a three dimensional map of the seafloor. Early echo sounders had a single beam and created a line of depth measurements.Echo sounders now have many beams to get a more detailed and more rapid picture of the seafloor.

Sampling Remotely

Samples of seawater from different depths in the water column are needed to understand ocean chemistry. To do this, bottles are placed along a cable at regular depths and closed as a weight is dropped down the cable. The water trapped in the bottle can be analyzed later in a laboratory (**Figure** 2.23).

Scientists are also interested in collecting rock and sediment samples from the seafloor. A dredge is a giant rectangular bucket that is dragged along behind a ship to collect loose rocks. Gravity corers are metal tubes that fall to the seafloor and slice into the sediments to collect a sample. The research vessel, the *Joides Resolution*, drills deep into the seafloor to collect samples of the sediment and ocean crust. Scientists analyze the samples for chemistry and paleomagnetism.

Submersibles

Samples of seawater and rocks can be collected directly by scientists in a **submersible**. These subs can take scientists down to make observations. The subs have arms for collecting samples. The human operated vehicle Alvin can dive up to 4,500 m beneath the ocean surface and has made more than 4,400 dives since 1964 (**Figure** 2.24).

Remotely Operated Vehicles

To avoid the expense, dangers, and limitations of human missions under the sea, **remotely operated vehicles**, or ROVs, allow scientists to study the ocean's depths by using small vehicles carrying cameras and scientific instruments. ROVs were used to study the *Titanic*, which would have been far too dangerous for a manned sub to enter. Scientists control ROVs electronically with sophisticated operating systems.

Footage of the NOAA *Titanic* Expedition of 2004 is visible in this video: http://www.youtube.com/watch?v=6Z7REEnwKOQ.

Vocabulary

- **echo sounder**: a device towed behind a ship that uses sound pulses to determine the location of the seafloor and so can be used to map the seafloor

FIGURE 2.23
A Niskin bottle being deployed off the side of a research ship.

- **remotely operated vehicle**: a small vehicle carrying scientific instruments that can be used to explore the oceans and is operated from aboard ship or from on land
- **submersible**: a manned submarine that can explore the oceans and is not tethered to its mother ship

Summary

- Most of the ocean is less well known than the dark side of the Moon because it is inhospitable and inaccessible.
- Echo sounders use sound waves to make bathymetric maps.
- Submersibles and ROVs allow scientists to view otherwise inhospitable regions either directly or remotely.

Practice

Use this resource to answer the questions that follow.

MEDIA
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1. What is the only truly uncharted area of Earth?

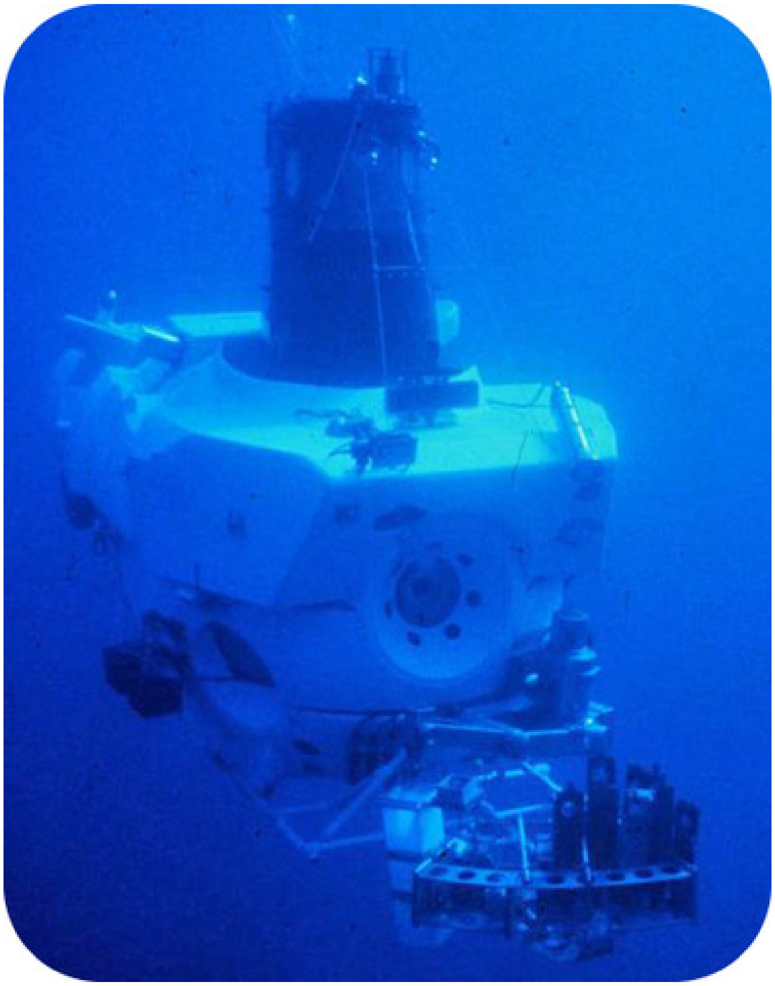

FIGURE 2.24
Alvin allows two people and a pilot to make a nine hour dive.

2. How were soundings taken in the past?
3. List the advantages of using multi-beam sonar.
4. How is texture captured?
5. What is groundtruthing and why is it necessary?
6. Why is this project important?

Review

1. How does an echo sounder work?
2. Why is an ROV better for some tasks than a submersible? Why is a submersible better for some tasks than an ROV?
3. How do marine geologists collect rock and sediment samples?

2.7 Telescopes

- Describe different types of telescopes and explain their relationship to electromagnetic radiation.
- Explain how scientists use telescopes of various types to understand space.

WWGD? What would Galileo do (if he could see the things we can see through a telescope)?

If you think oceans are inhospitable, try space! Humans have been to our Moon and many have orbited Earth in spacecraft, even staying for months at a time in a space station. Much of what has been learned about space since Galileo has been through a telescope. Although astronomers use very large telescopes, many of which pick up wavelengths of energy other than visible light, there is still much to be gained from looking at the planets and stars on a clear night. If you haven't ever looked at the night sky through a telescope you should try to soon!

Electromagnetic Radiation

Electromagnetic (EM) radiation is energy that is transmitted through space as a wave. Light is one type of EM wave. An EM wave has two components: an electric field and a magnetic field. Each of these components oscillates between positive and negative values. The distance between two adjacent oscillations is called a **wavelength**. Frequency measures the number of wavelengths that pass a given point every second. Wavelength and frequency are reciprocal, which means that as one increases, the other decreases.

Visible light — the light that human eyes can see — comes in a variety of colors. The color of visible light is determined by its wavelength. Visible light ranges from wavelengths of 400 nm to 700 nm, corresponding to the colors violet through red. EM radiation with wavelengths shorter than 400 nm or longer than 700 nm exists all around you — you just can't see it. The full range of electromagnetic radiation, or the **electromagnetic spectrum**, is shown in **Figure** 2.25.

Like our Sun, every star emits light at a wide range of wavelengths, all across the visible spectrum and even outside the visible spectrum. Astronomers can learn a lot from studying the details of the spectrum of light from a star.

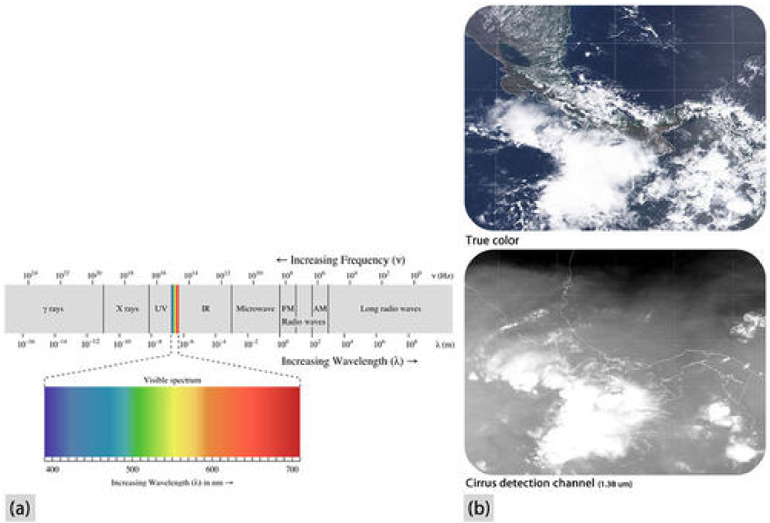

FIGURE 2.25
(a) Visible light is part of the electromagnetic spectrum, which ranges from gamma rays with very short wavelengths, to radio waves with very long wavelengths. (b) These are images of the same scene. In the top, only the wavelengths of visible light show. In the bottom, a layer of thick clouds appears in the infrared wavelengths.

Types of Telescopes

The term "telescope" was coined by the Italian scientist and mathematician Galileo Galilei (1564–1642). Galileo built the first telescope in 1608 and subsequently made many improvements to telescope design.

Optical Telescopes

Telescopes that rely on the refraction, or bending, of light by lenses are called **refracting telescopes**, or simply "refractors." Galileo's and other early telescopes were all refractors. Many of the small telescopes used by amateur astronomers today are refractors. Refractors, including this one at the Lick Observatory near San Jose, California, are particularly good for viewing details within our solar system, such as the surface of Earth's moon or the rings around Saturn.

Around 1670, Sir Isaac Newton created the first **reflecting telescopes**, or "reflectors." The mirrors in a reflecting telescope are much lighter than the heavy glass lenses in a refractor. This is significant, because:

- To support the thick glass lenses, a refractor must be strong and heavy.
- Mirrors are easier to make precisely than it is to make glass lenses.
- Because they do not need to be as heavy to support the same size lens, reflectors can be made larger than refractors.

Larger telescopes can collect more light and so they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Several large reflecting telescopes are located at the summit of Mauna Loa volcano in Hawaii, shown in **Figure** 2.26.

Using sound and laser technology, researchers have begun to reveal the secrets of the ocean floor from the Sonoma Coast to Monterey Bay. By creating complex 3-D maps, they're hoping to learn more about waves and achieve ambitious conservation goals.

Find out more by watching this video at http://www.kqed.org/quest/television/amateur-astronomers.

MEDIA

Click image to the left for more content.

FIGURE 2.26

Telescopes on top of Mauna Kea in Hawaii.

Radio Telescopes

Even larger telescopes are built to collect light at longer wavelengths — radio waves. **Radio telescopes** collect and focus radio waves or **microwaves**, the waves with the shortest wavelength, from space.

The largest single telescope in the world is at the Arecibo Observatory in Puerto Rico (**Figure** 2.27). This telescope is located in a naturally occurring hole so that it does not collapse under its own weight. Since the telescope is set into the ground, it cannot be aimed to different parts of the sky and so can only observe the part of the sky that happens to be overhead at a given time.

A group of radio telescopes can be linked together with a computer so that they are all observing the same object (**Figure** 2.28). The computer combines the data, making the group function like one single telescope.

Scientists have upped their search for extraterrestrial intelligence with the Allen Telescope Array, a string of 350 radio telescopes, located 300 miles north of San Francisco. Find out why SETI scientists now say we might be hearing from ET sooner than you think.

See more at http://science.kqed.org/quest/video/seti-the-new-search-for-et/.

MEDIA

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SETI listens for signs of other civilization's technology. Dr. Jill Tartar explains the program: What it's looking for; what the problems are; what the potential benefits are.

See more at http://science.kqed.org/quest/video/interview-with-astronomer-jill-tarter-part-i-web-only/.

FIGURE 2.27
The radio telescope at the Arecibo Observatory has a diameter of 305 m.

FIGURE 2.28
Radio telescopes at the Very Large Array, the National Radio Observatory in New Mexico.

MEDIA
Click image to the left for more content.

SETI listens for signs of other civilization's technology. Dr. Jill Tartar explains the Allen Telescope Array and its role in SETI.

See more at http://science.kqed.org/quest/video/interview-with-astronomer-jill-tarter-part-ii-web-only/.

MEDIA
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Space Telescopes

Earth's atmosphere not only blocks radiation in some parts of the EM spectrum, but also distorts light. Observatories built on high mountains lessen these problems, but **space telescopes** avoid such problems completely because they orbit outside Earth's atmosphere. Space telescopes can carry instruments to observe objects emitting various types of electromagnetic radiation, such as visible, infrared, or ultraviolet light; gamma rays; or x-rays.

The Hubble Space Telescope (HST), shown in **Figure** 2.29, has orbited Earth for more than 20 years, sending back the most amazing images and helping to answer many of the biggest questions in astronomy. The James Webb Space Telescope, designed to replace the aging Hubble, is targeted for launch in 2018.

Find out more by visiting the Hubble Space Telescope website at http://hubblesite.org.

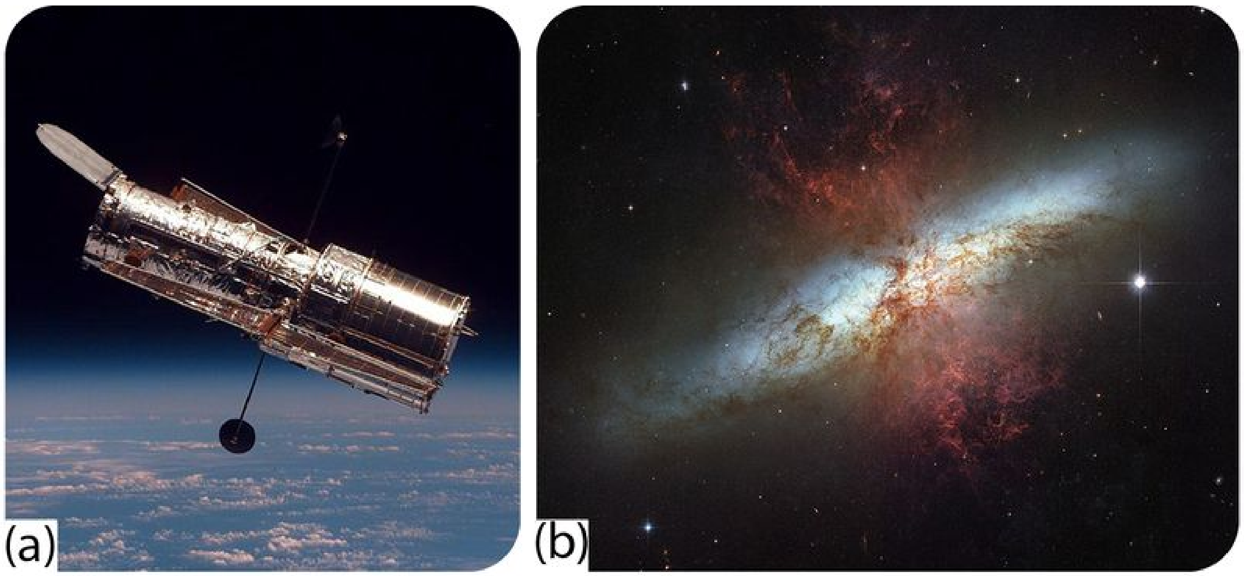


FIGURE 2.29

(a) The Hubble Space Telescope orbits Earth at an altitude of 589 km (366 mi). It collects data in visible, infrared, and ultraviolet wavelengths. (b) This starburst cluster is one of the many fantastic images taken by the HST over the past two decades.

Vocabulary

- **electromagnetic radiation**: Energy transmitted through space as a wave.
- **electromagnetic spectrum**: The full range of electromagnetic radiation.
- **frequency**: The number of wavelengths that pass a given point every second.
- **microwave**: The shortest wavelength radio waves.
- **radio telescope**: A radio antenna that collects radio waves or microwaves.
- **reflecting telescope**: Telescopes that use mirrors to collect and focus light.
- **refracting telescope**: Telescopes that use convex lenses to collect and focus light.
- **space telescope**: Telescopes in orbit above Earth's atmosphere.
- **visible light**: The portion of energy in the electromagnetic spectrum that is visible to humans.

- **wavelength**: Horizontal distance from wave crest to wave crest, or wave trough to wave trough.

Summary

- Electromagnetic radiation is energy transmitted as waves with different wavelengths, which appear in the electromagnetic spectrum.
- Refracting and reflecting telescopes are optical telescopes that use lenses to gather light.
- Radio telescopes collect radio waves and are sometimes used in large arrays.
- Space telescopes can see much more than Earth-bound telescopes since the atmosphere doesn't affect their information.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Where were telescopes developed?
2. What did Galileo do for the telescope?
3. What was the old belief about the Moon and other celestial bodies?
4. List Galileo's discoveries with the telescope.
5. What book did Galileo publish?
6. What did Galileo learn from Venus?
7. Explain Galileo's conflict with the Roman Catholic Church.
8. Which planet remains a mystery to scientists? Why?

Review

1. Describe each of the types of telescopes discussed here: reflecting, refracting, radio, and space.
2. What are the limitations of each type of telescope discussed here?
3. Look at the electromagnetic spectrum. Do you think other types of telescopes could get other types of information if they gathered different wavelengths?

2.8 Satellites, Shuttles, and Space Stations

- Describe tools astronomers use to study space.

Function over fashion?

Why do astronauts need to wear such a funny suit? What would happen if they didn't? Just like space telescopes see more when they're outside Earth's atmosphere, astronauts can see and learn more from space, too. And to do that they need to surround themselves in a habitable environment. Despite a few setbacks, some of them tragic, the space program has made tremendous advances in our understanding of what lies beyond our planet. Space programs also advance technologies here on Earth.

Rockets

A **rocket** is propelled into space by particles flying out of one end at high speed. A rocket in space moves like a skater holding the fire extinguisher. Fuel is ignited in a chamber, which causes an explosion of gases. The explosion creates pressure that forces the gases out of the rocket. As these gases rush out the end, the rocket moves in the opposite direction, as predicted by Newton's Third Law of Motion. The reaction force of the gases on the rocket pushes the rocket forward. The force pushing the rocket is called thrust. Nothing would get into space without being thrust upward by a rocket.

FIGURE 2.30
The space shuttle Atlantis being launched into orbit by a rocket on Cape Canaveral, Florida.

Satellites

One of the first uses of rockets in space was to launch satellites. A **satellite** is an object that orbits a larger object. An **orbit** is a circular or elliptical path around an object. The Moon was Earth's first satellite, but now many human-made "artificial satellites" orbit the planet. Thousands of artificial satellites have been put into orbit around Earth. We have even put satellites into orbit around the Moon, the Sun, Venus, Mars, Jupiter, and Saturn.

There are four main types of satellites.

- Imaging satellites take pictures of Earth's surface for military or scientific purposes. Imaging satellites study the Moon and other planets.
- Communications satellites receive and send signals for telephone, television, or other types of communications.
- Navigational satellites are used for navigation systems, such as the Global Positioning System (GPS).
- The International Space Station, the largest artificial satellite, is designed for humans to live in space while conducting scientific research.

Space Stations

Humans have a presence in space at the International Space Station (ISS). Modern space stations are constructed piece by piece to create a modular system. The primary purpose of the ISS is scientific research, especially in medicine, biology, and physics.

Space Shuttles

Craft designed for human spaceflight, like the Apollo missions, were very successful, but were also very expensive, could not carry much cargo, and could be used only once. To outfit the ISS, NASA needed a space vehicle that

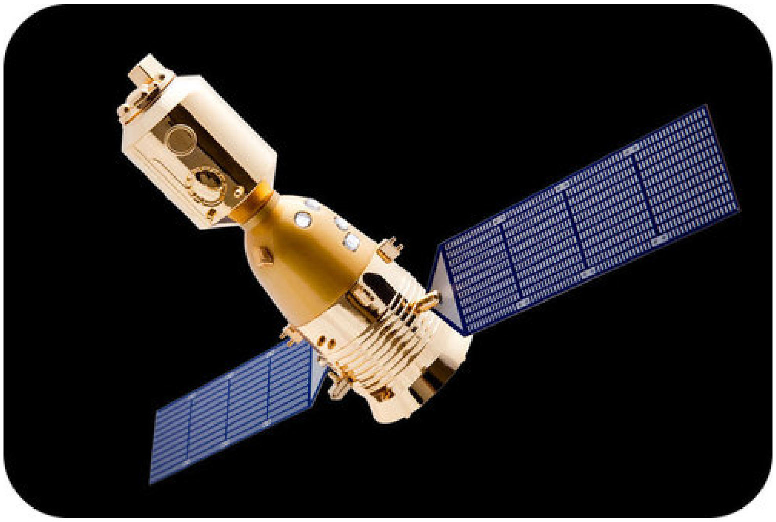


FIGURE 2.31
Satellites operate with solar panels for energy.

FIGURE 2.32
A photograph of the International Space Station was taken from the space shuttle Atlantis in June 2007. Construction of the station is scheduled to be finished in 2011.

was reusable and able to carry large pieces of equipment, such as satellites, space telescopes, or sections of a space station. The resulting spacecraft was a **space shuttle**, shown in (**Figure** 2.33).

A space shuttle has three main parts. The part you are probably most familiar with is the **orbiter**, with wings like an airplane. When a space shuttle launches, the orbiter is attached to a huge fuel tank that contains liquid fuel. On the sides of the fuel tank are two large "booster rockets." All of this is needed to get the orbiter out of Earth's atmosphere. Once in space, the orbiter can be used to release equipment (such as a satellite or supplies for the International Space Station), to repair existing equipment such as the Hubble Space Telescope, or to do experiments directly on board the orbiter.

When the mission is complete, the orbiter re-enters Earth's atmosphere and flies back to Earth more like a glider than an airplane. The Space Shuttle program did 135 missions between 1981 and 2011, when the remaining shuttles

FIGURE 2.33
Atlantis on the launch pad in 2006. Since 1981, the space shuttle has been the United States' primary vehicle for carrying people and large equipment into space.

were retired. The ISS is now serviced by Russian Soyuz spacecraft.

FIGURE 2.34
The space shuttle orbiter Atlantis touches down at the Kennedy Space Center in Florida.

Vocabulary

- **orbiter**: The main part of the space shuttle that has wings like an airplane.
- **rocket**: A device propelled by particles flying out one end at high speed.

- **satellite**: An object, either natural or human made, that orbits a larger object.
- **space shuttle**: A reusable spacecraft capable of carrying large pieces of equipment or a space station.
- **space station**: A large spacecraft in space on which humans can live for an extended period of time.
- **thrust**: The forward force produced by gases escaping from a rocket engine.

Summary

- Rockets are propelled into space by particles flying out one end at high speed. Nothing would get into space without them.
- Thousands of artificial satellites orbit Earth. Satellites are used for imaging, communications, navigation, and human habitation.
- Space stations are continuously inhabited by humans and are used for scientific research.

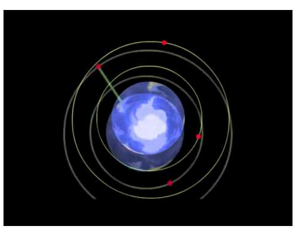
Practice

Use these resources to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What are satellites used for?
2. Explain how geostationary orbit works.
3. How far are geostationary orbits above the earth?
4. What is orbital position?
5. What determines satellite life?



MEDIA

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6. What are the two types of satellites?
7. Explain the characteristics of each type of satellite.

MEDIA

Click image to the left for more content.

8. How do astronauts get to the ISS?

9. List your observations about the ISS.

Review

1. How does a rocket work?

2. Why are there so many satellites orbiting Earth at this time?

3. Would you like to spend months in the International Space Station? If so, what would you be interested in studying? If not, why not?

Summary

In *Principles of Science* you learned what science is and how science is different from other ways of viewing the world. In this Concept, you will learn about what Earth Science encompasses and how it is done. Earth scientists learn about the world by using a lot of amazing tools and scientific principles. To understand things that are small or far away, a microscope or a telescope is necessary. To learn about things on the ground, a good map is useful. Rocks and other earth materials are analyzed chemically. As technology has advanced we've learned more about the oceans and space. One of the most important principles - and the most important for understanding Earth history - is "the present is the key to the past." By understanding the present, we can try to piece together Earth's magnificent 4.6 billion year history.

2.9 References

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CHAPTER 3 Materials of Earth's Crust

Chapter Outline

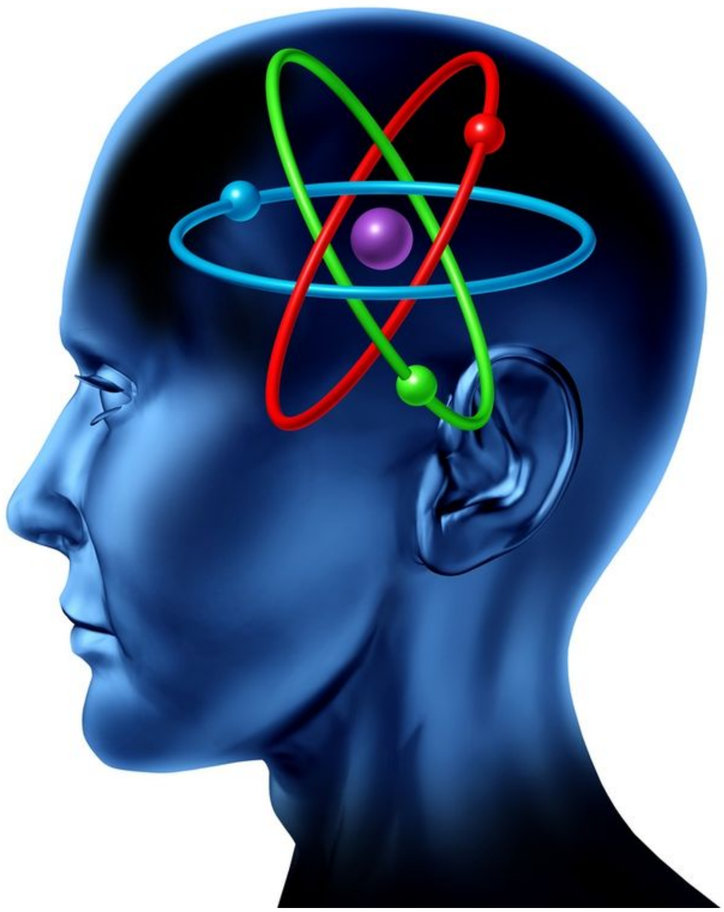
Introduction

What is Earth's crust made of?

The best way to learn about Earth's crust would be to travel around the world, viewing minerals, rocks and structures in a variety of places to see what they are and how they can be coaxed into telling Earth's story. A simpler thing to do to learn a lot about Earth materials is to visit a museum. In a museum you can see lots of samples with good explanations of what they are and, more importantly, what they tell scientists about our planet. So the next time you're in a major city, find a way to spend a few hours in a natural history museum! In this chapter we'll learn about a variety of Earth materials.

3.1 Atoms to Molecules

- Describe atoms and isotopes.



What is your brain made of?

Everything you can see, touch, smell, feel, and taste is made of atoms. Atoms are the basic building-block of all matter (including you and me, and everyone else you'll ever meet), so if we want to know about what Earth is made of, then we have to know a few things about these incredibly small objects.

Atoms

Everyday experience should convince you that matter is found in myriad forms, yet all the matter you have ever seen is made of atoms, or atoms stuck together in configurations of dizzying complexity. A chemical **element** is a substance that cannot be made into a simpler form by ordinary chemical means. The smallest unit of a chemical element is an **atom**, and all atoms of a particular element are identical.

Parts of an Atom

There are two parts to an atom (**Figure** 3.1):

- At the center of an atom is a **nucleus** made up of two types of particles called protons and neutrons.
  - **Protons** have a positive electrical charge. The number of protons in the nucleus determines what element the atom is.
  - **Neutrons** are about the size of protons but have no charge.
- **Electrons**, much smaller than protons or neutrons, have a negative electrical charge, move at nearly the speed of light, and orbit the nucleus at exact distances, depending on their energy.

An introduction to the atom is seen on this Khan Academy video: http://www.khanacademy.org/video/introduction-to-the-atom.

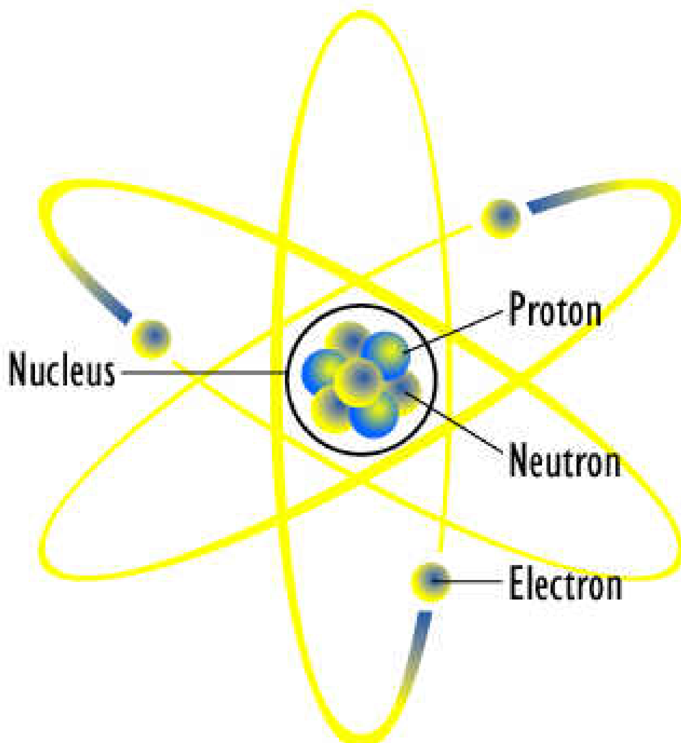


FIGURE 3.1
Major parts of an atom. What chemical element is this? (Hint: 3 protons, 3 electrons)

Atomic Mass

Because electrons are minuscule compared with protons and neutrons, the number of protons plus neutrons gives the atom its **atomic mass**. All atoms of a given element always have the same number of protons, but may differ in the number of neutrons found in the nucleus.

Isotopes

Atoms of an element with differing numbers of neutrons are called **isotopes**. For example, carbon always has 6 protons but may have 6, 7, or 8 neutrons. This means there are three isotopes of carbon: carbon-12, carbon-13, and carbon-14, however, carbon-12 is by far the most abundant.

Ions

Atoms are stable when they have a full outermost electron energy level. To fill its outermost shell, an atom will give, take, or share electrons. When an atom either gains or loses electrons, this creates an **ion**. Ions have either a positive or a negative electrical charge. What is the charge of an ion if the atom loses an electron? An atom with the same number of protons and electrons has no overall charge, so if an atom loses the negatively charged electron, it has a positive charge. What is the charge of an ion if the atom gains an electron? If the atom gains an electron, it has a negative charge.

Molecules

In the previous section we said that many atoms are more stable when they have a net charge: they are more stable as ions. When a cation gets close to an anion, they link up because of their different net charges — positive charges attract negative charges and vice versa. When two or more atoms link up, they create a **molecule**. A molecule of water is made of two atoms of hydrogen (H) and one atom of oxygen (O). The **molecular mass** is the sum of the masses of all the atoms in the molecule. A collection of molecules is called a compound.

Vocabulary

- **atom**: The smallest unit of a chemical element.
- **atomic mass**: The number of protons and neutrons in an atom.
- **electron**: Tiny negatively charged particles that orbit the nucleus.
- **element**: A pure chemical substance with one type of atom.
- **ion**: An atom with one or more electrons added or subtracted; it has an electrical charge.
- **isotope**: A chemical element that has a different number of neutrons.
- **molecular mass**: The sum of the masses of all of the atoms in a molecule.
- **molecule**: The smallest unit of a compound; it is made of atoms.
- **neutron**: A neutral particle in the nucleus of an atom.
- **nucleus**: The center of an atom, made of protons and neutrons.
- **proton**: A positively charged particle in a nucleus.

Summary

- An atom has negatively-charged electrons in orbit around its nucleus, which is composed of positively-charged protons and neutrons, which have no charge.
- Isotopes of an element must have a given number of protons but may have variety of numbers of neutrons.
- An atom that gains or loses electrons is an ion.

Practice

Use this resource to answer the questions that follow.

Basic Atomic Structure http://www.youtube.com/watch?v=lP57gEWcisY.

Please follow the link above to answer the following questions:

1. What is found at the center of an atom?

2. What makes up the nucleus?

3. What is the charge on the nucleus?

4. What is equal in neutral atoms?

5. List the parts of an atom and identify the charge of each.

Review the basic chemistry with these matching games at:

1. http://www.neok12.com/quiz/ATOM0001
2. http://www.neok12.com/quiz/ATOM0002
3. http://www.neok12.com/quiz/ATOM0003

Review

1. If an atom has 8 protons, 8 neutrons, and 8 electrons and then loses an electron, what is it? If it loses a neutron, what is it?
2. What charge(s) does an ion have, positive, negative, or neutral?
3. What is a molecule made of and what is its molecular mass?

3.2 Chemical Bonding

- Explain how different types of chemical bonds form.

How do compounds stick together?

When you think of bonding, you may not think of ions. Like most of us, you probably think of bonding between people. Like people, molecules bond — and some bonds are stronger than others. It's hard to break up a mother and baby, or a molecule made up of one oxygen and two hydrogens!

Chemical Bonding

Ions come together to create a molecule so that electrical charges are balanced; the positive charges balance the negative charges and the molecule has no electrical charge. To balance electrical charge, an atom may share its electron with another atom, give it away, or receive an electron from another atom.

The joining of ions to make molecules is called **chemical bonding**. There are three main types of chemical bonds that are important in our discussion of minerals and rocks:

- **Ionic bond**: Electrons are transferred between atoms. An ion will give one or more electrons to another ion. Table salt, sodium chloride (NaCl), is a common example of an ionic compound. Note that sodium is on the left side of the periodic table and that chlorine is on the right side of the periodic table. In the figure below, an atom of lithium donates an electron to an atom of fluorine to form an ionic compound. The transfer of the electron gives the lithium ion a net charge of +1, and the fluorine ion a net charge of -1. These ions bond because they experience an attractive force due to the difference in sign of their charges.

- **Covalent bond** : In a covalent bond, an atom shares one or more electrons with another atom.

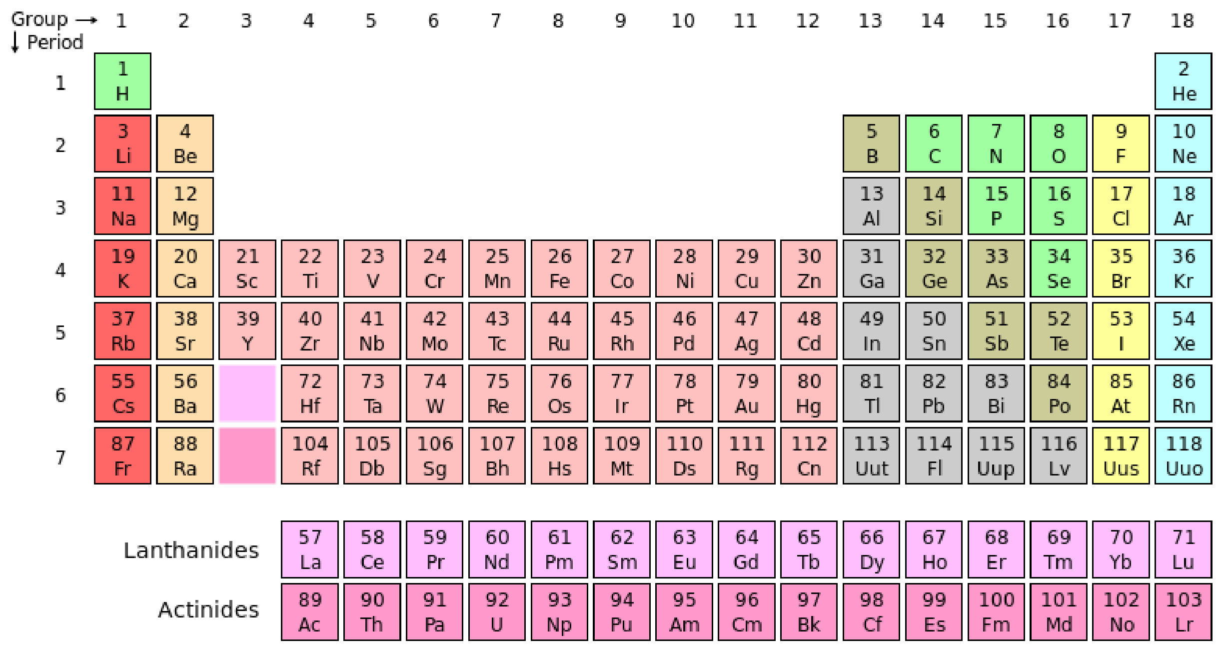


FIGURE 3.2

Periodic Table of the Elements.

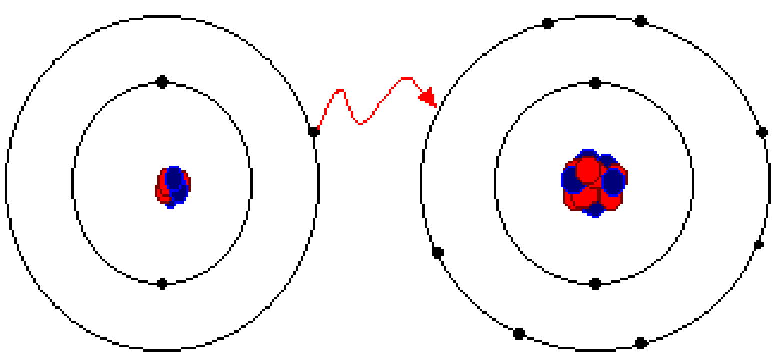


FIGURE 3.3

Lithium (left) and fluorine (right) form an ionic compound called lithium fluoride.

In the picture of methane (CH_4) below, the carbon ion (with a net charge of +4) shares a single electron from each of the the four hydrogens. Covalent bonding is prevalent in organic compounds. In fact, your body is held together by electrons shared by carbons and hydrogens! Covalent bonds are also very strong, meaning it takes a lot of energy to break them apart.

- **Hydrogen bond**: These weak, intermolecular bonds are formed when the positive side of one polar molecule is attracted to the negative side of another polar molecule.

Water is a classic example of a **polar molecule** because it has a slightly positive side, and a slightly negative side. In fact, this property is why water is so good at dissolving things. The positive side of the molecule is attracted to

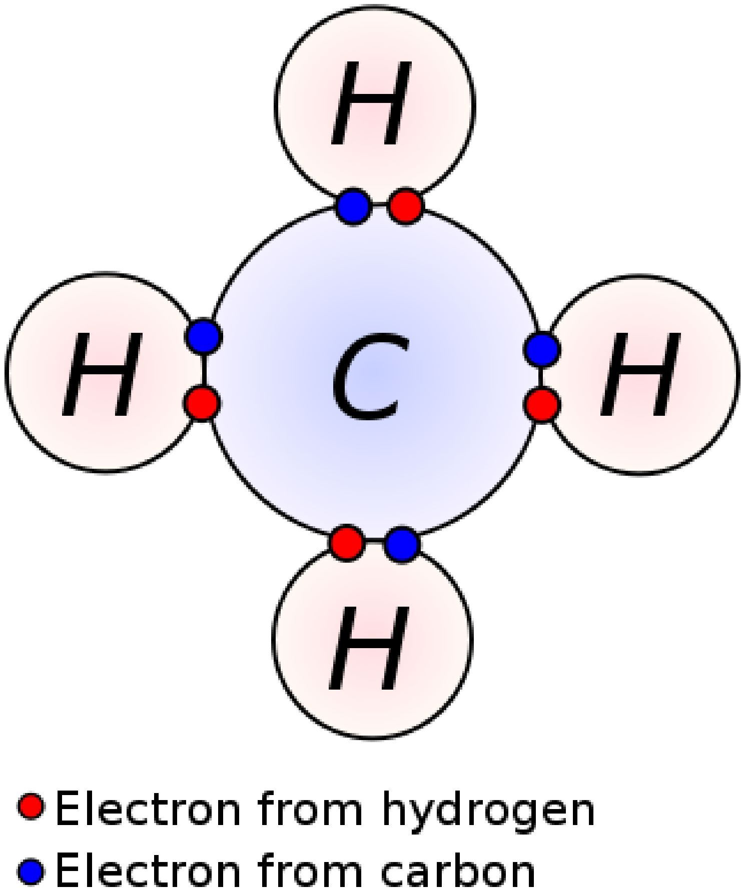


FIGURE 3.4
Methane is formed when four hydrogens and one carbon covalently bond.

negative ions and the negative side is attracted to positive ions.

A video about chemical bonding, from Khan Academy: http://www.khanacademy.org/video/ionic–covalent–and-metallic-bonds.

Water is a covalently bonded, polar molecule. Watch this animation to see how it forms: http://www.youtube.com/watch?v=qmgE0w6E6ZI.

Vocabulary

- **chemical bond**: A force that holds two atoms together.
- **covalent bond**: Electrons shared between atoms.
- **ionic bond**: A chemical bond in which atoms give or accept atoms.
- **metallic bond**: Attractive forces between freely moving electrons and positively charged metal ions.
- **polar molecule**: A molecule with an unevenly distributed electrical charge.

Summary

- In an ionic bond, an atom gives away one or more electrons to another atom.
- In a covalent bond, two atoms share one or more electrons.
- A hydrogen bond is a relatively weak bond between two oppositely charged sides of two or more molecules. Water is a polar molecule.

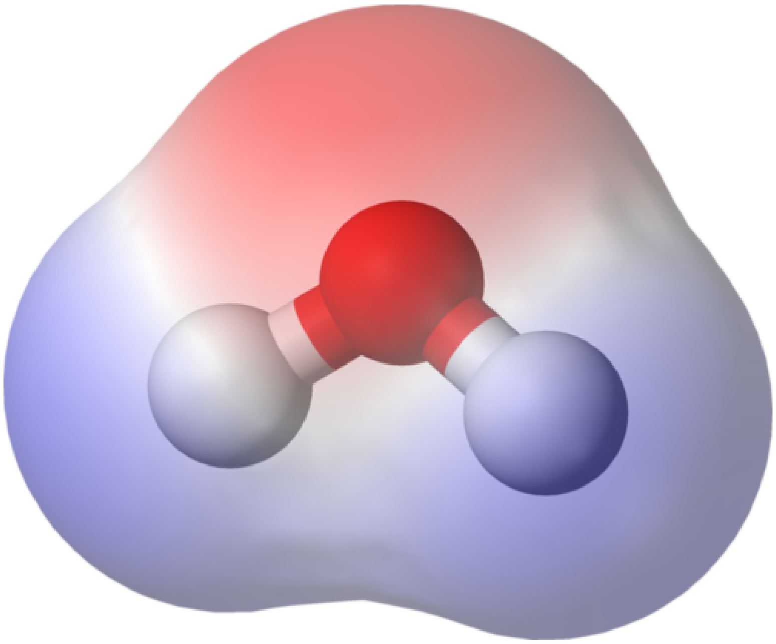
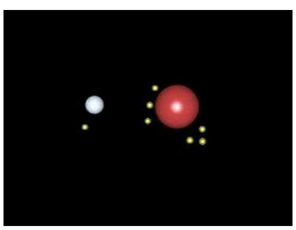


FIGURE 3.5
Water is a polar molecule. Because the oxygen atom has the electrons most of the time, the hydrogen side (blue) of the molecule has a slightly positive charge while the oxygen side (red) has a slightly negative charge.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is ionic bonding?
2. How many valence electrons does sodium have?
3. How many valence electrons does chlorine have?
4. What is the charge on a sodium ion?
5. What is covalent bonding?
6. How many valence electrons does oxygen have?

Review

1. How is a covalent bond different from an ionic bond?
2. Why is a hydrogen bond a relatively weak bond?
3. Diagram the polarity of a water molecule.

3.3 Minerals

- Describe the characteristics that define minerals.

Are you a mineral?

There used to be a TV commercial that said "you are what you eat." If that's true - and to some extent it is - then you are a mineral. Nearly all of our food is salted, and what is salt but the mineral halite? You also wear minerals, play with and on minerals, and admire the beauty of minerals. However, a mineral by definition cannot be organic, so despite what you heard on TV, you aren't what you eat!

What is a Mineral?

Minerals are everywhere! Scientists have identified more than 4,000 minerals in Earth's crust, although the bulk of the planet is composed of just a few.

A **mineral** possesses the following qualities:

- It must be solid.
- It must be crystalline, meaning it has a repeating arrangement of atoms.
- It must be naturally occurring.
- It must be inorganic.
- It must have a specific chemical composition.

Minerals can be identified by their physical properties, such as hardness, color, luster (shininess), and odor. The most common laboratory technique used to identify a mineral is X-ray diffraction (XRD), a technique that involves shining an X-ray light on a sample, and observing how the light exiting the sample is bent. XRD is not useful in the field, however.

The definition of a mineral is more restricted than you might think at first. For example, glass is made of sand, which is rich in the mineral quartz. But glass is not a mineral, because it is not crystalline. Instead, glass has a random assemblage of molecules. What about steel? Steel is made by mixing different metal minerals like iron, cobalt, chromium, vanadium, and molybdenum, but steel is not a mineral because it is made by humans and therefore is not naturally occurring. However, almost any rock you pick up is composed of minerals. Below we explore the qualities of minerals in more detail.

Crystalline Solid

Minerals are "crystalline" solids. A **crystal** is a solid in which the atoms are arranged in a regular, repeating pattern. Notice that in **Figure** 3.6 the green and purple spheres, representing sodium and chlorine, form a repeating pattern. In this case, they alternate in all directions.

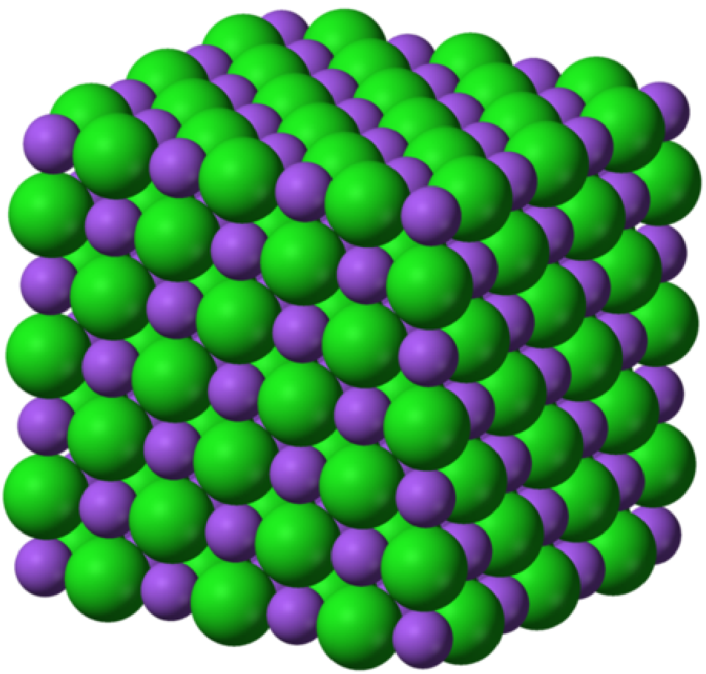


FIGURE 3.6

Sodium ions (purple balls) bond with chloride ions (green balls) to make table salt (halite). All of the grains of salt that are in a salt shaker have this crystalline structure.

Inorganic

Organic substances are the carbon-based compounds made by living creatures and include proteins, carbohydrates, and oils. Inorganic substances have a structure that is not characteristic of living bodies. Coal is made of plant and animal remains. Is it a mineral? Coal is a classified as a sedimentary rock, but is not a mineral.

Naturally Occurring

Minerals are made by natural processes, those that occur in or on Earth. A diamond created deep in Earth's crust is a mineral, but a diamond made in a laboratory by humans is not. Be careful about buying a laboratory-made "diamond" for jewelry. It may look pretty, but it's not a diamond and is not technically a mineral.

Chemical Composition

Nearly all (98.5%) of Earth's crust is made up of only eight elements – oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium – and these are the elements that make up most minerals.

All minerals have a specific chemical composition. The mineral silver is made up of only silver atoms and diamond is made only of carbon atoms, but most minerals are made up of **chemical compounds**. Each mineral has its own chemical formula. Table salt (also known as halite), pictured in **Figure** 3.6, is NaCl (sodium chloride). Quartz is always made of two oxygen atoms (red) bonded to a silicon atom (grey), represented by the chemical formula SiO_2 (**Figure** 3.7).

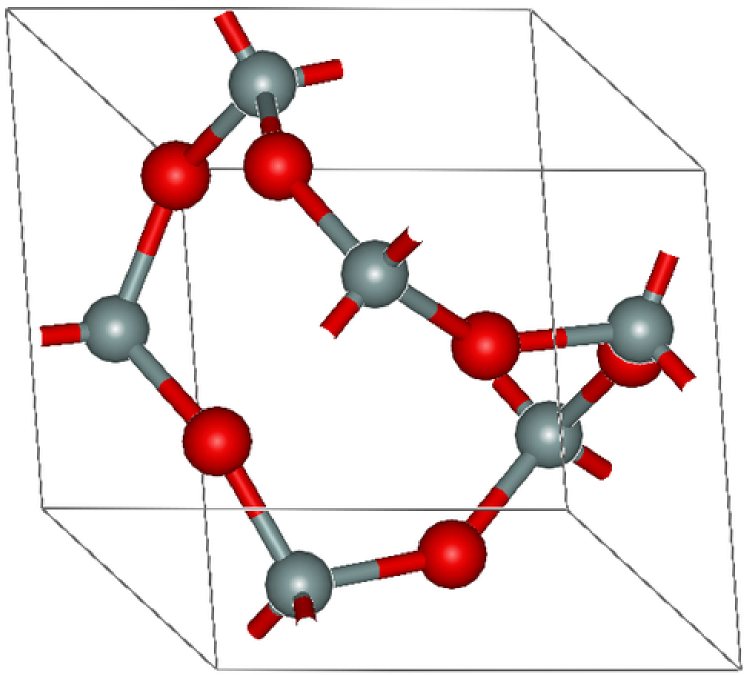


FIGURE 3.7
Quartz is made of two oxygen atoms (red) bonded to a silicon atom (grey).

In nature, things are rarely as simple as in the lab, and so it should not come as a surprise that some minerals have a range of chemical compositions. One important example in Earth science is olivine, which always has silicon and oxygen as well as some iron and magnesium, $(Mg, Fe)_2SiO_4$.

Physical Properties

Some minerals can be identified with little more than the naked eye. We do this by examining the physical properties of the mineral in question, which include:

- Color: the color of the mineral.
- Streak: the color of the mineral's powder (this is often different from the color of the whole mineral).
- Luster: shininess.
- Density: mass per volume, typically reported in "specific gravity," which is the density relative to water.
- Cleavage: the mineral's tendency to break along planes of weakness.
- Fracture: the pattern in which a mineral breaks.
- Hardness: what minerals it can scratch and what minerals can scratch it.

How physical properties are used to identify minerals is described in the "Minerals III: Mineral Identification" lesson.

Vocabulary

- **chemical compound**: A substance in which the atoms of two or more elements bond together.
- **crystal**: A solid in which all the atoms are arranged in a regular, repeating pattern.
- **mineral**: A naturally occurring inorganic, crystalline solid with a characteristic chemical composition.

Summary

- A mineral is an inorganic, crystalline solid.
- A mineral is formed through natural processes and has a definite chemical composition.
- Minerals can be identified by their characteristic physical properties, such as crystalline structure, hardness, density, breakage, and color.

Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/minerals.html

1. What are minerals?
2. How many minerals have been found?
3. List three examples of gems.
4. How are minerals identified?
5. What is the hardest mineral?
6. What is slate used for?

Review

1. Is coal a mineral? Why or why not?
2. Is a diamond made in a laboratory a mineral? Why or why not?
3. How does the internal structure of a mineral reflect in its physical appearance?

3.4 Mineral Groups

- Describe the characteristics of mineral groups.

How could a mineral crystal grow as big as two giraffes?

The crystals in Giant Crystal Cave in Mexico measure up to 36 feet long. How could minerals grow that big? Beyond requiring many years, the environment was completely suited for crystal growth, with lots of space, a perfect 136^{o}F temperature and lots of mineral-rich water.

Mineral Groups

Minerals are divided into groups based on chemical composition. Most minerals fit into one of eight mineral groups.

Silicate Minerals

The roughly 1,000 silicate minerals make up over 90% of Earth's crust. **Silicates** are by far the largest mineral group. Feldspar and quartz are the two most common silicate minerals. Both are extremely common rock-forming minerals.

The basic building block for all silicate minerals is the silica tetrahedron, which is illustrated in **Figure** 3.8. To create the wide variety of silicate minerals, this pyramid-shaped structure is often bound to other elements, such as calcium, iron, and magnesium.

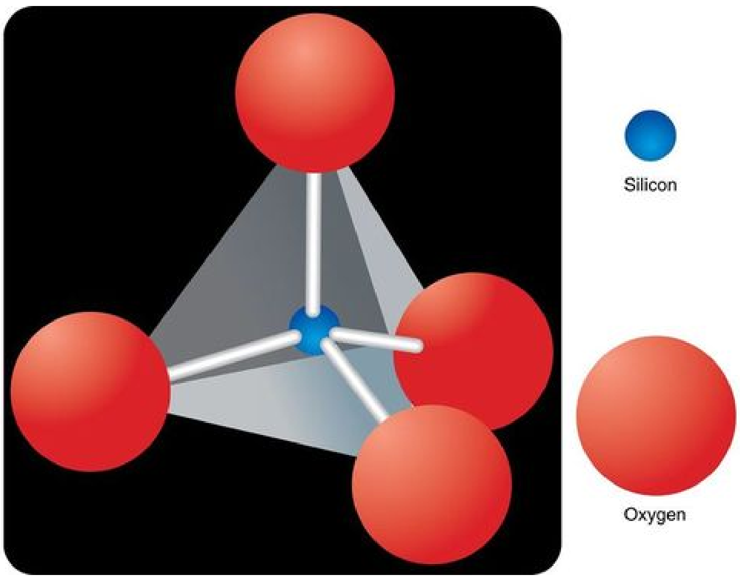


FIGURE 3.8
One silicon atom bonds to four oxygen atoms to form a silica tetrahedron.

Silica tetrahedrons combine together in six different ways to create different types of silicates (**Figure** 3.9). Tetrahedrons can stand alone, form connected circles called rings, link into single and double chains, form large flat sheets of pyramids, or join in three dimensions.

Native Elements

Native elements contain atoms of only one type of element. Only a small number of minerals are found in this category. Some of the minerals in this group are rare and valuable. Gold (**Figure** 3.10), silver, sulfur, and diamond are examples of native elements.

Carbonates

The basic carbonate structure is one carbon atom bonded to three oxygen atoms. Carbonates consists of some cation (like C, Fe, Cu, Mg, Ba, Sr, Pb) bonded to a carbonate molecule. Calcite ($CaCO_3$) is the most common carbonate mineral (**Figure ??**).

Halides

Halide minerals are salts that form when salt water evaporates. Halite is a halide mineral, but table salt (see **Figure** 3.13) is not the only halide. The chemical elements known as the halogens (fluorine, chlorine, bromine, or iodine)

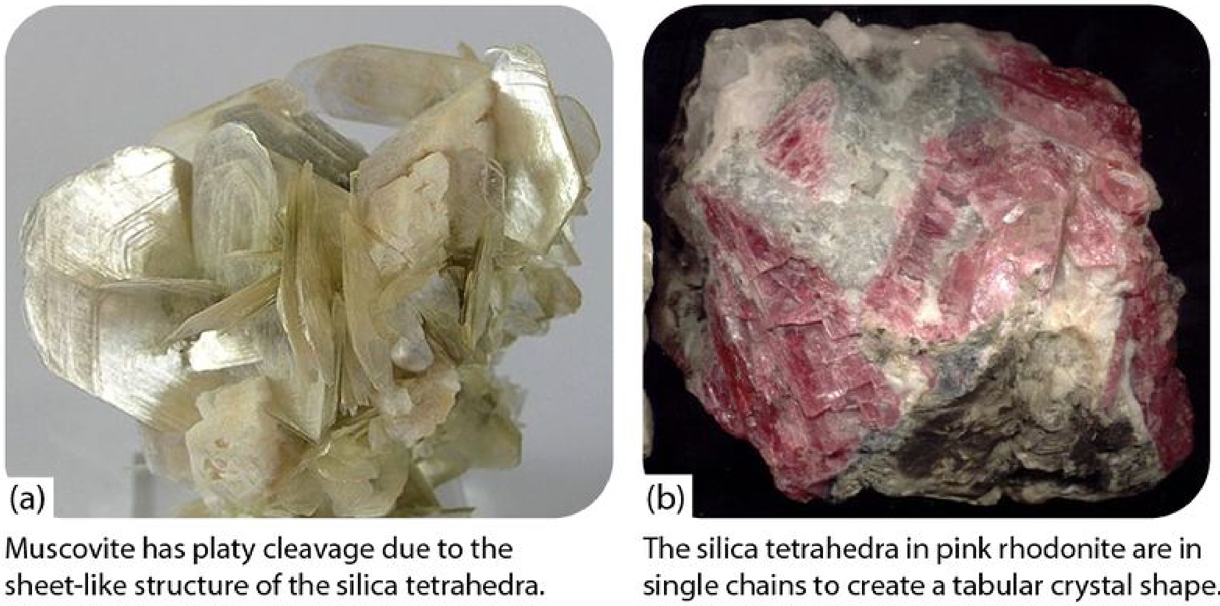


FIGURE 3.9
The different ways that silica tetrahedrons can join together cause these two minerals to look very different.

FIGURE 3.10
A gold nugget.

FIGURE 3.11
Calcite.

bond with various metallic atoms to make halide minerals. All halides are ionic minerals, which means that they are typically soluble in water.

Oxides

Oxides contain one or two metal elements combined with oxygen. Many important metal ores are oxides. Hematite (Fe_2O_3), with two iron atoms to three oxygen atoms, and magnetite (Fe_3O_4) (**Figure** 3.14), with three iron atoms to four oxygen atoms, are both iron oxides.

Phosphates

Phosphate minerals are similar in atomic structure to the silicate minerals. In the phosphates, phosphorus bonds to oxygen to form a tetrahedra. As a mineral group they aren't particularly common or important rock-forming minerals, but they are important for you and I. Apatite (**Figure** 3.15) is a phosphate ($Ca_5(PO_4)_3(F,OH)$) and is one of the major components of human bone!

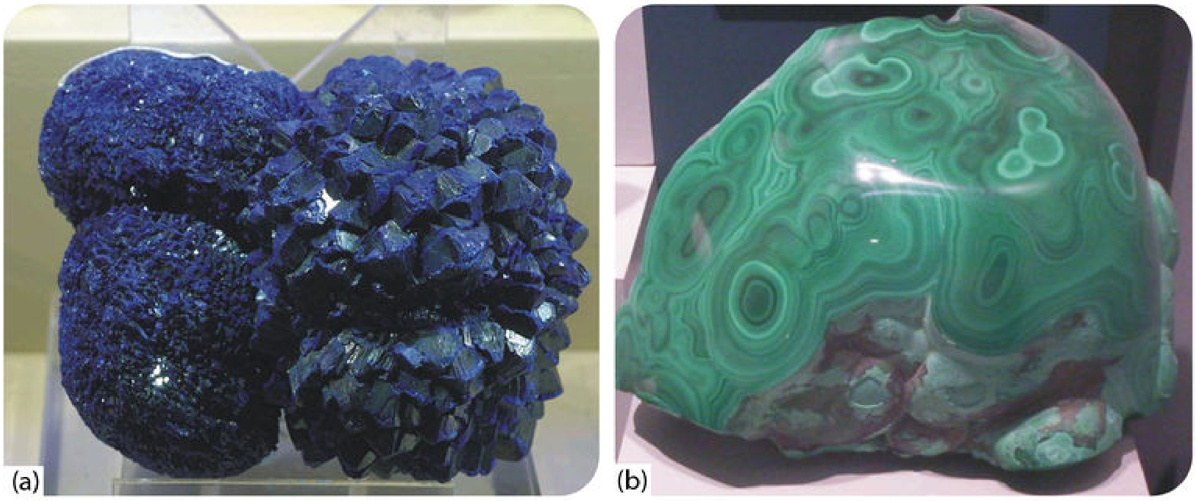


FIGURE 3.12

Two carbonate minerals: (a) deep blue azurite and (b) opaque green malachite. Azurite and malachite are carbonates that contain copper instead of calcium.

FIGURE 3.13

Beautiful halite crystals.

FIGURE 3.14
Magnetite is one of the most distinctive oxides since it is magnetic.

FIGURE 3.15
Apatite.

Sulfates

Sulfate minerals contain sulfur atoms bonded to four oxygen atoms, just like silicates and phosphates. Like halides, they form where salt water evaporates. The most common sulfate mineral is probably gypsum ($CaSO_4(OH)_2$) (**Figure** 3.16). Some gigantic 11-meter gypsum crystals have been found (See opening image). That is about as long as a school bus!

Sulfides

Sulfides are formed when metallic elements combine with sulfur in the absence of oxygen. Pyrite (**Figure** 3.17) (FeS_2) is a common sulfide mineral colloquially known as "fool's gold" because it has a golden metallic looking mineral. There are three easy ways to discriminate real gold from fools gold: real gold is extremely dense, real gold does not grow into perfect cubes, as pyrite commonly does, and pyrite smells like rotten eggs (because of the sulfur).

FIGURE 3.16
Gypsum.

FIGURE 3.17
Pyrite.

Vocabulary

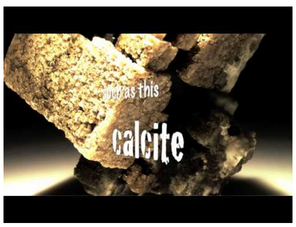
- **silicate**: Mineral made of a silica tetrahedron, with a silicon ion and oxygen ions.

Summary

- Silicates, made of building blocks of silica tetrahedrons, are the most abundant minerals on Earth.
- Silica tetrahedrons combine together in six different ways to create rings, single and double chains, large flat sheets, or 3-dimensional structures.
- Other mineral groups have other anions like carbonates, oxides, or phosphates.
- Minerals that are native elements are made of only one element.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. How are minerals classified?

2. What do silicate minerals contain?

3. Where are silicate minerals found?

4. List three examples of silicates.

5. What do non-silcate minerals contain?

6. What is a native element?

7. What are native elements used in?

8. List examples of carbonates.

9. What are halide minerals used for?

10. What are oxides used for?

11. What are sulfate minerals used for?

12. What are sulfide minerals used for?

Review

1. What is the most common group of minerals on Earth?

2. How are the silicates categorized?

3. Your friend brings you a fist-sized perfect cube of a golden mineral, which he tells you is gold. Should you believe him?

3.5 Mineral Identification

- Explain how minerals are identified by their physical characteristics.

Can you identify this mineral?

Check out the mineral above. How would you figure out what kind of mineral it is? By color? Shape? Whether it's shiny or dull? Are there lines (striations) running across the minerals? This mineral has shiny, gold, cubic crystals with striations, and smells like sulfur. What is it? In this lesson, we will discuss how to identify a mineral as one would "in the field," that is, without using fancy lab equipment.

How Are Minerals Identified?

There are a multitude of laboratory and field techniques for identifying minerals. While a mineralogist might use a high-powered microscope to identify some minerals, or even techniques like x-ray diffraction, most are recognizable using physical properties.

The most common field techniques put the observer in the shoes of a detective, whose goal it is to determine, by process of elimination, what the mineral in question is. The process of elimination usually includes observing things like color, hardness, smell, solubility in acid, streak, striations and/or cleavage.

Check out the mineral in **Figure ??**. What is the mineral's color? What is its shape? Are the individual crystals shiny or dull? Are there lines (striations) running across the minerals? In this lesson, the properties used to identify minerals are described in more detail.

Color, Streak, and Luster

Color

Color may be the first feature you notice about a mineral, but color is not often important for mineral identification. For example, quartz can be colorless, purple (amethyst), or a variety of other colors depending on chemical impurities **Figure** 3.18.

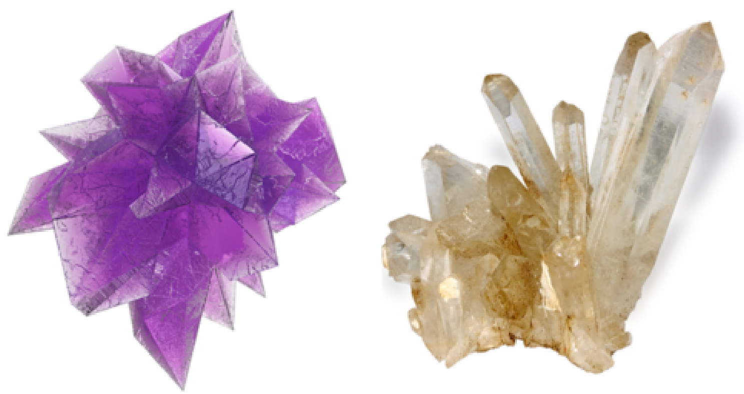


FIGURE 3.18

Purple quartz, known as amethyst, and clear quartz are the same mineral despite the different colors.

Streak

Streak is the color of a mineral's powder, which often is not the same color as the mineral itself. Many minerals, such as the quartz above, do not have streak.

Hematite is an example of a mineral that displays a certain color in hand sample (typically black to steel gray, sometimes reddish), and a different streak color (red/brown).

Luster

Luster describes the reflection of light off a mineral's surface. Mineralogists have special terms to describe luster. One simple way to classify luster is based on whether the mineral is metallic or non-metallic. Minerals that are opaque and shiny, such as pyrite, have a metallic luster. Minerals such as quartz have a non-metallic luster. Different types of non-metallic luster are described in **Table** 3.1.

TABLE 3.1: **Six types of non-metallic luster.**

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

TABLE 3.1: (continued)

Luster	Appearance
Vitreous	Glassy

Specific Gravity

Density describes how much matter is in a certain amount of space: density = mass/volume.

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. For example, the water in a drinking glass has the same density as the water in the same volume of a swimming pool.

Gold has a density of about 19 g/cm^3; pyrite has a density of about 5 g/cm^3 - that's another way to tell pyrite from gold. Quartz is even less dense than pyrite and has a density of 2.7 g/cm^3.

The specific gravity of a substance compares its density to that of water. Substances that are more dense have higher specific gravity.

Hardness

Hardness is a measure of whether a mineral will scratch or be scratched. Mohs Hardness Scale, shown in **Table** 3.2, is a reference for mineral hardness.

TABLE 3.2: **Mohs Hardness Scale: 1 (softest) to 10 (hardest).**

Hardness	Mineral
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

(Source: http://en.wikipedia.org/wiki/Mohs_scale, Adapted by: Rebecca Calhoun, License: Public Domain)

With a Mohs scale, anyone can test an unknown mineral for its hardness. Imagine you have an unknown mineral. You find that it can scratch fluorite or even apatite, but feldspar scratches it. You know then that the mineral's hardness is between 5 and 6. Note that no other mineral can scratch diamond.

Cleavage and Fracture

Breaking a mineral breaks its chemical bonds. Since some bonds are weaker than other bonds, each type of mineral is likely to break where the bonds between the atoms are weaker. For that reason, minerals break apart in characteristic ways.

Cleavage is the tendency of a mineral to break along certain planes to make smooth surfaces. Halite (**Figure** 3.20) breaks between layers of sodium and chlorine to form cubes with smooth surfaces.

Mica has cleavage in one direction and forms sheets (**Figure** 3.21).

FIGURE 3.19
The streak of hematite across an unglazed porcelain plate is red-brown.

FIGURE 3.20
Halite has cubic cleavage.

Minerals can cleave into polygons. Fluorite forms octahedrons (**Figure** 3.22).

<–

Fluorite has octahedral cleavage.

–>

One reason gemstones are beautiful is that the cleavage planes make an attractive crystal shape with smooth faces.

FIGURE 3.21
Sheets of mica.

FIGURE 3.22
Fluorite has octahedral cleavage.

Fracture is a break in a mineral that is not along a cleavage plane. Fracture is not always the same in the same mineral because fracture is not determined by the structure of the mineral.

Minerals may have characteristic fractures (**Figure** 3.23). Metals usually fracture into jagged edges. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, form smooth curved surfaces when they fracture.

FIGURE 3.23
Chrysotile has splintery fracture.

Other Identifying Characteristics

Some minerals have other unique properties, some of which are listed in **Table** 3.3. Can you name a unique property that would allow you to instantly identify a mineral that's been described quite a bit in this lesson? (Hint: It is most likely found on your dinner table.)

TABLE 3.3: Some minerals have unusual properties that can be used for identification.

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)
Taste	Some minerals taste salty	Halite

(Adapted by: Rebecca Calhoun, License: CC-BY-SA)

A simple lesson on how to identify minerals is seen in this video: http://www.youtube.com/watch?v=JeFVwqBuYl4#38;feature=channel.

Vocabulary

- **cleavage**: The tendency of a mineral to break along certain planes to make smooth surfaces.
- **density**: The amount of matter in a certain amount of space; mass divided by volume.
- **fracture**: The way a mineral breaks when it is not broken along a cleavage plane.
- **hardness**: The ability of a mineral to resist scratching.
- **luster**: The way light reflects off of the surface of the mineral.

Summary

- Some minerals have a unique property that makes them fairly easy to identify, such as high specific gravity or salty taste.

1. What color streak will pyrite leave on sandpaper?

2. What color streak would real gold leave on sandpaper?

3. List some examples of the different types of quartz.

4. What characteristic do all types of quartz share?

5. What is unique about mica?

6. What is mica used for?

7. What was azurite used for in ancient times?

8. In what colors can calcite be found?

9. What color does green calcite streak?

10. What is galena?

11. How can you tell that fluorite is not a calcite mineral?

12. How many sides does garnet have?

Review

1. How does color differ from streak and luster?

2. How does cleavage differ from fracture?

3. What's the first thing you should do when trying to identify a mineral? What do you do if you still can't identify it?

3.6 Mineral Formation

- Explain how different types of minerals form.

Is carbon a girl's best friend?

Yes! (At least if you think that diamond is a girl's best friend, anyway.) When people think of carbon they think of black dust left over from a fire, but the diamond is just carbon that was squeezed very hard at extremely high pressure. Formed at lower pressure, the carbon mineral is graphite, the mineral that is pencil "lead." Graphite would make a very different sort of ring.

Mineral Formation

Minerals form in a variety of ways:

- crystallization from magma
- precipitation from ions in solution

- biological activity
- a change to a more stable state as in metamorphism
- precipitation from vapor

Formation from Magma

Imagine a rock that becomes so hot it melts. Many minerals start out in liquids that are hot enough to melt rocks. **Magma** is melted rock inside Earth, a molten mixture of substances that can be hotter than 1,000^{o}C. Magma cools slowly inside Earth, which gives mineral crystals time to grow large enough to be seen clearly (**Figure** 3.24).

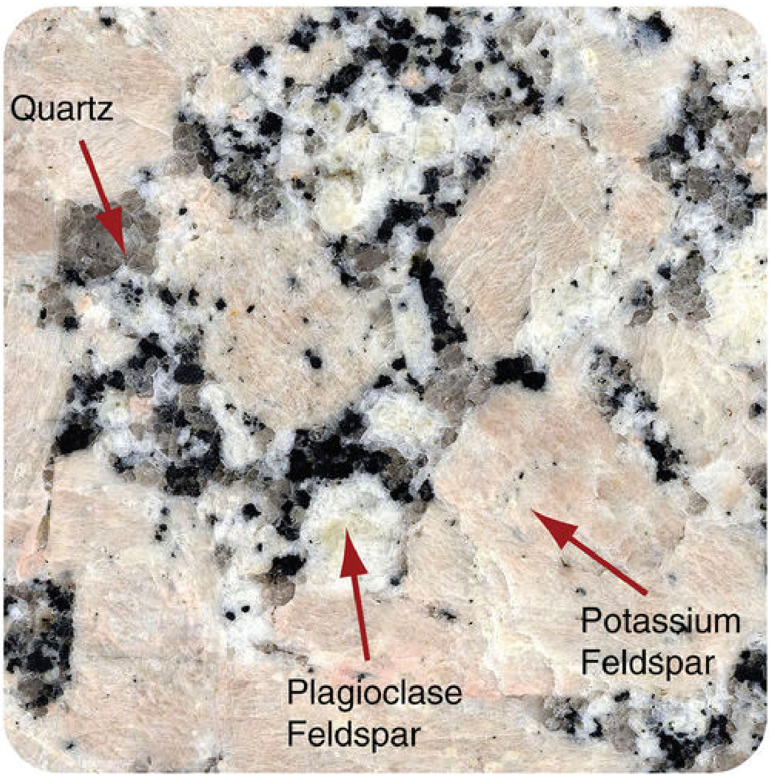


FIGURE 3.24
Granite is rock that forms from slowly cooled magma, containing the minerals quartz (clear), plagioclase feldspar (shiny white), potassium feldspar (pink), and biotite (black).

When magma erupts onto Earth's surface, it is called **lava**. Lava cools much more rapidly than magma. Crystals do not have time to form and are very small. The chemical composition between minerals that form rapidly or slowly is often the same, only their size differs.

Existing rocks may be heated enough so that the molecules are released from their structure and can move around. The molecules may match up with different molecules to form new minerals as the rock cools. This occurs during metamorphism, which will be discussed in the "Metamorphic Rock I" lesson.

Formation from Solutions

Water on Earth, such as the water in the oceans, contains chemical elements mixed into a solution. Various processes can cause these elements to combine to form solid mineral deposits.

Minerals from Salt Water

When water evaporates, it leaves behind a solid precipitate of minerals, as shown in **Figure** 3.25.

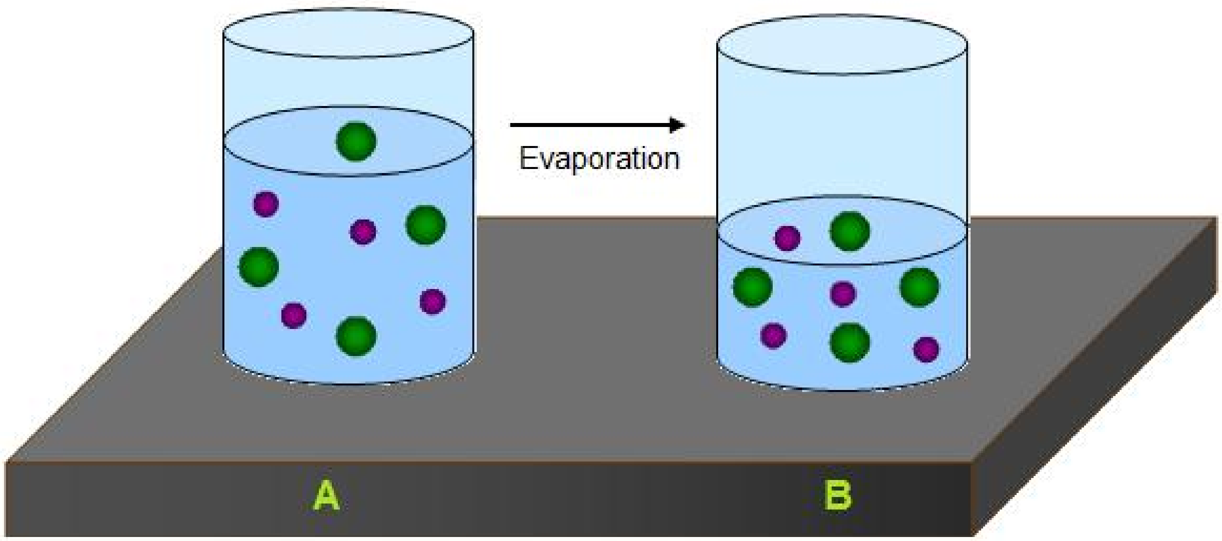


FIGURE 3.25
When the water in glass A evaporates, the dissolved mineral particles are left behind.

Water can only hold a certain amount of dissolved minerals and salts. When the amount is too great to stay dissolved in the water, the particles come together to form mineral solids, which sink. Halite easily precipitates out of water, as does calcite. Some lakes, such as Mono Lake in California (**Figure** 3.26) or The Great Salt Lake in Utah, contain many mineral precipitates.

Minerals from Hot Underground Water

Magma heats nearby underground water, which reacts with the rocks around it to pick up dissolved particles. As the water flows through open spaces in the rock and cools, it deposits solid minerals. The mineral deposits that form when a mineral fills cracks in rocks are called **veins** (**Figure** 3.27).

When minerals are deposited in open spaces, large crystals form (**Figure** 3.28).

Minerals Under Pressure

In the last several years, many incredible discoveries have been made exploring how minerals behave under high pressure, like rocks experience inside the Earth. If a mineral is placed in a special machine and then squeezed, eventually it may convert into a different mineral. Ice is a classic example of a material that undergoes solid-solid "phase transitions" as pressure and/or temperature is changed. A "phase diagram" is a graph which plots the stability of phases of a compound as a function of pressure and temperature.

The most current phase diagram for water (ice) is included below; it is very complicated! The phase diagram is split up into 3 main areas, denoted by color (blue for solid crystalline phases, green for liquid phases, and brown for gas

FIGURE 3.26
Tufa towers form when calcium-rich spring water at the bottom of Mono Lake bubbles up into the alkaline lake. The tufa towers appear when lake level drops.

FIGURE 3.27
Quartz veins formed in this rock.

phases). Each of the Roman numerals in the blue area corresponds to a different arrangement of H_2O molecules. Notice that the highest pressure structure of ice is hexagonal (high symmetry) while the low pressure form of ice is orthorhombic (low symmetry). This is a common result for high pressure minerals.

FIGURE 3.28
Amethyst formed when large crystals grew in open spaces inside the rock. These special rocks are called geodes.

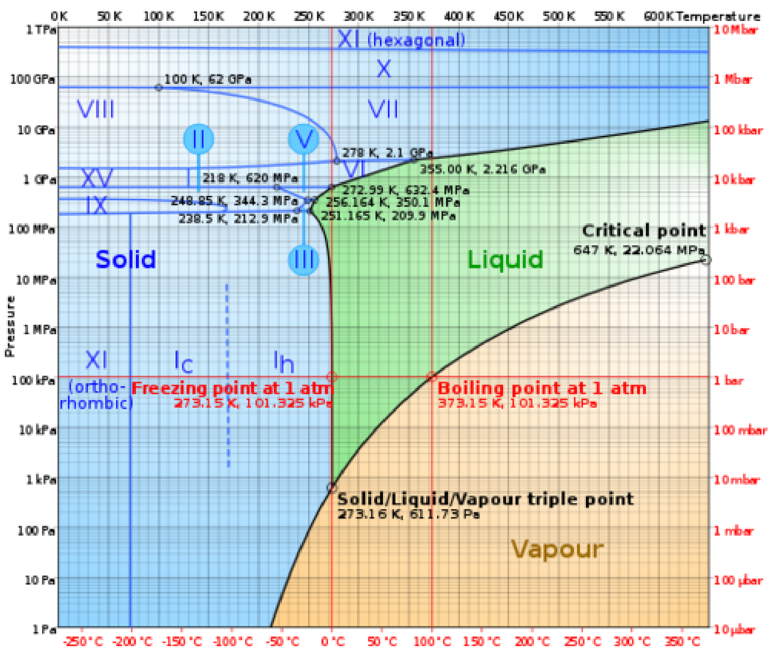


FIGURE 3.29
A sample phase diagram, this one for water.

Vocabulary

- **lava**: Molten rock that has reached Earth's surface.
- **magma**: Molten rock deep inside Earth.
- **vein**: Minerals that cooled from a fluid and filled cracks in a rock.

Summary

- Minerals form as magma cools.
- Minerals form when they precipitate from hot fluids that have cooled down.
- Minerals form when the concentration of ions gets too great in a fluid.

Practice

Use this resource to answer the questions that follow.

http://nature.berkeley.edu/classes/eps2//wisc/Lect3.html

1. How do minerals form in water?
2. What crystals are formed from silica-based minerals?
3. What crystals are formed from copper-based minerals?
4. What is a pegmatite?
5. What can magma rich in boron crystallize into?
6. What other gems can be found in magma?

Review

1. How do minerals form in veins?
2. How do minerals form from cool water?
3. When do large crystals form from magma? When do small crystals form from magma?

3.7 Rocks

- Define rock.

How many different rock types are in this photo?

A beach or river bed is a good place to see a lot of different rock types since the rocks there represent the entire drainage system. How could you tell how many different rock types were in the photo? What characteristics would you look for?

What Are Rocks?

A **rock** is a naturally formed, non-living Earth material. Rocks are made of collections of mineral grains that are held together in a firm, solid mass (**Figure** 3.30).

How is a rock different from a mineral? Rocks are made of minerals. The mineral grains in a rock may be so tiny that you can only see them with a microscope, or they may be as big as your fingernail or even your finger (**Figure** 3.31).

Rocks are identified primarily by the minerals they contain and by their texture. Each type of rock has a distinctive set of minerals. A rock may be made of grains of all one mineral type, such as quartzite. Much more commonly, rocks are made of a mixture of different minerals. Texture is a description of the size, shape, and arrangement of mineral grains. Are the two samples in **Figure** 3.32 the same rock type? Do they have the same minerals? The same texture?

FIGURE 3.30
The different colors and textures seen in this rock are caused by the presence of different minerals.

FIGURE 3.31
A pegmatite from South Dakota with crystals of lepidolite, tourmaline, and quartz (1 cm scale on the upper left).

TABLE 3.4: (continued)

TABLE 3.4: Properties of Sample 1 and Sample 2

Sample	Minerals	Texture	Formation	Rock type
Sample 1	plagioclase, hornblende, pyroxene	Crystals, visible to naked eye	Magma cooled slowly	Diorite
Sample 2	plagioclase, hornblende, pyroxene	One type of crystal visible, rest microscopic	Magma erupted and cooled quickly	Andesite

As seen in **Table** 3.4, these two rocks have the same chemical composition and contain mostly the same minerals, but they do not have the same texture. Sample 1 has visible mineral grains, but Sample 2 has some visible grains in a fine matrix. The two different textures indicate different histories. Sample 1 is a diorite, a rock that cooled slowly from magma (molten rock) underground. Sample 2 is an andesite, a rock that cooled rapidly from a very similar magma that erupted onto Earth's surface.

A few rocks are not made of minerals because the material they are made of does not fit the definition of a mineral. Coal, for example, is made of organic material, which is not a mineral. Can you think of other rocks that are not made of minerals?

Vocabulary

- **rock**: A collection of minerals.

Summary

- Nearly all rocks are made of minerals. A few are made of materials that do not fit the definition of minerals.
- Rocks are typically identified by the minerals they contain and their textures.
- The texture of a rock describes the size, shape, and arrangement of mineral grains and is a reflection of how the rock formed.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is a rock?

2. What type of rock is this?

3. What mineral produces the pink pieces?

4. What mineral produces the white pieces?

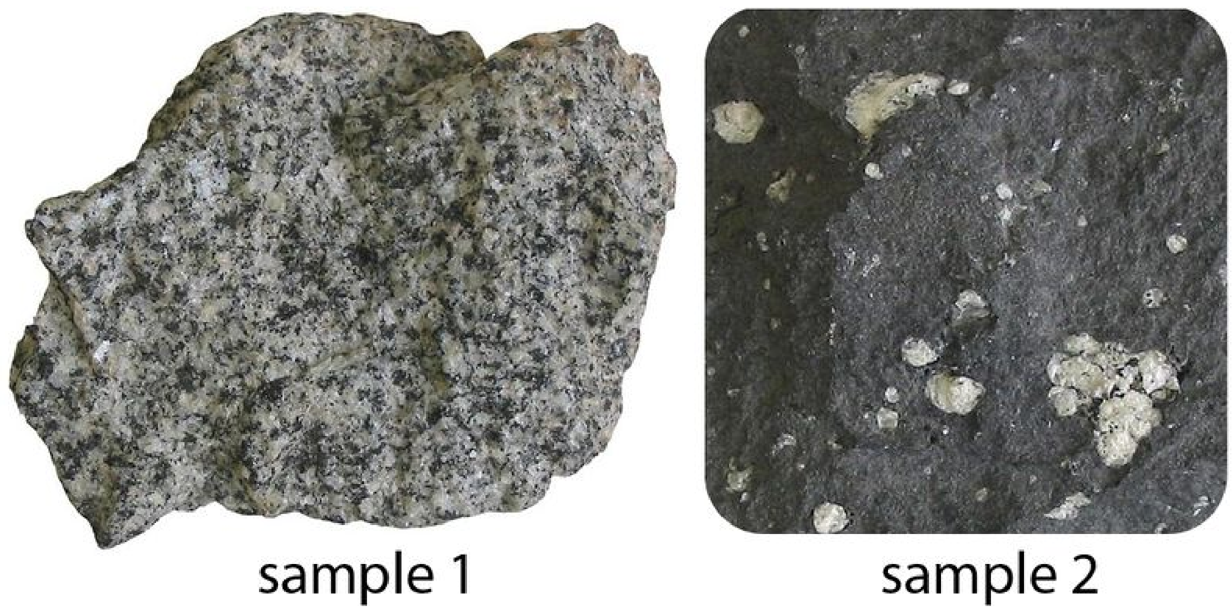


FIGURE 3.32
Rock samples

5. What mineral produces the black pieces?
6. What is a mineral?

Review

1. Name a rock type that is not made of minerals and state how a rock could not be made of minerals.
2. Can a rock be made of only one type of mineral, or do rocks need to be made of at least two minerals?
3. Why is texture so important in classifying rock types?

3.8 Rocks and Processes of the Rock Cycle

- Explain the processes of the rock cycle.

Is this what geologists mean by the rock cycle?

Okay, very punny. The rock cycle shows how any type of rock can become any other type of rock. Some rocks may stay the same type for a long time, for example, if they're at the base of the crust, but other rocks may relatively rapidly change from one type to another.

The Rock Cycle

The **rock cycle**, illustrated in **Figure** 3.33, depicts how the three major rock types – igneous, sedimentary, and metamorphic - convert from one to another. Arrows connecting the rock types represent the processes that accomplish these changes.

Rocks change as a result of natural processes that are taking place all the time. Most changes happen very slowly. Rocks deep within the Earth are right now becoming other types of rocks. Rocks at the surface are lying in place before they are next exposed to a process that will change them. Even at the surface, we may not notice the changes. The rock cycle has no beginning or end.

The Three Rock Types

Rocks are classified into three major groups according to how they form. These three types will be described in more detail in other lessons in this concept, but here is an introduction.

- **Igneous rocks** form from the cooling and hardening of molten magma in many different environments. The chemical composition of the magma and the rate at which it cools determine what rock forms. Igneous rocks

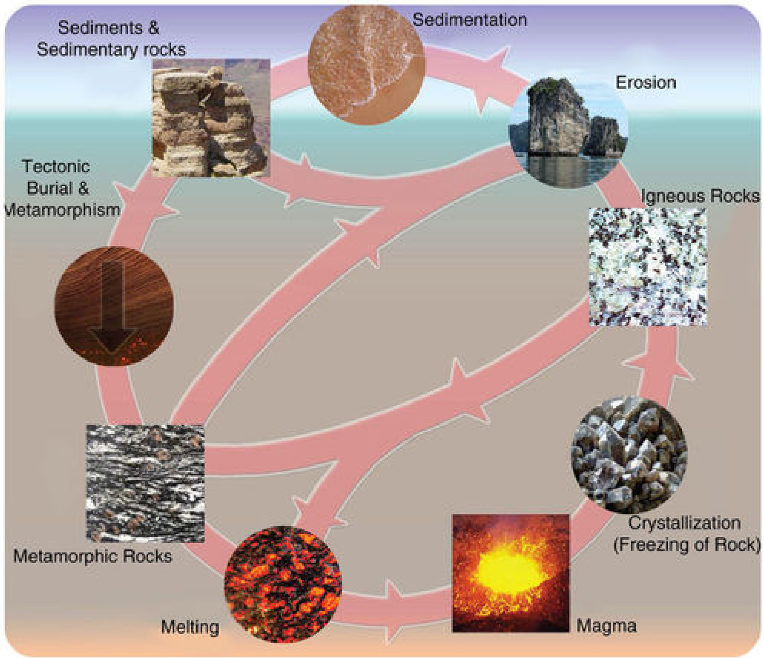


FIGURE 3.33
The Rock Cycle.

can cool slowly beneath the surface or rapidly at the surface. These rocks are identified by their composition and texture. More than 700 different types of igneous rocks are known.

- **Sedimentary rocks** form by the compaction and cementing together of **sediments**, broken pieces of rock-like gravel, sand, silt, or clay. Those sediments can be formed from the weathering and erosion of preexisting rocks. Sedimentary rocks also include chemical **precipitates**, the solid materials left behind after a liquid evaporates.
- **Metamorphic rocks** form when the minerals in an existing rock are changed by heat or pressure below the surface.

A simple explanation of the three rock types and how to identify them can be seen in this video: http://www.youtube.com/watch?v=tQUe9C40NEE#38;feature=fvw.

This video discusses how to identify igneous rocks: http://www.youtube.com/watch?v=Q0XtLjE3siE#38;feature=channel.

This video discusses how to identify a metamorphic rocks: http://www.youtube.com/watch?v=qs9x_bTCiew#38;feature=related.

The Processes of the Rock Cycle

Several processes can turn one type of rock into another type of rock. The key processes of the rock cycle are crystallization, erosion and sedimentation, and metamorphism.

Crystallization

Magma cools either underground or on the surface and hardens into an igneous rock. As the magma cools, different crystals form at different temperatures, undergoing **crystallization**. For example, the mineral olivine crystallizes out of magma at much higher temperatures than quartz. The rate of cooling determines how much time the crystals will have to form. Slow cooling produces larger crystals.

Erosion and Sedimentation

Weathering wears rocks at the Earth's surface down into smaller pieces. The small fragments are called sediments. Running water, ice, and gravity all transport these sediments from one place to another by **erosion**. During **sedimentation**, the sediments are laid down or deposited. In order to form a sedimentary rock, the accumulated sediment must become compacted and cemented together.

Metamorphism

When a rock is exposed to extreme heat and pressure within the Earth but does not melt, the rock becomes metamorphosed. **Metamorphism** may change the mineral composition and the texture of the rock. For that reason, a metamorphic rock may have a new mineral composition and/or texture.

Vocabulary

- **crystallization**: The formation of mineral grains from cooling magma.
- **erosion**: The transport of weathered materials and sediments by water, wind, ice, or gravity.
- **igneous rock**: A rock formed from cooled magma.
- **metamorphic rock**: A rock that forms from a previous rock that is exposed to heat and/or pressure.
- **metamorphism**: A solid state change in an existing rock due to high temperature and/or pressure that creates a metamorphic rock.
- **precipitate**: Solid substance that separates out of a liquid to form a solid, usually when the liquid evaporates.
- **rock cycle**: The never-ending cycle in which one rock type changes into another rock type.
- **sediment**: Small particle of soil or rock deposited by wind or water.
- **sedimentary rock**: A rock that forms from the compaction of sediments or the precipitation of material from a liquid
- **sedimentation**: Sediments are laid down in a deposit.
- **weathering**: The chemical or physical breakdown of rocks, soils or minerals at Earth's surface.

Summary

- The three main rock types are igneous, metamorphic and sedimentary.
- The three processes that change one rock to another are crystallization, metamorphism, and erosion and sedimentation.
- Any rock can transform into any other rock by passing through one or more of these processes. This creates the rock cycle.

Practice

Use these resources to answer the questions that follow.

This *Science Made Fun* video discusses the conditions under which the three main rock types form **(3c)**: http://www.youtube.com/watch?v=G7AWGhQynTY#38;feature=related (3:41).

MEDIA

Click image to the left for more content.

1. How do igneous rocks form?
2. What are the two types of igneous rocks and how do they differ?
3. What are metamorphic rocks?
4. How do metamorphic rocks form?
5. How do sedimentary rocks form?
6. List three examples of igneous rocks.
7. List three examples of sedimentary rocks.
8. What forms coal?
9. List three examples of metamorphic rocks.
10. Can an igneous rock become an igneous rock? Can a sedimentary rock become a sedimentary rock? Can a metamorphic rock become a metamorphic rock?
11. Draw an diagram of the rock cycle and include the processes that transform rocks from one type to another.

Review the rock cycle - click a rock to begin.

http://www.phschool.com/atschool/phsciexp/active_art/rock_cycle/index.html

Test your rock identification skills with this activity:

Name that Rock - http://library.thinkquest.org/J002289/rocks.html

Review

1. What processes must a metamorphic rock go through to become an igneous rock?
2. What processes must a sedimentary rock go through to become a metamorphic rock?
3. What types of rocks can become sedimentary rocks and how does that happen?

3.9 Igneous Rocks

- Describe the factors that determine the composition of igneous rocks.

What makes this landscape so remarkable?

This photo is of the Sierra Nevada Mountains in California. The rocks look so uniform because they are all igneous intrusive rocks that cooled from a felsic magma to create the granite that you see. Later, the rock was uplifted and modified by glaciers during the Pleistocene ice ages.

Magma Composition

Different factors play into the composition of a magma and the rock it produces.

Composition of the Original Rock

The rock beneath the Earth's surface is sometimes heated to high enough temperatures that it melts to create magma. Different magmas have different composition and contain whatever elements were in the rock or rocks that melted. Magmas also contain gases. The main elements are the same as the elements found in the crust. **Table** 3.5 lists the abundance of elements found in the Earth's crust and in magma. The remaining 1.5% is made up of many other elements that are present in tiny quantities.

TABLE 3.5: Elements in Earth's Crust and Magma

Element	Symbol	Percent
Oxygen	O	46.6%

TABLE 3.5: (continued)

Element	Symbol	Percent
Silicon	Si	27.7%
Aluminum	Al	8.1%
Iron	Fe	5.0%
Calcium	Ca	3.6%
Sodium	Na	2.8%
Potassium	K	2.6%
Magnesium	Mg	2.1%
Total		**98.5%**

(Source: http://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust)

How Rocks Melt

Whether rock melts to create magma depends on:

- Temperature: Temperature increases with depth, so melting is more likely to occur at greater depths.
- Pressure: Pressure increases with depth, but increased pressure raises the melting temperature, so melting is less likely to occur at higher pressures.
- Water: The addition of water changes the melting point of rock. As the amount of water increases, the melting point decreases.
- Rock composition: Minerals melt at different temperatures, so the temperature must be high enough to melt at least some minerals in the rock. The first mineral to melt from a rock will be quartz (if present) and the last will be olivine (if present).

The different geologic settings that produce varying conditions under which rocks melt will be discussed in Concept Plate Tectonics.

What Melts and What Crystallizes

As a rock heats up, the minerals that melt at the lowest temperatures melt first. **Partial melting** occurs when the temperature on a rock is high enough to melt only some of the minerals in the rock. The minerals that will melt will be those that melt at lower temperatures. **Fractional crystallization** is the opposite of partial melting. This process describes the crystallization of different minerals as magma cools.

Here's a fractional crystallization animation: http://authors.ck12.org/wiki/images/d/df/Fractional_Crystallization.swf.

Bowen's Reaction Series indicates the temperatures at which minerals melt or crystallize (**Figure** 3.34). An understanding of the way atoms join together to form minerals leads to an understanding of how different igneous rocks form. Bowen's Reaction Series also explains why some minerals are always found together and some are never found together.

To see a diagram illustrating Bowen's Reaction Series, visit this website: http://csmres.jmu.edu/geollab/Fichter/RockMin/RockMin.html.

This excellent video that explains Bowen's Reaction Series in detail: http://www.youtube.com/watch?v=en6ihAM9fe8.

If the liquid separates from the solids at any time in partial melting or fractional crystallization, the chemical composition of the liquid and solid will be different. When that liquid crystallizes, the resulting igneous rock will have a different composition from the parent rock.

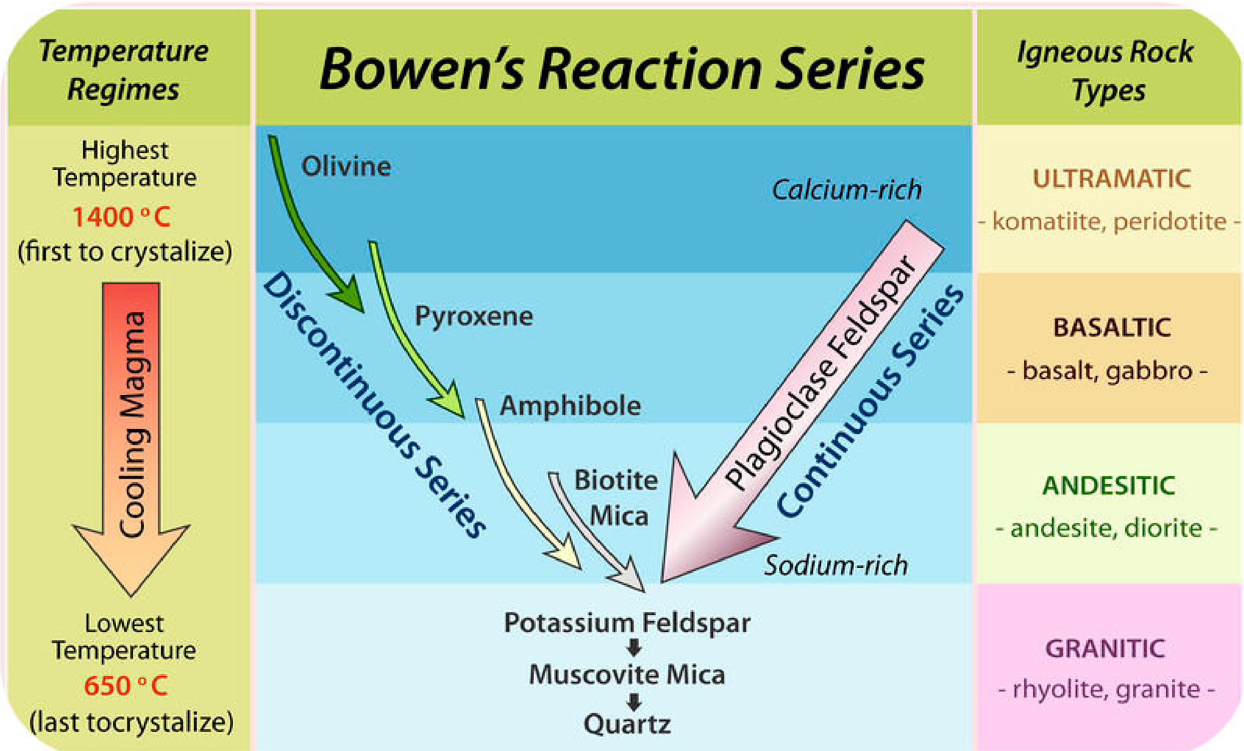


FIGURE 3.34

Bowen's Reaction Series.

Vocabulary

- **fractional crystallization**: The crystallization of a fraction of the minerals in magma depending on temperature.
- **partial melting**: The melting of some, but not all, of the minerals in a rock, depending on temperature.

Summary

- Melting of an existing rock to create magma depends on that rock's composition and on the temperature, pressure, and water content found in that environment.
- Bowen's Reaction Series indicates the temperatures at which minerals crystallize from a magma or melt from a rock.
- Since minerals melt at different temperatures, a rock in which some minerals have melted has undergone partial melting; the opposite process, in which some minerals crystallize out of a magma, is fractional crystallization.

Practice

Use this resource to answer the questions that follow.

Geology: Igneous Rocks

http://www.videojug.com/film/geology-igneous-rocks

MEDIA

Click image to the left for more content.

1. How is igneous rock formed?
2. How does crystallization occur?
3. Explain how extrusive igneous rock is formed.
4. Explain how intrusive igneous rock is formed.
5. What is pyroclastic rock?
6. How are pyroclastic rocks formed?

Review

1. Why are olivine and quartz never found together in an igneous rock?
2. How do changes in temperature, pressure, and fluids cause melting?
3. Briefly describe what Bowen's Reaction Series depicts.

3.10 Intrusive and Extrusive Igneous Rocks

- Compare and contrast intrusive and extrusive igneous rock.

How can igneous rock be so black and shiny?

This rock is lava that rapidly cooled on Kilauea volcano in Hawaii Volcanoes National Park on the Big Island of Hawaii. The lava cooled so fast that crystals had little time to form. How does this rock compare with the granite further down this lesson?

Intrusive and Extrusive Igneous Rocks

The rate at which magma cools determines whether an igneous rock is intrusive or extrusive. The cooling rate is reflected in the rock's texture.

Intrusive Igneous Rocks

Igneous rocks are called **intrusive** when they cool and solidify beneath the surface. Intrusive rocks form plutons and so are also called plutonic. A **pluton** is an igneous intrusive rock body that has cooled in the crust. When magma cools within the Earth, the cooling proceeds slowly. Slow cooling allows time for large crystals to form, so intrusive igneous rocks have visible crystals. Granite is the most common intrusive igneous rock (see **Figure** 3.35 for an example).

Igneous rocks make up most of the rocks on Earth. Most igneous rocks are buried below the surface and covered with sedimentary rock, or are buried beneath the ocean water. In some places, geological processes have brought igneous rocks to the surface. **Figure** 3.36 shows a landscape in California's Sierra Nevada made of granite that has been raised to create mountains.

FIGURE 3.35
Granite is made of four minerals, all visible to the naked eye: feldspar (white), quartz (translucent), hornblende (black), and biotite (black, platy).

FIGURE 3.36
California's Sierra Nevada is intrusive igneous rock exposed at Earth's surface.

Extrusive Igneous Rocks

Igneous rocks are called **extrusive** when they cool and solidify above the surface. These rocks usually form from a volcano, so they are also called **volcanic rocks** (**Figure** 3.37).

Extrusive igneous rocks cool much more rapidly than intrusive rocks. There is little time for crystals to form, so extrusive igneous rocks have tiny crystals (**Figure** 3.38).

What does the andesite photo in the lesson "Types of Rocks" indicate about how that magma cooled? The rock has large crystals set within a matrix of tiny crystals. In this case, the magma cooled enough to form some crystals before erupting. Once erupted, the rest of the lava cooled rapidly. This is called **porphyritic** texture.

Cooling rate and gas content create other textures (see **Figure** 3.39 for examples of different textures). Lavas that cool extremely rapidly may have a glassy texture. Those with many holes from gas bubbles have a **vesicular** texture.

FIGURE 3.37
Extrusive igneous rocks form after lava cools above the surface.

FIGURE 3.38
Cooled lava forms basalt with no visible crystals. Why are there no visible crystals?

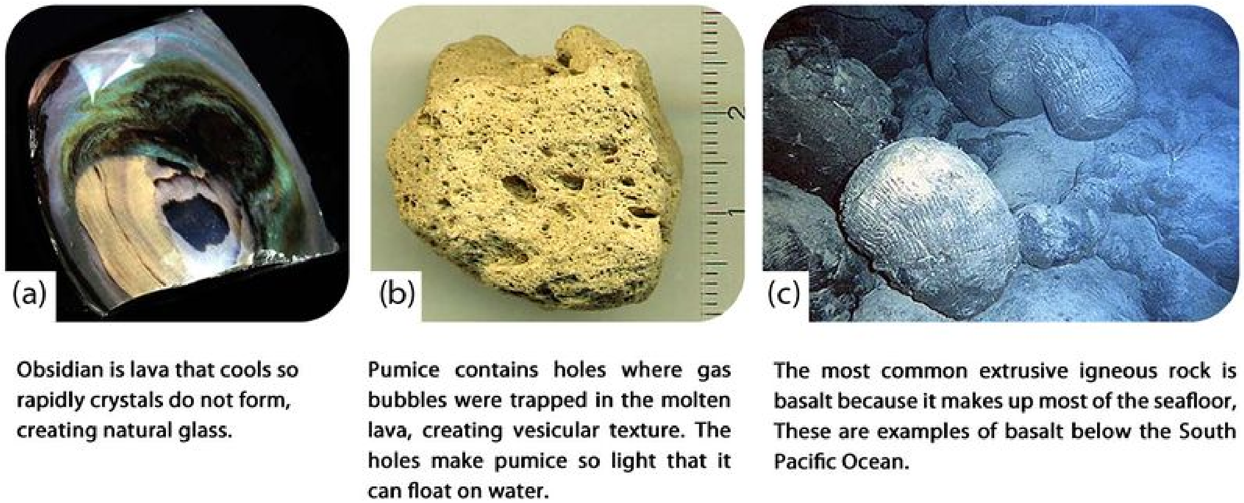


FIGURE 3.39

Different cooling rate and gas content resulted in these different textures.

Vocabulary

- **extrusive**: Igneous rocks that form at Earth's surface from rapidly cooling lava.
- **intrusive**: Igneous rocks that form inside the Earth from slowly cooling magma.
- **pluton**: An igneous intrusive rock body that has cooled in the crust.
- **porphyritic**: Igneous rock texture in which visible crystals are found in a matrix of tiny crystals.
- **vesicular**: Igneous rock texture with holes that indicate the presence of gas bubbles in the magma.
- **volcanic rock**: Rock that originates in a volcano or volcanic feature.

Summary

- Intrusive igneous rocks cool from magma slowly because they are buried beneath the surface, so they have large crystals.
- Extrusive igneous rocks cool from lava rapidly because they form at the surface, so they have small crystals.
- Texture reflects how an igneous rock formed.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=deC5af9AW6w

1. How are intrusive rocks formed?

2. What size are the crystals in very coarse rocks?

3. What are the most common coarse rocks?

4. How are extrusive rocks formed?

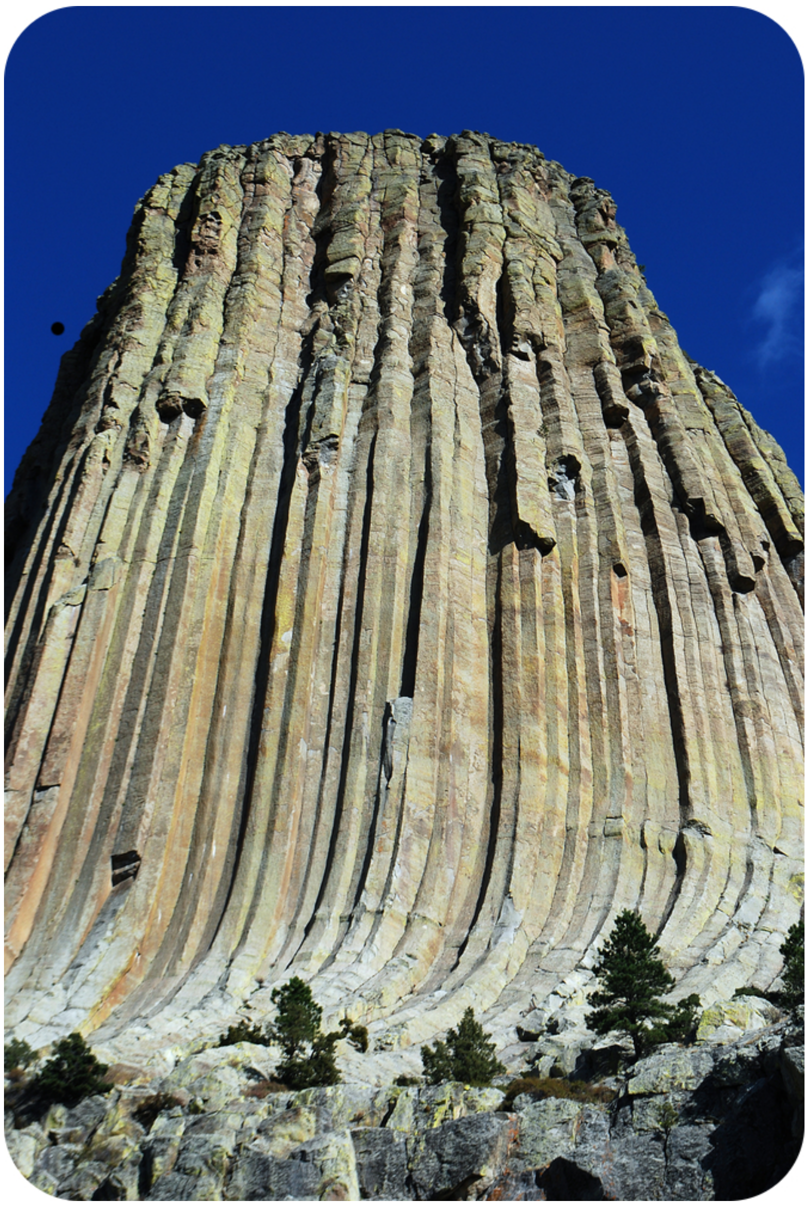
5. List the three textures for extrusive rocks.
6. Describe rhyolite.
7. Describe pumice.
8. Explain why obsidian appear black.

Review

1. How does a rock develop a vesicular texture?
2. What are the other names for igneous intrusive rock and igneous extrusive rocks and how do they get those names?
3. What sequence of events causes a rock to develop porphyritic texture?

3.11 Igneous Rock Classification

- Explain how igneous rocks are classified by composition and by cooling rate.



Is this an intrusive or an extrusive igneous rock?

From this view the amazing structure of rocks that make up Devil's Tower doesn't really indicate whether the structure formed slowly or quickly. A close up view would show small crystals in a mafic rock, indicating a rapid cooling from a basalt lava. Cooling was slow enough that the hexagonal "posts" could form.

Igneous Rock Classification

Igneous rocks are first classified by their composition, from felsic to ultramafic. The characteristics and example minerals in each type are included in **Table** 3.6.

TABLE 3.6: Properties of Igneous Rock Compositions

Composition	Color	Density	Minerals
Felsic	Light	Low	Quartz, orthoclase feldspar
Intermediate	Intermediate	Intermediate	Plagioclase feldspar, biotite, amphibole
Mafic	Dark	High	Olivine, pyroxene
Ultramafic	Very dark	Very high	Olivine

Second to composition in igneous rock classification is texture. Texture indicates how the magma that formed the rock cooled.

TABLE 3.7: Silica Composition and Texture of Major Igneous Rocks

Type	Amount of Silica	Extrusive	Intrusive
Ultramafic	<45%	Komatiite	Peridotite
Mafic	45-52%	Basalt	Gabbro
Intermediate	52-63%	Andesite	Diorite
Intermediate-Felsic	63-69%	Dacite	Granodiorite
Felsic	>69% SiO_2	Rhyolite	Granite

Some of the rocks in **Table** 3.7 were pictured earlier in this concept. Look back at them and, using what you know about the size of crystals in extrusive and intrusive rocks and the composition of felsic and mafic rocks, identify the rocks in the photos in **Figure** 3.40:

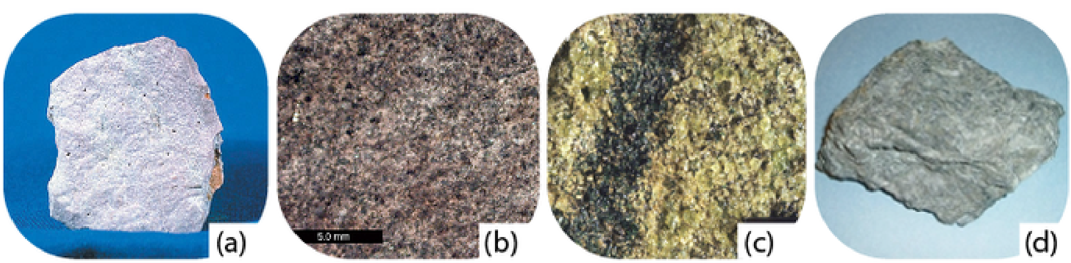


FIGURE 3.40
These are photos of A) rhyolite, B) gabbro, C) peridotite, and D) komatiite.

Summary

- Composition is the first criteria on which to classify igneous rocks, with categories from felsic to ultramafic; color is a first order indicator of composition.

- Texture is the second criteria for classifying igneous rocks because texture indicates how a rock cooled.
- Igneous rocks are categorized in pairs with the same composition but different textures: gabbro-basalt, diorite-andesite, and granite-rhyolite.

Practice

Use this resource to answer the questions that follow.

Types of Igneous Rocks

http://www.youtube.com/watch?v=dgn-xSZHItU

MEDIA

Click image to the left for more content.

1. Describe andesite.

2. What is basalt?

3. What is diorite?

4. Describe gabbro.

5. What is granite?

6. How is obsidian formed? What is it?

7. What is pegmatite?

8. What is peridotite composed of?

9. What is pumice?

10. What is rhyolite?

11. Describe scoria. How does it differ from pumice?

12. What is tuff?

Review

1. Describe the formation of the igneous rock pair gabbro-basalt. What makes the rocks the same and what makes them different?

2. How does the composition of a rock affect its color?

3. What are ultramafic rocks and where are they likely to be found?

3.12 Sedimentary Rocks

- Describe factors that determine the composition of sedimentary rocks.

What is this material and what created the ripples?

If you've walked on a sandy beach or on a sand dune, you may have seen ripples like this formed from wind or waves. Sand is small broken pieces of rock that can be moved around. They can also be lithified to become a rock known as sandstone.

Sediments

Sandstone is one of the common types of sedimentary rocks that form from sediments. There are many other types. Sediments may include:

- fragments of other rocks that often have been worn down into small pieces, such as sand, silt, or clay.
- **organic** materials, or the remains of once-living organisms.
- chemical precipitates, which are materials that get left behind after the water evaporates from a solution.

Rocks at the surface undergo mechanical and chemical weathering. These physical and chemical processes break rock into smaller pieces. Mechanical weathering simply breaks the rocks apart. Chemical weathering dissolves the less stable minerals. These original elements of the minerals end up in solution and new minerals may form. Sediments are removed and transported by water, wind, ice, or gravity in a process called erosion (**Figure** 3.41). Much more information about weathering and erosion can be found in Concept Surface Processes and Landforms.

Streams carry huge amounts of sediment (**Figure** 3.42). The more energy the water has, the larger the particle it can carry. A rushing river on a steep slope might be able to carry boulders. As this stream slows down, it no longer has the energy to carry large sediments and will drop them. A slower moving stream will only carry smaller particles.

FIGURE 3.41

Water erodes the land surface in Alaska's Valley of Ten Thousand Smokes

FIGURE 3.42

A river dumps sediments along its bed and on its banks.

Sediments are deposited on beaches and deserts, at the bottom of oceans, and in lakes, ponds, rivers, marshes, and swamps. Landslides drop large piles of sediment. Glaciers leave large piles of sediments, too. Wind can only transport sand and smaller particles. The type of sediment that is deposited will determine the type of sedimentary rock that can form. Different colors of sedimentary rock are determined by the environment where they are deposited. Red rocks form where oxygen is present. Darker sediments form when the environment is oxygen poor.

Vocabulary

- **organic**: Something from living organisms.

Summary

- Rocks undergo chemical or mechanical weathering to form smaller pieces.
- Sediments range in size from tiny bits of silt or clay to enormous boulders.
- Sediments are transported by wind, water, ice, or gravity into different environments.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/earth/geology/sed_intro.html

1. What percentage of rocks are sedimentary?
2. Where are sedimentary rocks found?
3. What can scientists learn from sedimentary rocks?
4. List and explain each of the types of sedimentary rocks?

http://www.windows2universe.org/earth/geology/sed_clastic.html

5. How is clastic sedimentary rock formed?
6. What holds the sediment together?
7. What is Cathedral Rocked made of?

Review

1. What does sediment size indicate about the history of that sediment?
2. How are chemical precipitates different from rocks that form from sediment particles?
3. Why are organic materials considered sediments but not minerals?

3.13 Lithification of Sedimentary Rocks

- Explain how sediments become rock by the processes of lithification.

What steps led to this rock formation?

What do you see? The rock is a sandstone, so first there were rocks that weathered and eroded. The cross-bedding indicates that the sand was deposited in a dune. The sand was then buried deeply enough that it turned into rock. This lesson will explore how something like sand could become a rock.

Sedimentary Rock Formation

Accumulated sediments harden into rock by **lithification**, as illustrated in the **Figure** 3.43. Two important steps are needed for sediments to lithify.

1. Sediments are squeezed together by the weight of overlying sediments on top of them. This is called **compaction**. Cemented, non-organic sediments become **clastic** rocks. If organic material is included, they are **bioclastic** rocks.
2. Fluids fill in the spaces between the loose particles of sediment and crystallize to create a rock by **cementation.**

The sediment size in clastic sedimentary rocks varies greatly (see **Table** in Sedimentary Rocks III: Classification).

Vocabulary

- **bioclastic**: Sedimentary rock that forms from pieces of living organisms.

FIGURE 3.43
This cliff is made of sandstone. Sands were deposited and then lithified.

- **cementation**: When fluids deposit ions to create a cement that hardens loose sediments.
- **clastic**: Contains fragments or clasts of preexisting rock; sedimentary rock made of clasts.
- **compaction**: When sediments are squeezed together by the weight of sediments and rocks on top of them.
- **lithification**: The creation of rock from sediments.

Summary

- Sedimentary rocks are made of fragments of older rocks or pieces of organisms.
- Compaction and cementation lead to lithification of sedimentary rocks.
- Compaction is the squeezing of sediments by the weight of the rocks and sediments above them. Cementation is when cement from fluids bind sediments together.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. Explain how sedimentary rocks form.
2. What is a conglomerate?
3. Explain how limestone forms.
4. Why are sedimentary rocks important?

Review

1. How does compaction lead to lithification?
2. How does cementation lead to lithification?
3. What is the difference between clastic and bioclastic sedimentary rocks?

3.14 Sedimentary Rock Classification

- Describe how sedimentary rocks are classified.

How do you know that this is a sedimentary rock?

If you look closely at the rock you will see that it is made of sand-sized particles that have been lithified to create sandstone. The rock is eroding into very unique shapes, but these shapes are more likely to form from a rock made of small cemented together grains than from an igneous or metamorphic rock.

Types of Sedimentary Rocks

TABLE 3.8: Sedimentary rock sizes and features.

Rock	Sediment Size	Other Features
Conglomerate	Large	Rounded
Breccia	Large	Angular
Sandstone	Sand-sized	
Siltstone	Silt-sized, smaller than sand	
Shale	Clay-sized, smallest	

When sediments settle out of calmer water, they form horizontal layers. One layer is deposited first, and another layer is deposited on top of it. So each layer is younger than the layer beneath it. When the sediments harden, the layers are preserved. Sedimentary rocks formed by the crystallization of chemical precipitates are called **chemical sedimentary rocks**. As discussed in the "Minerals" lessons, dissolved ions in fluids precipitate out of the fluid and settle out, just like the halite in **Figure** 3.44.

FIGURE 3.44
The evaporite, halite, on a cobble from the Dead Sea, Israel.

Biochemical sedimentary rocks form in the ocean or a salt lake. Living creatures remove ions, such as calcium, magnesium, and potassium, from the water to make shells or soft tissue. When the organism dies, it sinks to the ocean floor to become a biochemical sediment, which may then become compacted and cemented into solid rock (**Figure** 3.45).

FIGURE 3.45
Fossils in a biochemical rock, limestone, in the Carmel Formation in Utah.

Table 3.9 shows some common types of sedimentary rocks.

TABLE 3.9: Common Sedimentary Rocks

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic (fragments of non-organic sediments)
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Shale	Clastic
	Rock Salt	Chemical precipitate

TABLE 3.9: (continued)

Picture	Rock Name	Type of Sedimentary Rock
 	Rock Gypsum	Chemical precipitate
	Dolostone	Chemical precipitate
	Limestone	Bioclastic (sediments from organic materials, or plant or animal remains)
	Coal	Organic

Vocabulary

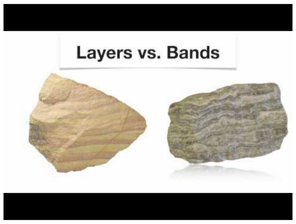
- **biochemical sedimentary rocks**: Rocks that form from materials created by living organisms removing ions from water and falling to the bottom to become sediments.
- **chemical sedimentary rocks**: Rocks that form from the hardening of chemical precipitates.

Summary

- Sediments settle out of water in horizontal layers.
- Sedimentary rocks are classified based on how they form and on the size of the sediments, if they are clastic.
- Clastic sedimentary rocks are formed from rock fragments, or clasts; chemical sedimentary rocks precipitate from fluids; and biochemical sedimentary rocks form as precipitation from living organisms.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. List the three types of sedimentary rocks.
2. List the characteristics of clastic rocks.
3. How do clastic rocks form?
4. Contrast conglomerates and breccia rocks.
5. What can be found in clastic rocks?
6. Explain the difference between layers and bands.
7. What can we learn from sedimentary rocks?
8. How do chemical rocks form?
9. What are bioclastic rocks?
10. List the two types of biocalstic rocks.

Review

1. How does an organism become a sedimentary rock?
2. How do chemical sedimentary rocks differ from clastic sedimentary rocks?
3. What are the different sedimentary rock types based on grain size, from small to large?

3.15 Metamorphic Rocks

- Explain how metamorphic rocks form.

Can you decipher the history of this rock?

The rock in this photo is a banded gneiss. The bands are of different composition, more felsic and more mafic, that separated as a result of heat and pressure. The waviness of the bands also shows how the rock was hot enough to alter but not to melt all the way.

Metamorphism

Any type of rock – igneous, sedimentary, or metamorphic — can become a metamorphic rock. All that is needed is enough heat and/or pressure to alter the existing rock's physical or chemical makeup without melting the rock entirely. Rocks change during metamorphism because the minerals need to be stable under the new temperature and pressure conditions. The need for stability may cause the structure of minerals to rearrange and form new minerals. Ions may move between minerals to create minerals of different chemical composition. Hornfels, with its alternating bands of dark and light crystals, is a good example of how minerals rearrange themselves during metamorphism. Hornfels is shown in **Table** in "Metamorphic Rock Classification."

Texture

Extreme pressure may also lead to **foliation**, the flat layers that form in rocks as the rocks are squeezed by pressure (**Figure** 3.46). Foliation normally forms when pressure is exerted in only one direction. Metamorphic rocks may also be non-foliated. Quartzite and limestone, shown in **Table** 3.10, are non-foliated.

FIGURE 3.46
A foliated metamorphic rock.

Types of Metamorphism

The two main types of metamorphism are both related to heat within Earth:

1. **Regional metamorphism**: Changes in enormous quantities of rock over a wide area caused by the extreme pressure from overlying rock or from compression caused by geologic processes. Deep burial exposes the rock to high temperatures.
2. **Contact metamorphism**: Changes in a rock that is in contact with magma. The changes occur because of the magma's extreme heat.

Vocabulary

- **contact metamorphism**: Changes in a rock that result from temperature increases when a body of magma contacts a cooler existing rock.
- **foliation**: Flat layers in rocks due to squeezing by pressure.
- **regional metamorphism**: Changes in rock that occur because of high pressure over a large area.

Summary

- Any type of rock - igneous, sedimentary or metamorphic - can become a metamorphic rock.
- Foliated rocks form when rocks being metamorphosed are exposed to pressure in one direction.
- Regional metamorphism occurs over a large area but contact metamorphism occurs when a rock is altered by a nearby magma.

Practice

Use this resource to answer the questions that follow.

http://library.thinkquest.org/J002289/meta.html

1. How do metamorphic rocks form?

2. Where does the heat come from to change these rocks?
3. What produces the pressure to change these rocks?
4. List the characteristics of metamorphic rocks.
5. List examples of metamorphic rocks.

Review

1. Why do changes in temperature or pressure cause rocks to change?
2. What are the similarities and differences in conditions that cause regional versus contact metamorphism?
3. What causes foliation in a metamorphic rock? Under what circumstances would you expect this to happen?

3.16 Metamorphic Rock Classification

- Describe how metamorphic rocks are classified.

Why is this called Marble Canyon?

Marble Canyon in the Grand Canyon is made of sedimentary rock. But Marble Canyon in Death Valley is made of marble, metamorphosed limestone. Notice how shiny the marble is where it was smoothed by sand in rushing water. The rock has the altered appearance of metamorphic rock.

Metamorphic Rocks

Table 3.10 shows some common metamorphic rocks and their original parent rock.

TABLE 3.10: Common Metamorphic Rocks

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Slate	Foliated	Metamorphism of shale
	Phyllite	Foliated	Metamorphism of slate, but under greater heat and pressure than slate
	Schist	Foliated	Often derived from metamorphism of claystone or shale; metamorphosed under more heat and pressure than phyllite
	Gneiss	Foliated	Metamorphism of various different rocks, under extreme conditions of heat and pressure
	Hornfels	Non-foliated	Contact metamorphism of various different rock types
	Quartzite	Non-foliated	Metamorphism of quartz sandstone

TABLE 3.10: (continued)

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Marble	Non-foliated	Metamorphism of limestone
	Metaconglomerate	Non-foliated	Metamorphism of conglomerate

Summary

- Foliated metamorphic rocks are platy; non-foliated metamorphic rocks are massive.
- The more extreme the amount of metamorphism, the more difficult it is to tell what the original rock was.
- Marble is metamorphosed limestone.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. How are metamorphic rocks classified?
2. How do metamorphic rocks form?
3. What is recrystallization?
4. Why are these rocks the most dense?
5. Where do metamorphic rocks form?
6. Where does regional metamorphism occur?
7. What is a foliated rock?
8. What does shale become when heated and put under pressure?
9. What is schist?
10. Describe gneiss.
11. What is the evidence for regional metamorphosis?

12. What is contact metamorphism?
13. Where does contact metamorphism occur?
14. Describe non-foliated rocks.
15. Why is hornfels unique?

Review

1. How do geologists tell what the parent rock of a metamorphic rock was, particularly a rock that was highly metamorphosed?

2. How do slate, phyllite, and schist differ from each other? How are they the same?

3. How does quartzite differ from a metamorphosed sandstone that is made of more than one mineral?

Summary

All matter is made of tiny particles. Protons, neutrons, and electrons form atoms that bond together to create molecules. Atoms are the smallest units that have the properties of the element they are and molecules are the smallest units of a compound. For example, water is made of hydrogen and oxygen, but a molecule of water is very different from an atom of hydrogen or an atom of oxygen. The atoms combine to form molecules by different types of chemical bonding. Molecules bond into structures as well. The structures created by molecules form the different types of minerals, most importantly silicates, which are the substances that make up most of Earth's crust. Other important minerals are carbonates and native elements, which are some of the most important materials used by society. Minerals come together to create the three major rock types, igneous, sedimentary, and metamorphic. These rocks are the material part of the rock cycle. Different processes can convert any type of rock into any other type of rock. These processes include weathering and erosion, melting and cooling, and burial and pressure, among others. Each rock contains a story of how it formed and what it formed from. Geologists piece together these stories to understand the geologic past of any region of our planet and of the planet as a whole.

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40. A) Courtesy of the US Geological Survey and the Mineral Information Institute; B) Mark A. Wilson (Wilson44691); C) Omphacite; D) GeoRanger. Four different rocks. All four images are in the public domain
41. Courtesy of the National Oceanic and Atmospheric Administration. Alaska's Valley of Ten Thousand Smokes. Public Domain
42. ZackClark. . Public Domain
43. Hartmut Josi Bennöhr. A cliff made of sandstone. GNU-FDL 1.2
44. Mark A. Wilson (Wilson44691). . Public Domain
45. Mark A. Wilson (Wilson44691). Fossils in a biochemical rock, limestone, in the Carmel Formation in Utah. Public Domain
46. Siim Sepp. A foliated metamorphic rock. GNU-FDL 1.2

Chapter 4

Earth as a Planet

Chapter Outline

Introduction

Is Earth a planet?

Yes! No one doubts that Earth is a planet, even though it's a lot different from the other planets in our solar system, like enormous Jupiter or scorching-hot Venus. The most different planet of all, though, was the planet that is no longer a planet, Pluto. Pluto is now categorized as a dwarf planet, more akin to Ceres and Makemake than Earth or Uranus. Changing Pluto's status forced scientists to confront the issue of what a planet is. We will look at some of the characteristics that make Earth a bona fide planet.

4.1 Earth's Shape

- Describe Earth's shape and explain how Earth's shape is related to its mass.

Before spacecraft, how did people know that Earth is spherical?

The ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. Was there other evidence of Earth's roundness available to people before spacecraft gave us a bird's eye view?

Earth's Shape

Earth is a sphere or, more correctly, an oblate spheroid, which is a sphere that is a bit squished down at the poles and bulges a bit at the equator. To be more technical, the minor axis (the diameter through the poles) is smaller than the major axis (the diameter through the equator). Half of the sphere is a **hemisphere**. North of the equator is the northern hemisphere and south of the equator is the southern hemisphere. Eastern and western hemispheres are also designated.

What evidence is there that Earth is spherical? What evidence was there before spaceships and satellites?

Try to design an experiment involving a ship and the ocean to show Earth is round. If you are standing on the shore and a ship is going out to sea, the ship gets smaller as it moves further away from you. The ship's bottom also starts to disappear as the vessel goes around the arc of the planet (**Figure** 4.1). There are many other ways that early scientists and mariners knew that Earth was not flat. Here is a summary of some: http://www.physlink.com/education/askexperts/ae535.cfm.

The Sun and the other planets of the solar system are also spherical. Larger satellites, those that have enough mass for their gravitational attraction to have made them round, are spherical as well.

FIGURE 4.1
Earth's curvature is noticeable when objects at a distance are below the arc.

Vocabulary

- **hemisphere**: One half of a sphere.

Summary

- Ancient Greeks knew that Earth was round because of the shadow the planet cast on the Moon during a lunar eclipse.
- A boat does not get smaller with distance but sinks below the horizon - more evidence for Earth's roundness.
- Earth is divided into hemispheres: northern, southern, eastern, and western.

Interactive Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What was the first photo of Earth? What did it prove?
2. Why are bodies in space round?
3. How did the planets form?
4. What is the only shape in nature that looks the same from all directions?
5. Why are there odd-shaped objects in space?

Review

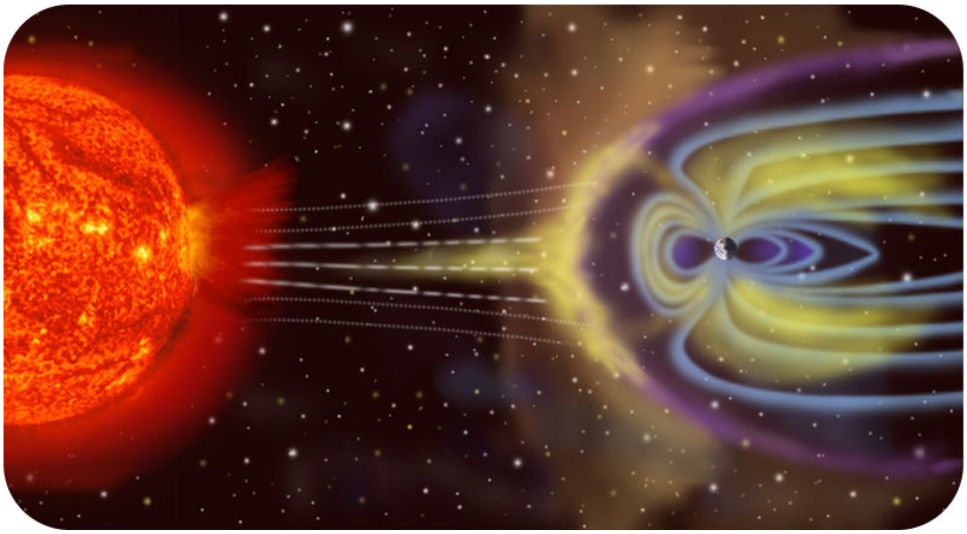
1. Describe where you live in terms of hemispheres.

2. If you met up with someone who claimed that Earth is flat, what evidence would you present to them that their assertion is not true?

3. What evidence do you have that our planet is flat? Which of these ideas do you believe and why?

4.2 Earth's Magnetic Field

- Describe Earth's magnetic field and explain its relationship to life on Earth.



What would happen if Earth suddenly lost its magnetic field?

The most obvious effect is that we would get lost, since our compasses wouldn't work. Less obvious is that without the magnetic field the solar wind would strip away ozone from Earth's atmosphere and leave us exposed to ultraviolet radiation. Would life on Earth look the way it does now? Most, if not all, lifeforms couldn't survive.

Earth's Magnetism

Earth is surrounded by a **magnetic field** (**Figure** 4.2) that behaves as if the planet had a gigantic bar magnet inside of it. Earth's magnetic field also has a north and south pole. The magnetic field arises from the convection of molten iron and nickel metals in Earth's liquid outer core.

Magnetic Reversals

Many times during Earth history, even relatively recent Earth history, the planet's magnetic field has flipped. That is, the north pole becomes the south pole and the south pole becomes the north pole. Scientists are not sure why this happens. One hypothesis is that the convection that drives the magnetic field becomes chaotic and then reverses itself. Another hypothesis is that an external event, such as an asteroid impact, disrupts motions in the core and causes the reversal. The first hypothesis is supported by computer models, but the second does not seem to be supported by much data. There is little correlation between impact events and magnetic reversals.

Vocabulary

- **magnetic field**: A field produced by a magnetic object that exerts a force on other magnetic materials or moving electrical charges. Earth's magnetic field behaves as if a magnet were contained within the planet.

FIGURE 4.2
Earth's magnetic field is like a bar magnet resides in the center of the planet.

Summary

- Earth's magnetic field is like a bar magnet through the planet, with the south magnetic pole nearly aligned with the north geographic pole and vice versa.
- The magnetic field is generated by convection in the liquid outer core.
- Occasionally the magnetic field flips, with the north pole becoming the south pole and the south pole becoming the north pole.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.pbs.org/wgbh/nova/earth/when-our-magnetic-field-flips.html

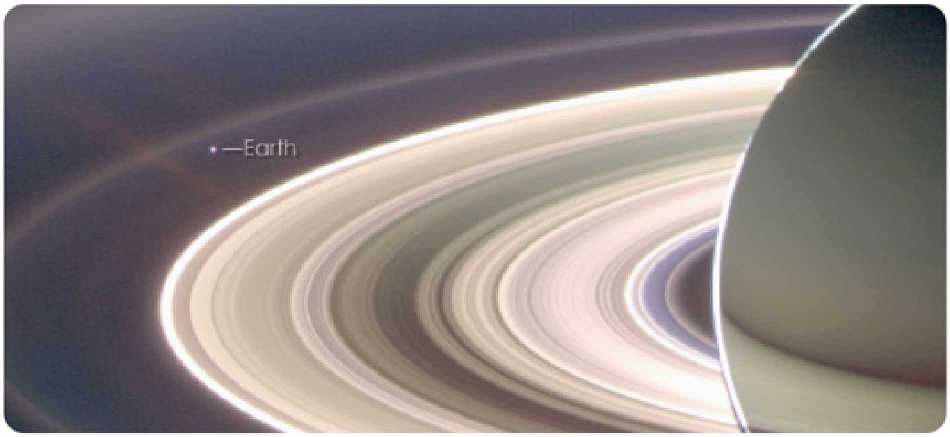
1. What creates Earth's magnetic field?
2. What happens to the intensity and direction of the magnetic field according to the computer model?
3. What was studied in Oregon?
4. How do anomalies appear in the model?
5. What has been happening over the past 300 years?
6. How often has the magnetic field reversed, according to the research?
7. How long has it been since the last reversal?
8. How long does a reversal take to complete?

Review

1. What would Earth's magnetic field be like if the planet was solid?
2. What roles does the magnetic field play for our planet?
3. How does the magnetic field resemble a bar magnet?

4.3 Revolutions of Earth

- Define the geocentric and heliocentric models of Earth's revolution.
- Describe Earth's revolution around the Sun.



How else can we identify a planet?

Saturn and Earth are both planets. Saturn is round, like Earth, but Saturn has fantastic rings, which Earth does not. A planet needs to be round but it doesn't need rings. Both of these bodies orbit a star, another thing planets need to do. That star is our Sun.

Earth Orbits a Star

Certainly no one today doubts that Earth orbits a star, the Sun. Photos taken from space, observations made by astronauts, and the fact that there has been so much successful space exploration that depends on understanding the structure of the solar system all confirm it. But in the early 17th century saying that Earth orbited the Sun rather than the reverse could get you tried for heresy, as it did Galileo. Let's explore the evolution of the idea that Earth orbits the Sun.

The Geocentric Universe

To an observer, Earth appears to be the center of the universe. That is what the ancient Greeks believed. This view is called the **geocentric model**, or "Earth-centered" model, of the universe. In the geocentric model, the sky, or heavens, are a set of spheres layered on top of one another. Each object in the sky is attached to a sphere and moves around Earth as that sphere rotates. From Earth outward, these spheres contain the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. An outer sphere holds all the stars. Since the planets appear to move much faster than the stars, the Greeks placed them closer to Earth. The geocentric model explained why all the stars appear to rotate around Earth once per day. The model also explained why the planets move differently from the stars and from each other.

One problem with the geocentric model is that some planets seem to move backwards (in retrograde) instead of in their usual forward motion around Earth. A demonstration animation of retrograde motion of Mars as it appears to Earth can be found here: http://projects.astro.illinois.edu/data/Retrograde/index.html.

Around 150 A.D. the astronomer Ptolemy resolved this problem by using a system of circles to describe the motion of planets (**Figure** 4.3). In Ptolemy's system, a planet moves in a small circle, called an epicycle. This circle moves around Earth in a larger circle, called a deferent. Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

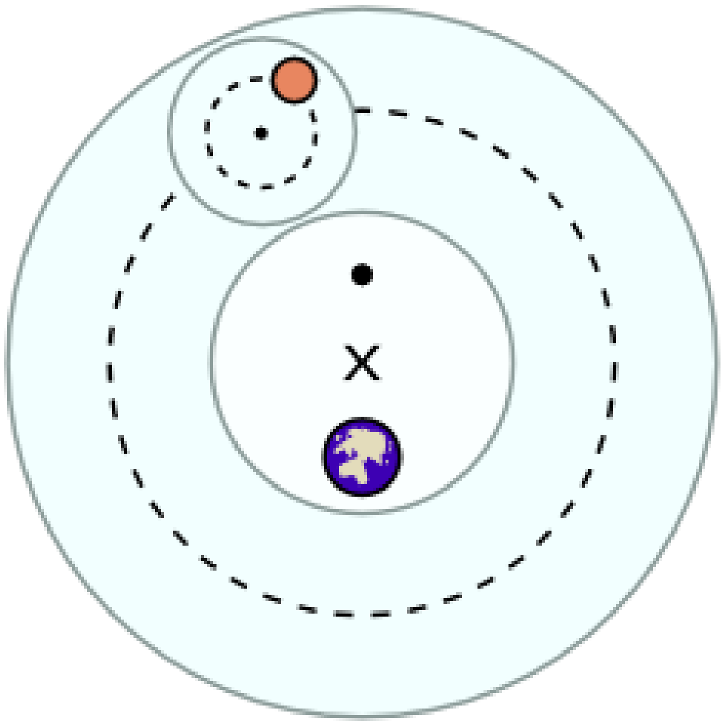


FIGURE 4.3
According to Ptolemy, a planet moves on a small circle (epicycle) that in turn moves on a larger circle (deferent) around Earth.

An animation of Ptolemy's system can be seen here: http://www.youtube.com/watch?v=FHSWVLwbbNw#38;NR=1

The Heliocentric Universe

Ptolemy's geocentric model worked, but it was complicated and occasionally made errors in predicting the movement of planets. At the beginning of the 16th century A.D., Nicolaus Copernicus proposed that Earth and all the other planets orbit the Sun. With the Sun at the center, this model is called the **heliocentric model**, or "sun-centered" model.

Although Copernicus' model was simpler – it didn't need epicycles and deferents - it still did not perfectly describe the motion of the planets. Johannes Kepler solved the problem a short time later when he determined that the planets moved around the Sun in ellipses (ovals), not circles (**Figure** 4.4). Kepler's model matched observations perfectly.

Animation of Kepler's Laws of Planetary Motion: http://projects.astro.illinois.edu/data/KeplersLaws/index.html

The heliocentric model did not catch on right away. When Galileo Galilei first turned a telescope to the heavens in 1610, he made several striking discoveries. Galileo discovered that the planet Jupiter has **moons** orbiting around it. This provided the first evidence that objects could orbit something besides Earth.

An animation of three of Jupiter's moons orbiting the planet can be seen here: http://upload.wikimedia.org/wikipedia/commons/e/e7/Galilean_moon_Laplace_resonance_animation_de.gif.

Galileo also discovered that Venus has phases like the Moon (**Figure** 4.5), which provides direct evidence that Venus

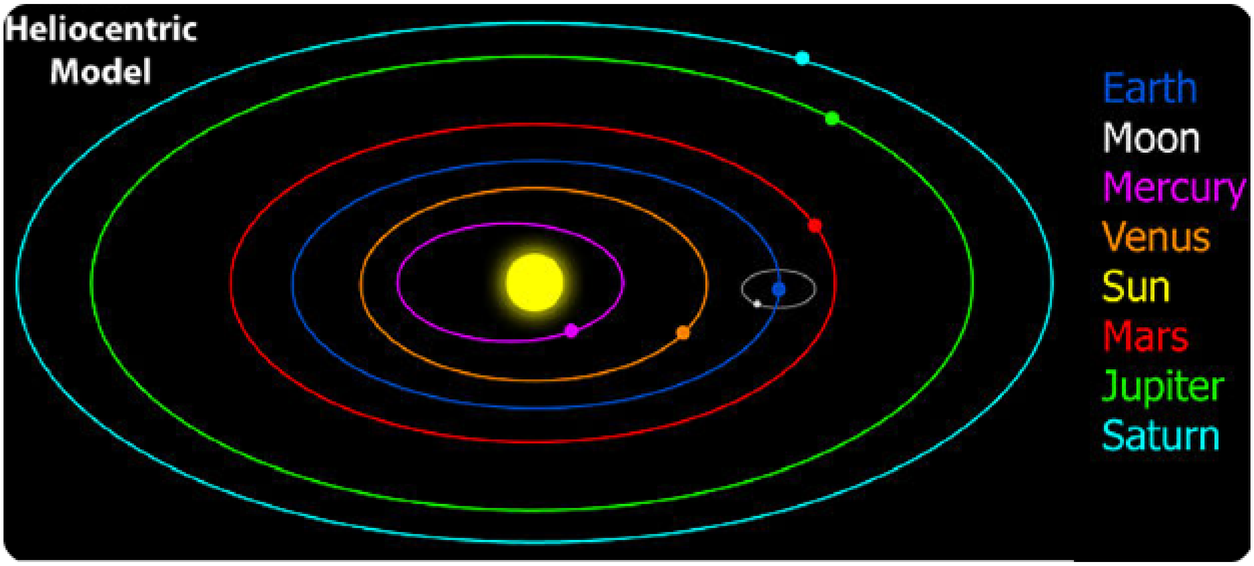


FIGURE 4.4
Kepler's model showed the planets moving around the sun in ellipses.

orbits the Sun.

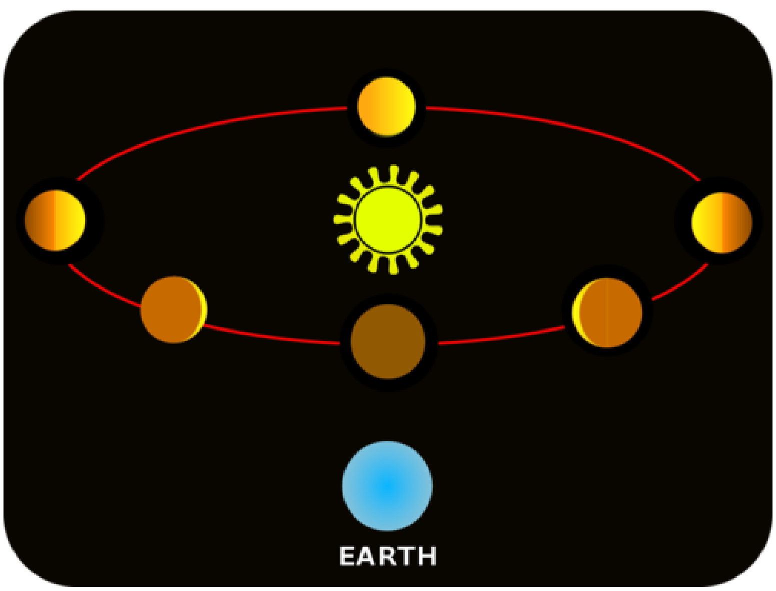


FIGURE 4.5
The phases of Venus.

Galileo's discoveries caused many more people to accept the heliocentric model of the universe, although Galileo himself was found guilty of heresy. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the Copernican Revolution.

In their elliptical orbits, each planet is sometimes farther away from the Sun than at other times. This movement is called **revolution**. At the same time, Earth spins on its **axis**. Earth's axis is an imaginary line passing through the planet's center that goes through both the North Pole and the South Pole. This spinning movement is called Earth's **rotation**.

Earth's Revolution

Copernicus, Galileo, and Kepler were all right: Earth and the other planets travel in an elliptical orbit around the Sun. The gravitational pull of the Sun keeps the planets in orbit. This ellipse is barely elliptical; it's very close to being a circle. The closest Earth gets to the Sun each year is at perihelion (147 million km) on about January 3rd, and the furthest is at aphelion (152 million km) on July 4th. The shape of Earth's orbit has nothing to do with Earth's seasons.

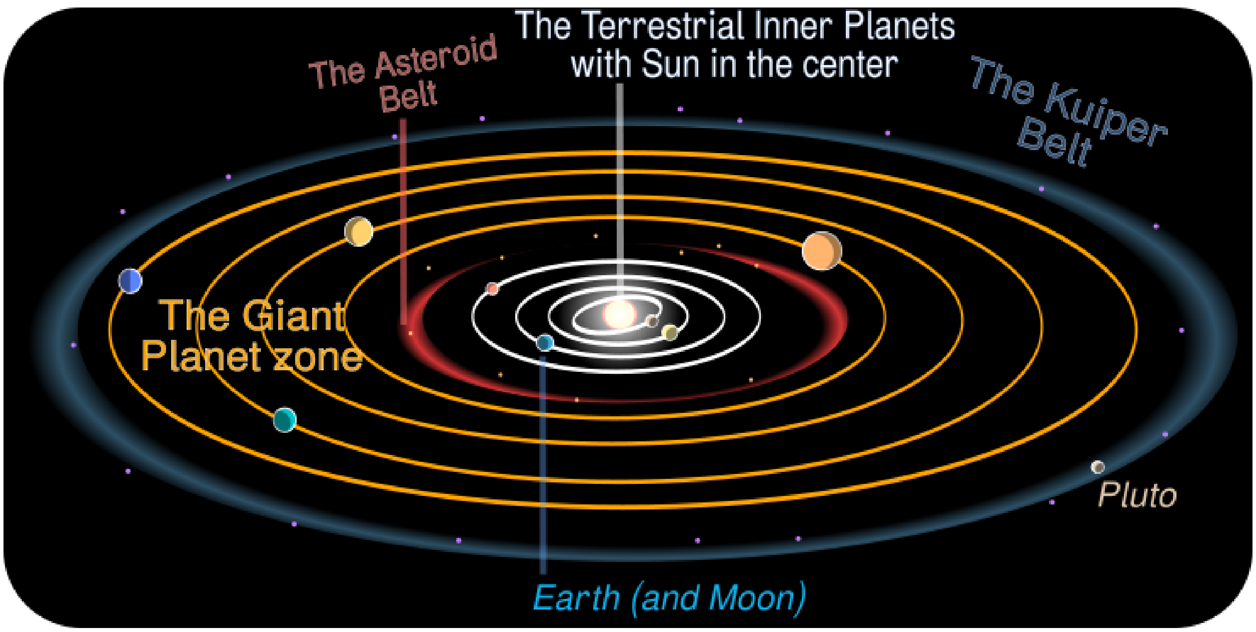


FIGURE 4.6

Earth and the other planets in the solar system make elliptical orbits around the Sun.

For Earth to make one complete revolution around the Sun takes 365.24 days. This amount of time is the definition of one year. Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Vocabulary

- **axis**: An imaginary line that runs from the North Pole to South Pole, and it includes the center of Earth.
- **geocentric model**: Model used by the ancient Greeks that puts the Earth at the center of the universe.
- **heliocentric model**: Model proposed by Copernicus that put the Sun at the center of the universe.
- **moon**: A celestial object that orbits a planet.
- **revolution**: The Earth's movement around the Sun in an orbital path.

Summary

- In the geocentric model of the universe, Earth is at the center.
- In the heliocentric model of the universe, the Sun is at the center. The heliocentric model is the modern view of the solar system, but not the entire universe.
- Earth and the other planets of the solar system revolve around the Sun.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.universetoday.com/36487/difference-between-geocentric-and-heliocentric/

1. What does geocentric mean?
2. What does heliocentric mean?
3. When did the heliocentric theory gain popularity?
4. Why was did geocentric theory remain popular for so long?
5. Why did the heliocentric theory eventually take precedence?

Review

1. How does the heliocentric model differ from the geocentric model?
2. Why do you think people had a hard time switching from one worldview to the other?
3. Describe Earth's orbit around the Sun.

4.4 Rotation of Earth

- Describe Earth's rotation on its axis.

What would you do if you were in Paris?

Take a view from the top of the Eiffel Tower? March up the stairs to eye the gargoyles at Notre Dame? Nibble on coffee and croissants in a sidewalk cafe? Visit Foucault's Pendulum in the Pantheon? Yes! When in Paris, don't forget to go to the Pantheon and visit this testament to Earth's rotation.

Foucault's Pendulum

In 1851, a French scientist named Léon Foucault took an iron sphere and swung it from a wire. He pulled the sphere to one side and then released it, creating a pendulum. Although a pendulum set in motion should not change its motion, Foucault observed that his pendulum did seem to change direction. Foucault concluded that Earth was moving underneath the pendulum. People at that time already knew that Earth rotated on its axis, but Foucault's experiment was nice confirmation.

FIGURE 4.7
Foucault's Pendulum is at the Pantheon in Paris, France.

Earth's Rotation

Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an **axis**. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**.

An observer in space will see that Earth requires 23 hours, 59 minutes, and 4 seconds to make one complete rotation on its axis. But because Earth moves around the Sun at the same time that it is rotating, the planet must turn just a little bit more to reach the same place relative to the Sun. Hence the length of a day on Earth is actually 24 hours.

At the equator, the Earth rotates at a speed of about 1,700 km per hour, but at the poles the movement speed is nearly nothing.

Day-Night Cycle

Earth rotates once on its axis about every 24 hours. To an observer looking down at the North Pole, the rotation appears counterclockwise. From nearly all points on Earth, the Sun appears to move across the sky from east to west each day. Of course, the Sun is not moving from east to west at all; Earth is rotating. The Moon and stars also seem to rise in the east and set in the west.

Earth's rotation means that there is a cycle of daylight and darkness approximately every 24 hours, the length of a day. Different places experience sunset and sunrise at different times and the amount of daylight and darkness also differs by location.

Shadows are areas where an object obstructs a light source so that darkness takes on the form of the object. On Earth, a shadow can be cast by the Sun, Moon, or (rarely) Mercury or Venus.

Vocabulary

- **axis**: An imaginary line that runs from the North Pole to South Pole, and it includes the center of Earth.
- **rotation**: The motion of the Earth spinning on its axis.

Summary

- Foucalt's pendulum shows that Earth moves beneath a swinging pendulum.
- Earth rotates on its axis every 24 hours.
- Earth rotates so that the Sun, Moon, and stars appear to travel from east to west each day.

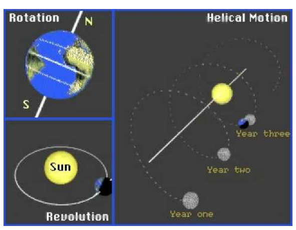
Interactive Practice

Use these resources to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Why does the Earth spin?
2. Why has the Earth's spin slowed?
3. What will eventually happen to the Moon?



MEDIA

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4. How long does it take for the Earth to complete a rotation?
5. What direction is the Earth rotating?

Review

1. How does Foucalt's pendulum show that Earth rotates on its axis?
2. Why do the Sun, Moon, and stars appear to rise in the east and set in the west each day?
3. Why does the equator travel at a speed of 1,700 km per hour and the poles not travel at all?

4.5 Coriolis Effect

- Explain the Coriolis effect and distinguish between an effect and a force.

Can you tell which hemisphere you're in?

People say that Coriolis effect determines the direction that water flushes down a toilet or sink. If that's true, then which hemisphere is this toilet in? It looks like it's in the Northern Hemisphere, because the spiral arms are going the same direction as a Northern Hemisphere hurricane. Unfortunately, there are too many other factors that determine the direction toilet water flushes, such as friction and the power of the flush. So we don't know where this toilet is.

Coriolis Effect

The **Coriolis effect** describes how Earth's rotation steers winds and surface ocean currents (**Figure** 4.8). Coriolis causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve. That's why it is incorrect to call Coriolis a force. It is not forcing anything to happen!

An example might make the Coriolis effect easier to visualize. If an airplane flies 500 miles due north, it will not arrive at the city that was due north of it when it began its journey. Over the time it takes for the airplane to fly 500 miles, that city moved, along with the Earth it sits on. The airplane will therefore arrive at a city to the west of the original city (in the Northern Hemisphere), unless the pilot has compensated for the change. So to reach his intended destination, the pilot must also veer right while flying north.

As wind or an ocean current moves, the Earth spins underneath it. As a result, an object moving north or south along the Earth will appear to move in a curve instead of in a straight line. Wind or water that travels toward the poles from the equator is deflected to the east, while wind or water that travels toward the equator from the poles gets bent to the west. The Coriolis effect bends the direction of surface currents to the right in the Northern Hemisphere and left in the Southern Hemisphere.

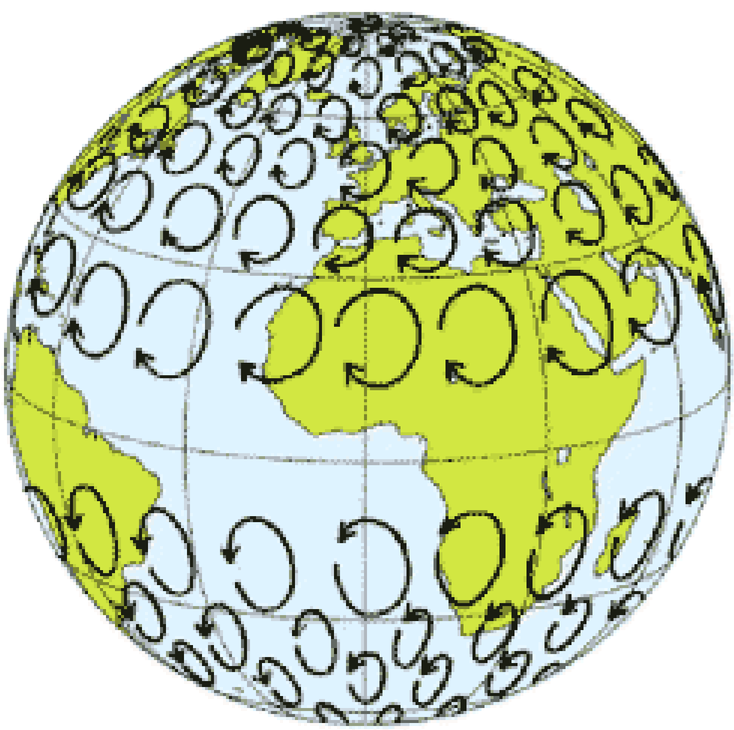


FIGURE 4.8
The Coriolis effect causes winds and currents to form circular patterns. The direction that they spin depends on the hemisphere that they are in.

Coriolis effect is demonstrated using a metal ball and a rotating plate in this video. The ball moves in a circular path just like a freely moving particle of gas or liquid moves on the rotating Earth **(5b)**: http://www.youtube.com/watch?v=Wda7azMvabE#38;feature=related (2:04).

MEDIA
Click image to the left for more content.

Vocabulary

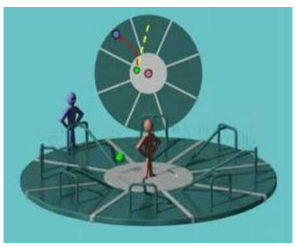
- **Coriolis effect**: The apparent deflection of a freely moving object like water or air because of Earth's rotation.

Summary

- Earth rotates beneath freely moving objects like water and air. Compared with a spot on the planet, the freely moving objects appear to be moving.
- Freely moving objects appear to move right in the Northern Hemisphere and left in the Southern Hemisphere.
- Coriolis is an effect rather than a force because it is not forcing a motion, it's just an appearance of a change of motion.

Practice

Use these resources to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is the Coriolis effect?
2. What is subject to the Coriolis effect?
3. What is the direction of deflection in the Northern Hemisphere?
4. What is the direction of deflection in the Southern Hemisphere?

Test your skills on the Coriolis effect.

http://www.montereyinstitute.org/noaa/lesson08/l8ex1.htm

5. What happens if pilots do not correct for the Coriolis effect?

Review

1. If an airplane flies from east to west in the Northern Hemisphere without changing latitude at all, in which direction will it appear to curve?
2. If an airplane flies from south to north in the Southern Hemisphere, in which direction will it appear to curve?
3. If freely moving objects are only appearing to curve their paths, why is this important?

4.6 Seasons

- Explain why seasons occur.

Do you like the seasons?

Do you live in a place with well-defined seasons? Do you appreciate the change of the seasons, from cold and dark to hot and bright, over the months? In other words, are you happy that Earth's axis is tilted?

Earth's Seasons

A common misconception is that the Sun is closer to Earth in the summer and farther away from it during the winter. Instead, the seasons are caused by the 23.5^o tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (**Figure** 4.9). **Solstice** refers to the position of the Sun when it is closest to one of the poles. At summer solstice, June 21 or 22, Earth's axis points toward the Sun and so the Sun is directly overhead at its furthest north point of the year, the Tropic of Cancer (23.5^o N).

During the summer, areas north of the equator experience longer days and shorter nights. In the Southern Hemisphere, the Sun is as far away as it will be and so it is their winter. Locations will have longer nights and shorter

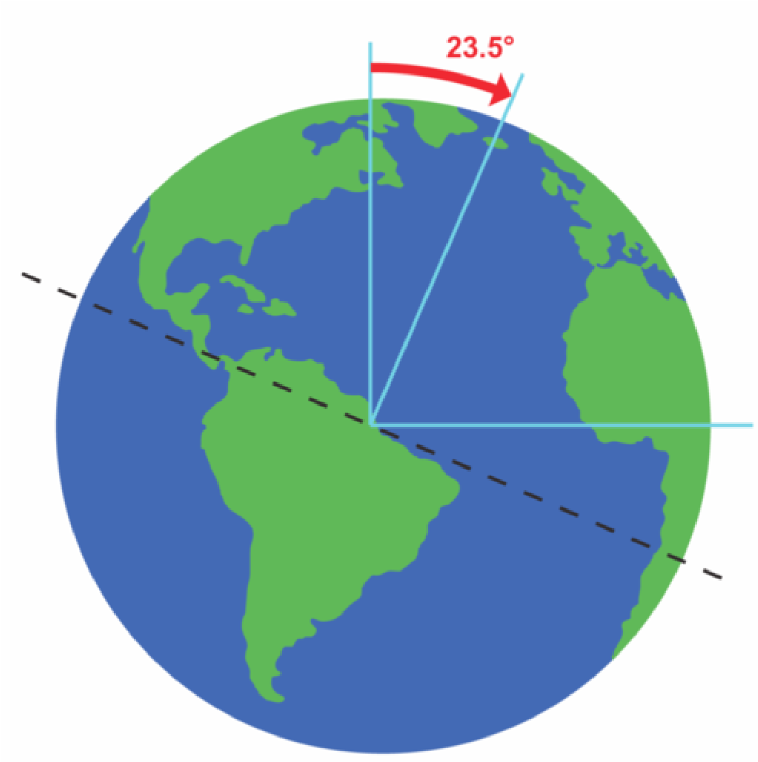


FIGURE 4.9
The Earth's tilt on its axis leads to one hemisphere facing the Sun more than the other hemisphere and gives rise to seasons.

days. The opposite occurs on winter solstice, which begins on December 21. More about seasons can be found in the "Atmospheric Processes" concept.

Check out this video on why Earth has seasons to learn more: http://www.youtube.com/watch?v=DuiQvPLWziQ#38;feature=related.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the equator.

Different areas also receive different amounts of sunlight in different seasons. What causes the seasons? The seasons are caused by the direction Earth's axis is pointing relative to the Sun.

The Earth revolves around the Sun once each year and spins on its axis of rotation once each day. This axis of rotation is tilted 23.5^o relative to its plane of orbit around the Sun. The axis of rotation is pointed toward Polaris, the North Star. As the Earth orbits the Sun, the tilt of Earth's axis stays lined up with the North Star.

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (**Figure** 4.10). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5^oN); that is, the angle of incidence of the sun's rays there is zero (the angle of incidence is the deviation in the angle of an incoming ray from straight on). When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

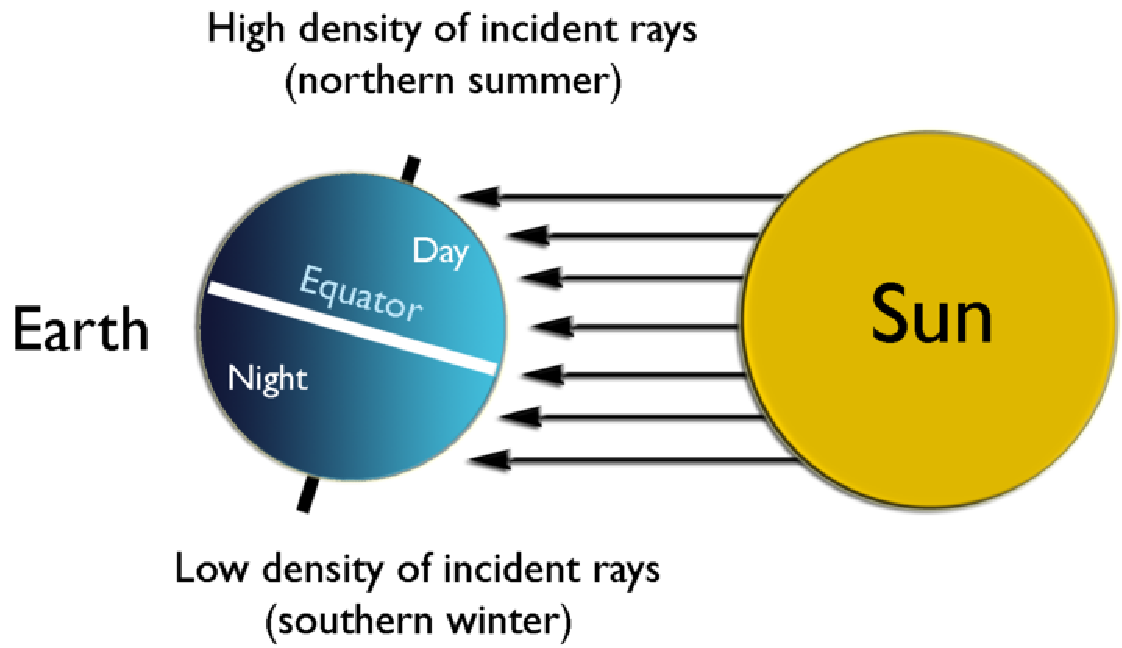


FIGURE 4.10
Summer solstice in the Northern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (**Figure** 4.11). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

An animation of the seasons from the University of Illinois is seen here: http://projects.astro.illinois.edu/data/Seasons/seasons.html. Notice the area of solar radiation, or insolation, in the lower right of the screen.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an **equinox** (**Figure** 4.12). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal, or spring, equinox happens March 21 or 22 in the Northern Hemisphere.

Vocabulary

- **equinox**: When the position of the Sun is halfway between its position during the solstices; it is directly above the equator.
- **solstice**: When the position of the Sun is closest to one of the poles; the north pole in Northern Hemisphere summer (summer solstice) and the south pole in Northern Hemisphere winter (winter solstice).

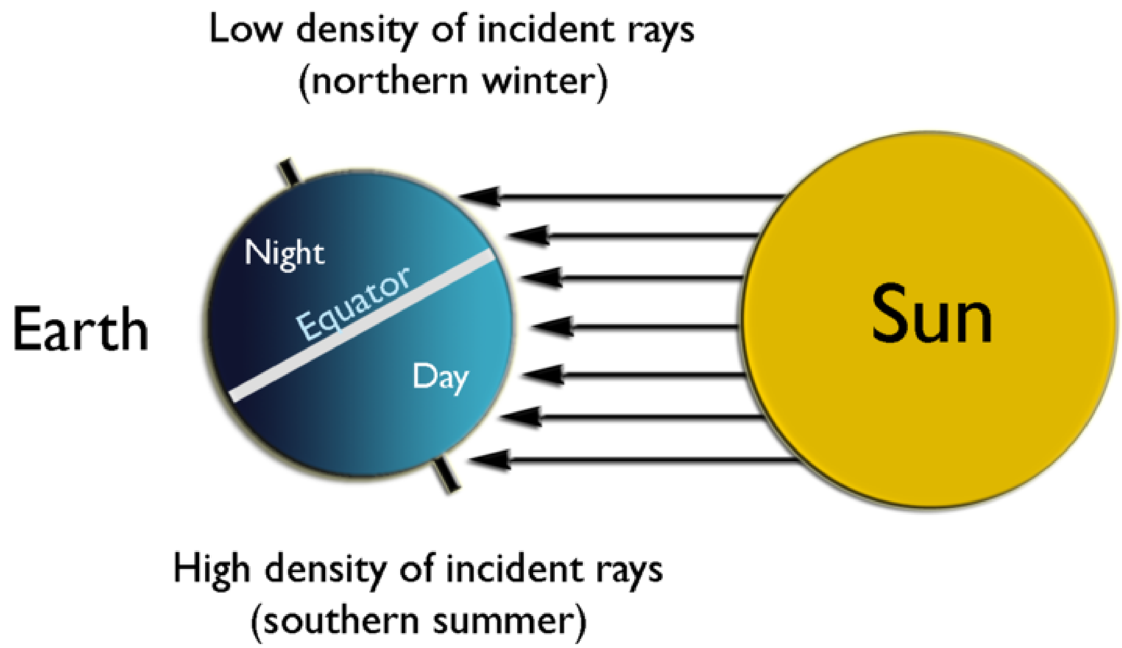


FIGURE 4.11
In Southern Hemisphere summer, the Sun's rays directly strike the Tropic of Capricorn (23.5^oS). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.

Summary

- In the Northern Hemisphere, at summer solstice the Sun is closest to the north pole (around June 22) and at winter solstice, the Sun is closest to the south pole (around December 22). In the Southern Hemisphere, the names are changed.
- Over the course of a year, the amount of solar energy received by the equator is greater than the amount received elsewhere.
- At equinox the Sun is directly over the equator; autumnal equinox is around September 22 and spring equinox is around March 22 in the Northern Hemisphere.

Practice

Use these resources to answer the questions that follow.

MEDIA
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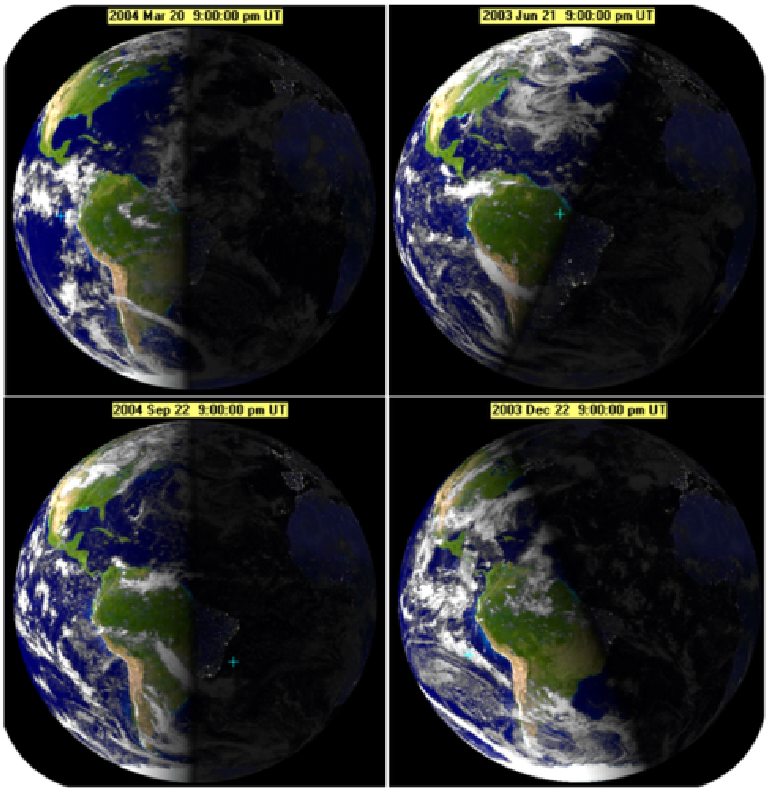


FIGURE 4.12
Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

1. What causes Earth's seasons?

2. What is the longest day of the year in the Northern Hemisphere?

3. What occurs at the equinoxes?

4. What happens during the winter solstice?

5. When is summer in the Southern Hemisphere?

http://www.learner.org/jnorth/tm/mclass/eclipticsimulator.swf

6. Place the observer on the Tropic of Capricorn and run the animation. When does the observer get the most direct sunlight (90 degree angle)?

7. Place the observer in the Arctic Circle and run the simulation. Explain what occurs for the observer over the year.

8. Place the observer close to your present latitude and run the simulation. Explain what the observer experiences over a year.

Review

1. At summer solstice in the Northern Hemisphere, what is the date and where is the Sun? What is happening in the Southern Hemisphere at that time?

2. Since the sun is up for months during the summer at the north pole, why is it that the equator actually gets the most solar radiation over the course of a year?

3. What are equinoxes and when do they come?

4.7 Eclipses

- Describe the types of eclipses and explain why eclipses occur.

If science weren't around to tell you what it is, would an eclipse scare you?

Ancient people could not predict eclipses and didn't know when one would end or even that it would end. Rituals to persuade the Sun or Moon to return to its normal state were developed. And they worked! The heavens always return to normal after an eclipse.

Solar Eclipses

A **solar eclipse** occurs when the new Moon passes directly between the Earth and the Sun (**Figure** 4.13). This casts a shadow on the Earth and blocks Earth's view of the Sun.

A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (**Figure** 4.14). When only a portion of the Sun is out of view, it is called a partial solar eclipse.

Solar eclipses are rare and usually only last a few minutes because the Moon casts only a small shadow (**Figure** 4.15).

A BBC video of a solar eclipse is seen here: http://www.youtube.com/watch?v=eOvWioz4PoQ.

As the Sun is covered by the moon's shadow, it will actually get cooler outside. Birds may begin to sing, and stars will become visible in the sky. During a solar eclipse, the corona and solar prominences can be seen.

A solar eclipse occurs when the Moon passes between Earth and the Sun in such a way that the Sun is either partially or totally hidden from view. Some people, including some scientists, chase eclipses all over the world to learn or just observe this amazing phenomenon.

See more at http://www.kqed.org/quest/television/eclipse-chasers.

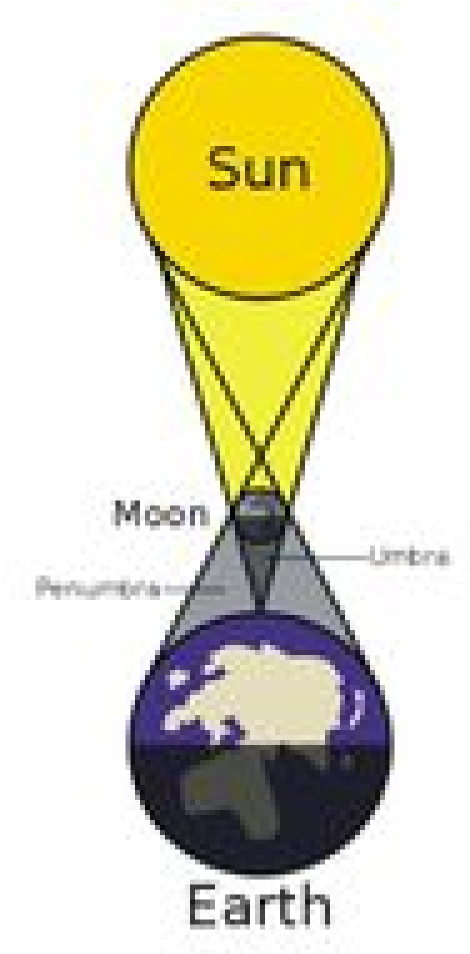


FIGURE 4.13
A solar eclipse, not to scale.

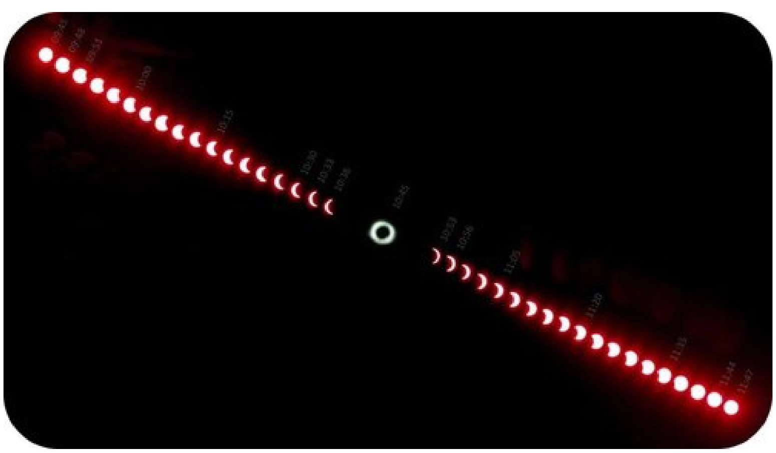


FIGURE 4.14
A solar eclipse shown as a series of photos.

MEDIA
Click image to the left for more content.

FIGURE 4.15
The Moon's shadow in a solar eclipse covers a very small area.

Lunar Eclipse

A **lunar eclipse** occurs when the full moon moves through Earth's shadow, which only happens when Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic (**Figure** 4.16). In an eclipse, Earth's shadow has two distinct parts: the **umbra** and the **penumbra**. The umbra is the inner, cone-shaped part of the shadow, in which all of the light has been blocked. The penumbra is the outer part of Earth's shadow where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent.

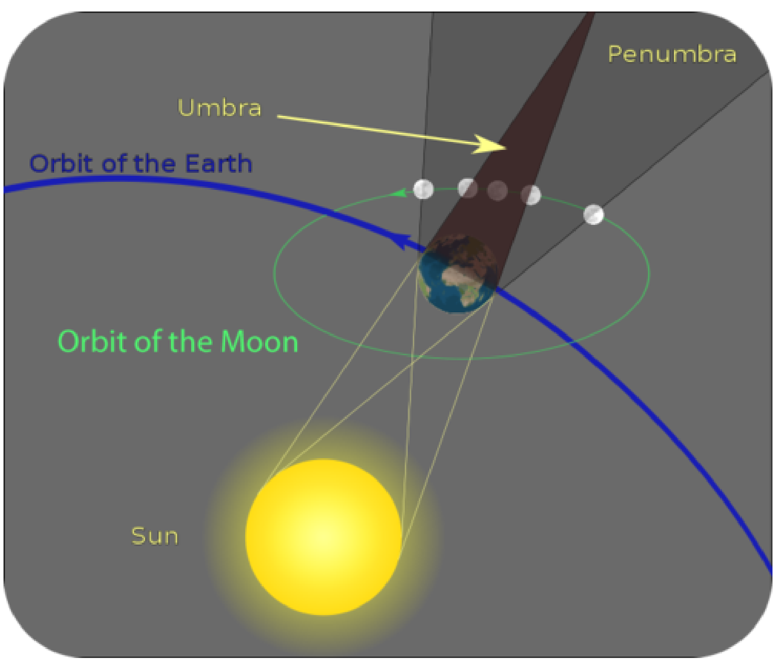


FIGURE 4.16
A lunar eclipse.

A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. Earth's shadow is large enough that a lunar eclipse lasts for hours and can be seen by any part of Earth with a view of the Moon at the time of the eclipse (**Figure** 4.17). A lunar eclipse does not occur every month because Moon's orbit is inclined 5-degrees to Earth's orbit, so the two bodies are not in the same plane every month.

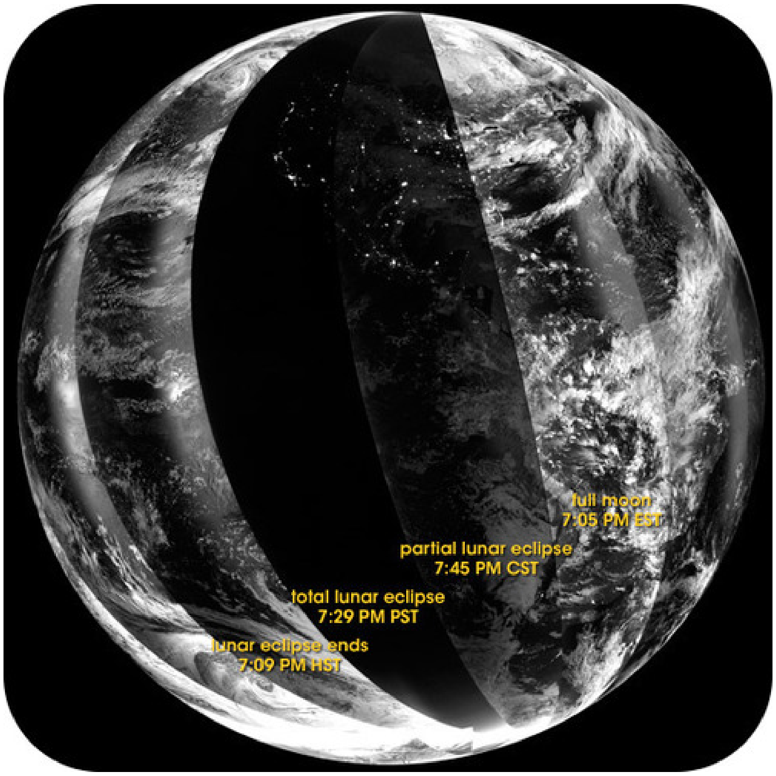


FIGURE 4.17
Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

The moon glows with a dull red coloring during a total lunar eclipse, which you can see in this video of a lunar eclipse over Hawaii: http://www.youtube.com/watch?v=2dk–lPAi04

Vocabulary

- **lunar eclipse**: An eclipse that occurs when the Moon moves through the shadow of the Earth and is blocked from view.
- **penumbra**: Outer part of shadow that remains partially lit during an eclipse.
- **solar eclipse**: Occurs when moon passes directly between the Earth and Sun; the Moon's shadow blocks the Sun from view.
- **umbra**: Inner cone shaped part of a shadow when all light is blocked during an eclipse.

Summary

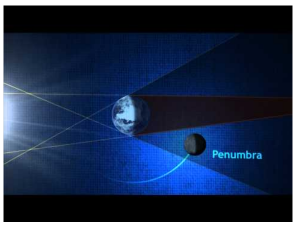
- During a solar eclipse, the new Moon passes between Earth and Sun.
- During a lunar eclipse, the full Moon moves through Earth's shadow.
- The umbra is the part of the shadow in which light is completely blocked and the penumbra is the part of the shadow that is partially lit.

Practice

Use these resources to answer the questions that follow.

http://www.teachersdomain.org/asset/ess05_vid_totaleclipse/

1. Why do the moon and sun seem to be the same size from Earth?
2. What causes a solar eclipse?
3. What is first contact?
4. What can be seen at totality?
5. How often do solar eclipses occur?



MEDIA

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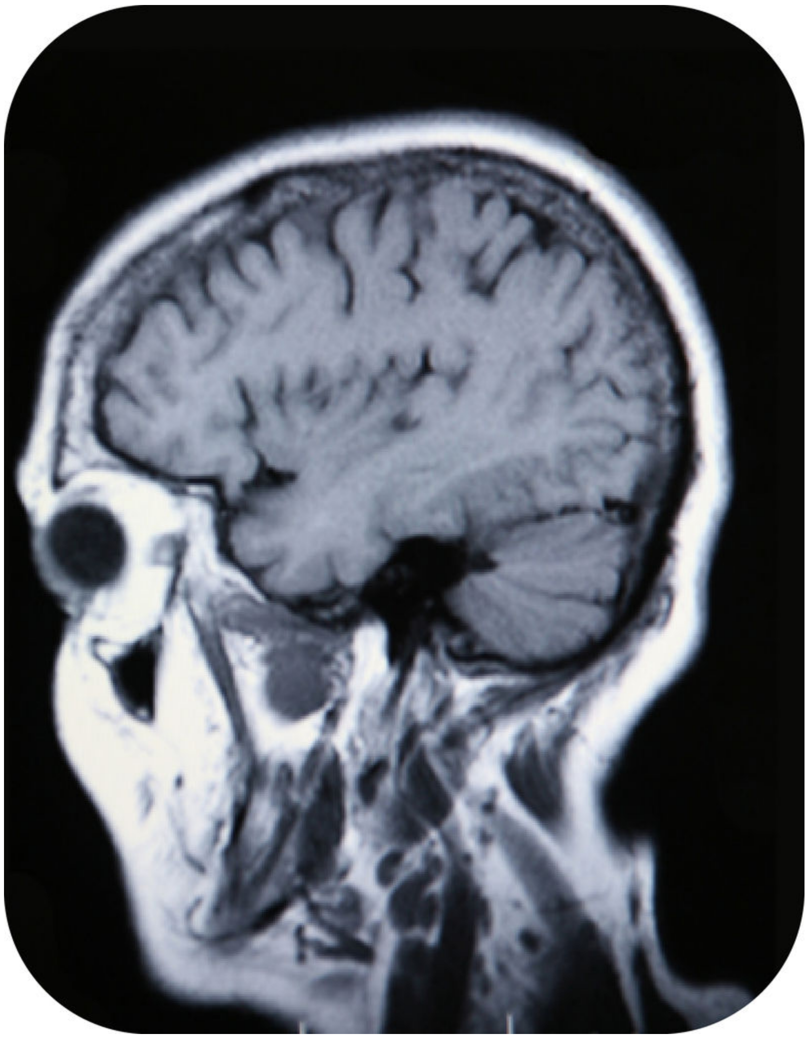
6. What are the phases of the moon?
7. How often do lunar eclipses occur?
8. Describe a lunar eclipse.
9. What is the penumbra?
10. What is the umbra?
11. How long does a lunar eclipse last?

Review

1. What happens during a solar eclipse?
2. What happens during a lunar eclipse?
3. Why do we not see lunar eclipses every month?

4.8 Seismic Waves

- Identify and define the components of a wave.
- Identify and define the types of seismic waves.
- Explain how scientists use seismic waves to study Earth's interior.



How is a seismologist like a medical doctor?

Just as a medical doctor uses an MRI, CT scan, or x-ray to see inside a patient's body, seismologists use wave energy to learn about Earth's interior. The difference is that the doctor can run the energy through the patient at any time. Scientists need to wait for an earthquake to get information about Earth's interior.

Waves

Energy is transmitted 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 distance between waves from crest to crest (or trough to trough) is its **wavelength**. The parts of a wave are illustrated in **Figure** 4.18.

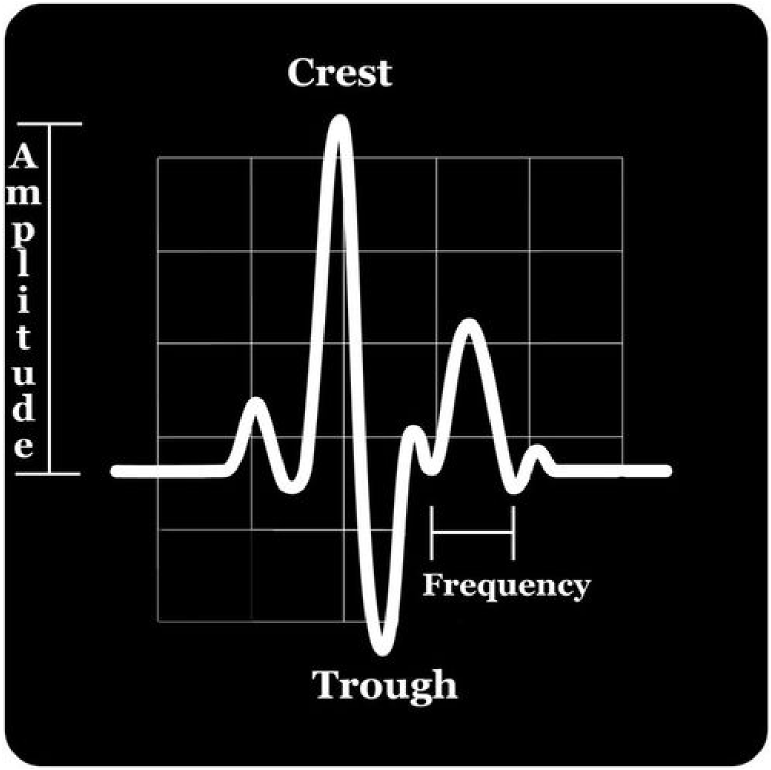


FIGURE 4.18
The crest, trough, and amplitude are illustrated in this diagram.

Earthquake Waves

The energy from earthquakes travels in waves. The study of seismic waves is known as **seismology**. Seismologists use seismic waves to learn about earthquakes and also to learn about the Earth's interior.

One ingenious way scientists learn about Earth's interior is by looking at earthquake waves. Seismic waves travel outward in all directions from where the ground breaks and are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

Body Waves

P-waves and S-waves are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. S-waves only move through solids (**Figure** 4.19). Surface waves only travel along Earth's surface. In an earthquake, body waves produce sharp jolts. They do not do as much damage as surface waves.

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a compression/expansion type motion, squeezing and unsqueezing Earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave shadow zone. No P-waves are picked up at seismographs 104^o to 140^o from the earthquakes focus.

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of

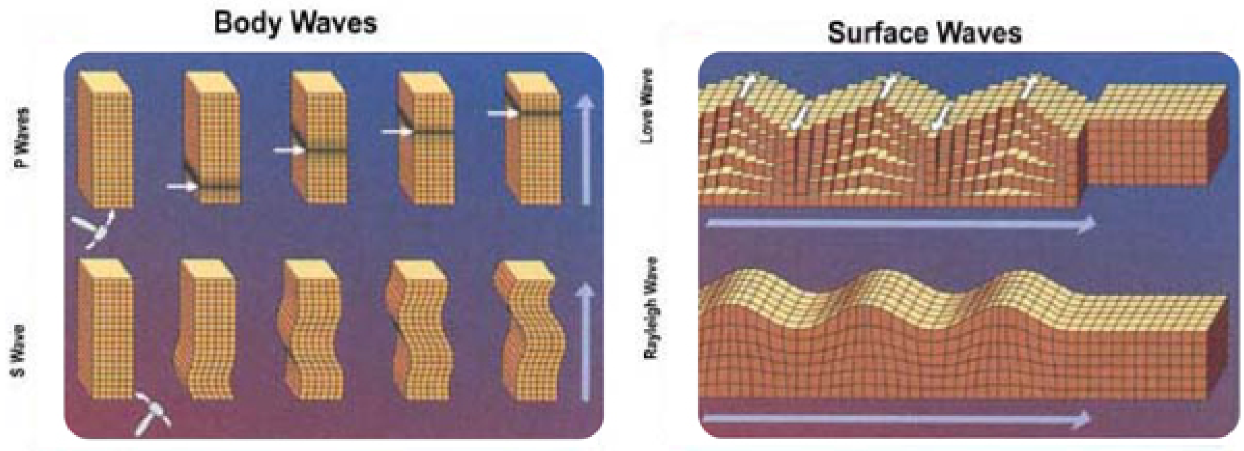


FIGURE 4.19

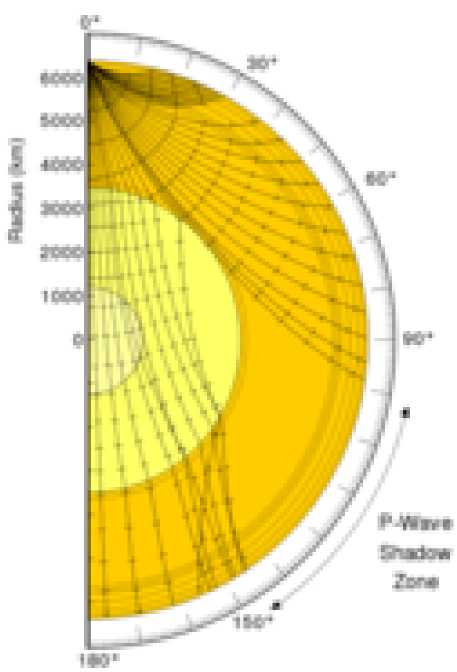


FIGURE 4.20
How P-waves travel through Earth's interior.

wave travel. This produces a change in shape for the Earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

Earth's Interior

By tracking seismic waves, scientists have learned what makes up the planet's interior (**Figure** 4.21).

- P-waves slow down at the mantle core boundary, so we know the outer core is less rigid than the mantle.
- S-waves disappear at the mantle core boundary, so we know the outer core is liquid.

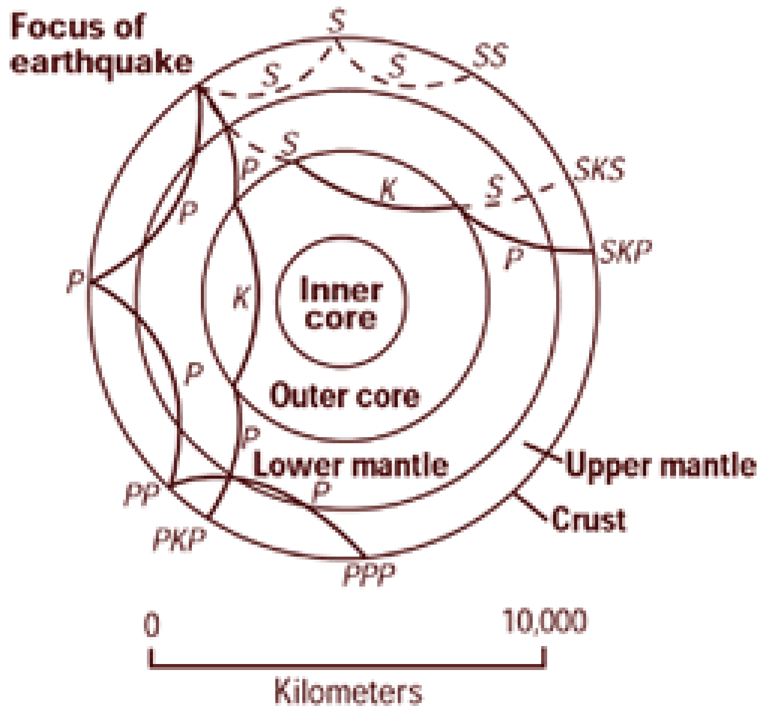


FIGURE 4.21
Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

Surface Waves

Surface waves travel along the ground, outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves, traveling at 2.5 km (1.5 miles) per second. There are two types of surface waves. The rolling motions of surface waves do most of the damage in an earthquake.

Interesting earthquake videos are seen at National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/. Titles include:

- "Earthquake 101."
- "Inside Earthquakes" looks at this sudden natural disaster.

This animation shows a seismic wave shadow zone: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone#38;flash_file=shadowzone#38;flash_width=220#38;flash_height=320.

Vocabulary

- **amplitude**: The height of a wave from the center to the top of the crest (or the bottom of the trough).
- **body wave**: Seismic waves that travel through the body of a planet; e.g. primary or secondary waves.
- **crest**: The highest point of a wave.
- **P-waves**: Primary waves; arrive first at a seismograph
- **S-waves**: Secondary waves; arrive second at a seismograph
- **seismology**: The study of seismic waves including earthquakes and the Earth's interior.

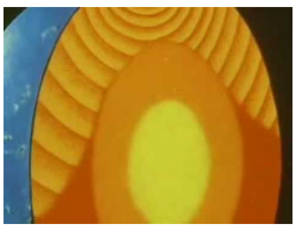
- **surface wave**: Seismic waves that travel along the ground surface; they do the most damage.
- **trough**: The lowest point of a wave.
- **wavelength**: Horizontal distance from wave crest to wave crest, or wave trough to wave trough.

Summary

- P-waves arrive first to a seismograph because they are faster. They travel through solids, liquids, and gases.
- S-waves arrive second to a seismograph, and they only travel through solids.
- The behavior of P- and S-waves indicates that the outer core is liquid.

Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What types of waves do earthquakes produce?
2. What are the fastest body waves?
3. What is the shadow zone?
4. What do S-waves do?
5. List and explain the two types of surface waves.

Review

1. What are the properties of P-waves?
2. What are the properties of S-waves?
3. How do scientists use seismic waves to learn about Earth's interior?

4.9 Earth's Interior Material

- Explain how information provided by study of density, magnetism, and rocks provide clues about Earth's interior.

In *A Journey to the Center of the Earth*, what did they find?

Jules Verne published *A Journey to the Center of the Earth* in 1864 with very little idea of what was below the surface. Unfortunately, there are no volcanic tubes in which to travel deep within the planet, as Verne had imagined. But scientists have learned a lot about Earth's interior using seismic waves, rocks, and calculations of Earth's density and magnetism.

Other Clues about Earth's Interior

1. Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal.
2. Since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic.
3. **Meteorites** are the remains of the material that formed the early solar system and are thought to be similar to material in Earth's interior (**Figure** 4.22).

FIGURE 4.22
This meteorite contains the mafic minerals olivine and pyroxene. It also contains metal flakes, similar to the material that separated into Earth's core (metal) and mantle (ultramafic rock).

Vocabulary

- **meteorite**: Fragment of planetary bodies, such as moons, planets, asteroids, and comets, that strike Earth.

Summary

- Earth's density indicates that it must contain a significant amount of metal.
- Since Earth has a magnetic field, there must be metal inside.
- Meteorites formed elsewhere in the solar system but by similar processes indicate something about Earth's interior.

Interactive Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. Who discovered the Earth's core?
2. How did he discover it?
3. What did he discover about the core?
4. What did Inge Lehmann discover?
5. What is the structure of the inner core?
6. What is the function of the outer core?

Review

1. Scientists know that Earth's interior contains metal, but how do they know it's in the core?
2. How does the meteorite in the photo above give clues as to what is found in Earth's interior?
3. If a planet in our solar system has a magnetic field, what do we know about it?

4.10 Earth's Layers

- Identify Earth's layers and describe their characteristics.

What's below our feet? What's way below?

If we could cut Earth open, we'd see the inner core at the center, then the outer core, the mantle in the middle and the crust on the outside. If you are talking about plates, though, there's the brittle lithosphere riding on the plastic asthenosphere. Whew!

Layers by Composition

The layers scientists recognize are pictured below (**Figure** 4.23).

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The two types are oceanic crust and continental crust.
2. The **mantle** is hot, ultramafic rock. It represents about 68% of Earth's mass.
3. The **core** is mostly iron metal. The core makes up about 31% of the Earth.

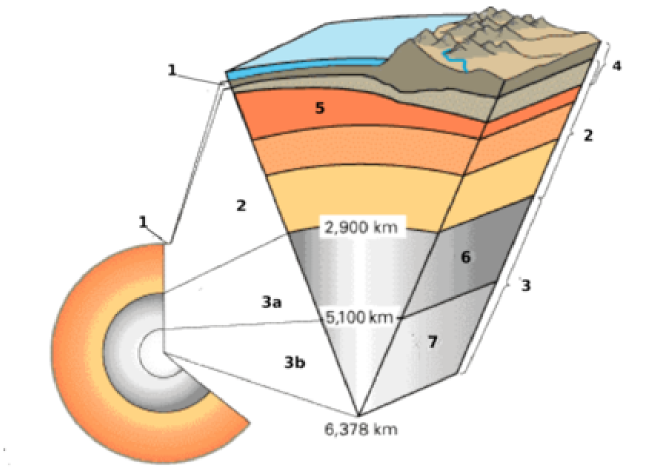


FIGURE 4.23
A cross section of Earth showing the following layers: (1) crust (2) mantle (3a) outer core (3b) inner core (4) lithosphere (5) asthenosphere (6) outer core (7) inner core.

Layers by Mechanical Properties

Lithosphere and asthenosphere are divisions based on mechanical properties:

1. The **lithosphere** is composed of both the crust and the portion of the upper mantle and behaves as a brittle, rigid solid.
2. The **asthenosphere** is partially molten upper mantle material and behaves plastically and can flow.

This animation shows the layers by composition and by mechanical properties: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_layers.html.

Vocabulary

- **asthenosphere**: The layer below the lithosphere, made of a portion of the upper mantle, that is ductile.
- **core**: The innermost, densest layer of a celestial body. Earth's metallic core has an inner solid layer and an outer layer of liquid metal. The sun's core is where nuclear fusion takes place.
- **crust**: The rocky outer layer of the Earth's surface. The two types of crust are continental and oceanic.
- **lithosphere**: The layer of solid, brittle rock that makes up the Earth's surface; the crust and the uppermost mantle.
- **mantle**: The middle layer of the Earth; made of hot rock that circulates by convection.

Summary

- By composition, Earth is divided into core, mantle, and crust.
- By mechanical properties, the crust and upper mantle are divided into lithosphere and asthenosphere.
- Continental crust is felsic, oceanic crust is mafic, the mantle is ultramafic, and the core is metallic.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/structure.html

1. What substances make up the inner core?

2. What is the structure of the inner core?
3. What is the structure of the outer core?
4. Explain the composition of the mantle.
5. What is the asthenosphere?

Review

1. What are the the layers of Earth based on composition and where are they located?
2. What is the composition of the different layers?
3. How do the lithosphere and asthenosphere differ from each other?

4.11 Earth's Crust

- Describe the characteristics of Earth's two types of crust, oceanic and continental.

How does a loaf of bread resemble Earth?

A loaf of homemade bread could almost resemble Earth. The raised parts of the crust are the continents and the depressed parts are the oceans. The inside is gooier than the brittle exterior, but it's still solid. How is a loaf of bread not like Earth?

Crust

Earth's outer surface is its crust, a cold, thin, brittle outer shell made of rock. The crust is very thin relative to the radius of the planet. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** 4.1.

TABLE 4.1:

Crust	Thickness	Density	Composition	Rock types
Oceanic	5-12 km (3-8 mi)	3.0 g/cm^3	Mafic	Basalt and gabbro
Continental	Avg. 35 km (22 mi)	2.7 g/cm^3	Felsic	All types

Oceanic Crust

Oceanic crust is composed of mafic magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro (**Figure** 4.24).

Sediments, primarily mud and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore,

FIGURE 4.24
Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

where it comes off the continents in rivers and on wind currents.

The oceanic crust is relatively thin and lies above the mantle. The cross section of oceanic crust below shows the layers that grade from sediments at the top to extrusive basalt lava, to the sheeted dikes that feed lava to the surface, to deeper intrusive gabbro, and finally to the mantle.

Continental Crust

Continental crust is made up of many different types of igneous, metamorphic, and sedimentary rocks. The average composition is granite, which is much less dense than the mafic rocks of the oceanic crust (**Figure** 4.26). Because it is thick and has relatively low density, continental crust rises higher on the mantle than oceanic crust, which sinks into the mantle to form basins. When filled with water, these basins form the planet's oceans.

Vocabulary

- **continental crust**: The portion of Earth's crust and mostly makes up the continents. It is relative thick and buoyant, and is composed of a variety of rocks that are made of a more felsic composition.
- **oceanic crust**: The portion of Earth's crust that makes up the seafloor. It is relatively thin, dense, and mafic.

Summary

- Oceanic crust is thinner and denser than continental crust.
- Oceanic crust is more mafic, continental crust is more felsic.
- Crust is very thin relative to Earth's radius.

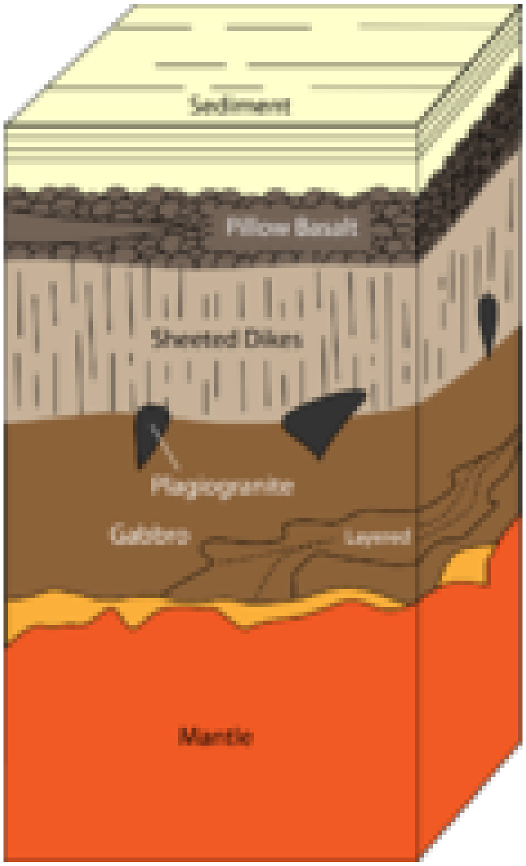


FIGURE 4.25
A cross-section of oceanic crust.

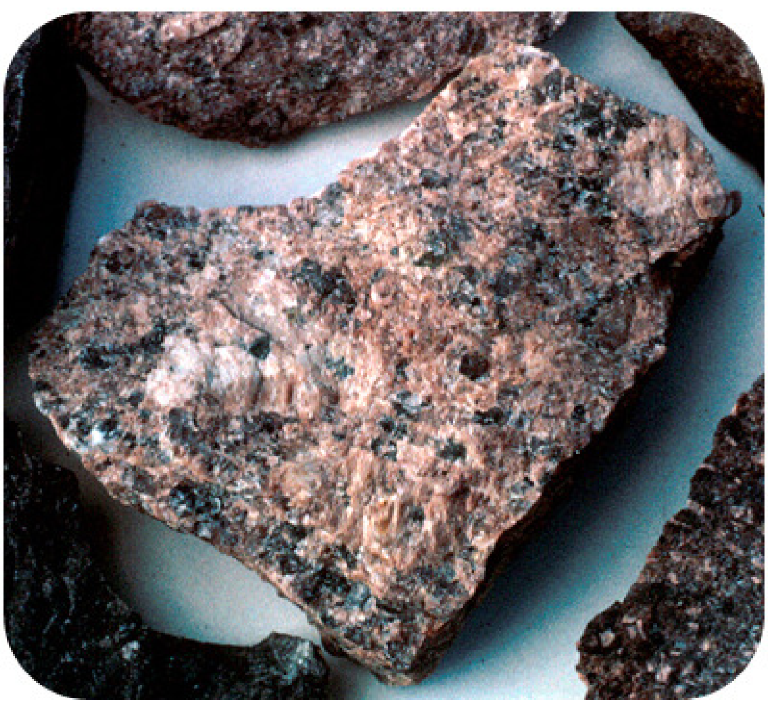


FIGURE 4.26
This granite from Missouri is more than 1 billion years old.

Interactive Practice

Use these resources to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/structure.html

Click on the crust to answer the questions below:

1. Describe the crust.
2. Where is the crust the thickest?

http://scign.jpl.nasa.gov/learn/plate1.htm

3. How thick is continental crust?
4. How thick is oceanic crust?
5. Compare the thickness of the crust in comparison with the rest of the layers of the earth.

Review

1. Describe the properties of oceanic crust.
2. Describe the properties of continental crust.
3. What type of rock makes up each of the types of crust?

4.12 Earth's Mantle

- Describe Earth's mantle and explain its relationship to conduction and convection.

What is a diamond delivery system?

Some events happened when Earth was younger and hotter that do not happen any more. **Kimberlite pipes** shot up from deep in the mantle. These pipes are the most important source of diamonds, which form at very high pressure. Most kimberlites surfaced long ago.

Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot.

Solid Rock

Scientists know that the mantle is made of rock based on evidence from seismic waves, heat flow, and meteorites. The properties fit the ultramafic rock **peridotite**, which is made of the iron- and magnesium-rich silicate minerals (**Figure** 4.27). Peridotite is rarely found at Earth's surface.

Heat Flow

Scientists know that the mantle is extremely hot because of the heat flowing outward from it and because of its physical properties.

Heat flows in two different ways within the Earth:

FIGURE 4.27
Peridotite is formed of crystals of olivine (green) and pyroxene (black).

1. **Conduction**: Heat is transferred through rapid collisions of atoms, which can only happen if the material is solid. Heat flows from warmer to cooler places until all are the same temperature. The mantle is hot mostly because of heat conducted from the core.
2. **Convection**: If a material is able to move, even if it moves very slowly, convection currents can form.

Convection in the mantle is the same as convection in a pot of water on a stove. Convection currents within Earth's mantle form as material near the core heats up. As the core heats the bottom layer of mantle material, particles move more rapidly, decreasing its density and causing it to rise. The rising material begins the convection current. When the warm material reaches the surface, it spreads horizontally. The material cools because it is no longer near the core. It eventually becomes cool and dense enough to sink back down into the mantle. At the bottom of the mantle, the material travels horizontally and is heated by the core. It reaches the location where warm mantle material rises, and the mantle **convection cell** is complete (**Figure** 4.28).

Vocabulary

- **conduction**: The process in which energy moves from a location of higher temperature to a location of lower temperature as heat. The material does not move, just the heat.
- **convection**: The movement of material due to differences in temperature.
- **convection cell**: A circular pattern of warm material rising and cool material sinking.
- **kimberlite pipe**: Volcanic rock shot up from between around 100 to 300 km depth that contains diamonds.
- **peridotite**: Very dense, very mafic igneous rock that is the composition of the upper mantle.

Summary

- The mantle is composed of solid peridotite.
- Conduction from the core heats the lower mantle.
- Mantle convection cells bring hot material up toward the surface and cooler material down toward the core.

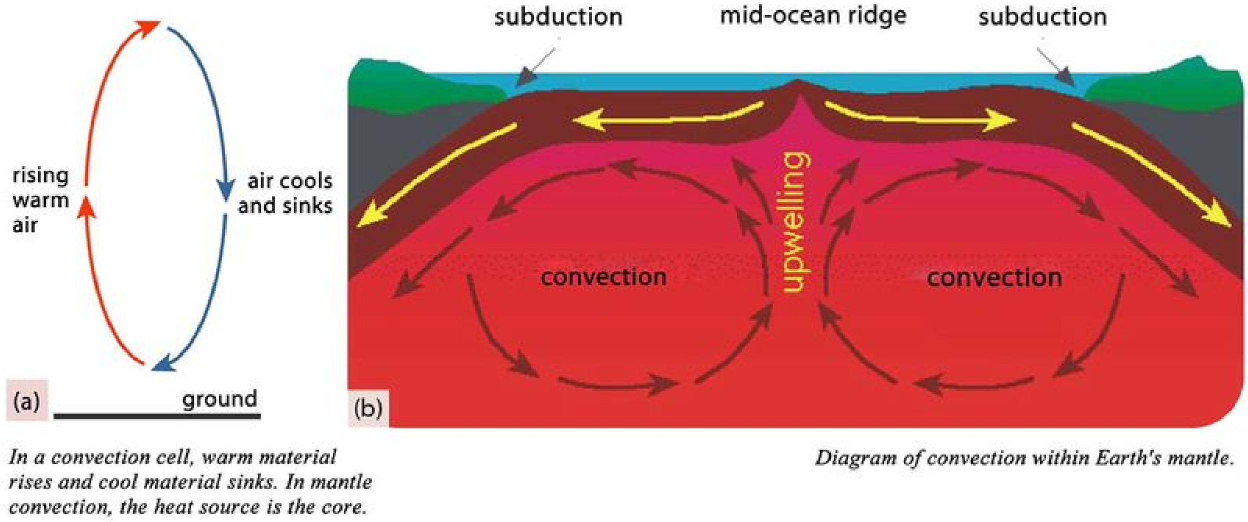
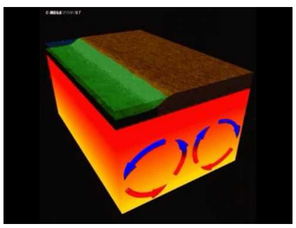


FIGURE 4.28
Convection.

Practice

Use these resources to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What incorrect statement does this video make about the asthenosphere?
2. What causes plate movement?
3. What is convection?

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

MEDIA
Click image to the left for more content.

4. What happens to the denser material?
5. What happens to the less dense material?

6. Where are convection currents found?

http://www.learner.org/interactives/dynamicearth/structure.html

7. Explain the structure of the mantle.

Review

1. What is the composition of the mantle and how do scientists know this?
2. What is conduction?
3. How does convection work in the mantle?

4.13 Earth's Core

- Describe the characteristics of Earth's inner core and outer core.

Do you want to take a journey to the center of the earth?

Jules Verne's imagined core was fiery. But we know that the outer core is molten metal, as seen above. As hot as a journey to Verne's center of the earth might have been, a visit to the real location would be worse.

Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal because:

1. The density of Earth's surface layers is much less than the overall density of the planet, as calculated from the planet's rotation. If the surface layers are less dense than average, then the interior must be denser than average. Calculations indicate that the core is about 85% iron metal with nickel metal making up much of the remaining 15%.
2. Metallic meteorites are thought to be representative of the core. The 85% iron/15% nickel calculation above is also seen in metallic meteorites (**Figure** 4.29).

If Earth's core were not metal, the planet would not have a magnetic field. Metals such as iron are magnetic, but rock, which makes up the mantle and crust, is not.

Scientists know that the outer core is liquid and the inner core is solid because:

1. S-waves stop at the inner core.

FIGURE 4.29
An iron meteorite is the closest thing to the Earth's core that we can hold in our hands.

2. The strong magnetic field is caused by convection in the liquid outer core. Convection currents in the outer core are due to heat from the even hotter inner core.

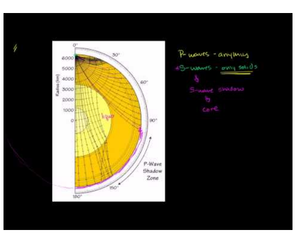
The heat that keeps the outer core from solidifying is produced by the breakdown of radioactive elements in the inner core.

Summary

- Earth's core is dense metal.
- The inner core is solid and the outer core is liquid, as indicated by seismic waves.
- Metallic meteorites, density calculations, and the magnetic field are all clues that about the composition of Earth's inner and outer core.

Interactive Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What materials can P-waves travel through?
2. What materials can S-waves travel through?
3. How do we know the outer core is liquid?
4. What happens to P-waves when they go through a liquid?

5. What do P-waves tell about the inner core?

Review

1. Why is there convection in the outer core and what is the result of this?

2. If scientists discovered a major mistake in their calculations and Earth's crust turned out to be much denser than they'd thought, what would this say about the material that makes up the core?

3. What is the outer core so hot?

4.14 Lithosphere and Asthenosphere

- Define lithosphere and asthenosphere, and describe their characteristics.

Can you think of a solid that can flow?

You use one twice a day! Toothpaste is a solid that can flow. Is the asthenosphere made of toothpaste? Only if the toothpaste is ultramafic in composition, and then it would only be able to flow if it were really, really hot. Still the toothpaste analogy gives you a good image of how the asthenosphere might behave if you squeezed it!

Lithosphere

The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid. The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. How are crust and lithosphere different from each other?

The definition of the lithosphere is based on how Earth materials behave, so it includes the crust and the uppermost mantle, which are both brittle. Since it is rigid and brittle, when stresses act on the lithosphere, it breaks. This is what we experience as an earthquake.

Although we sometimes refer to Earth's plates as being plates of crust, the plates are actually made of lithosphere. Much more about Earth's plates follows in the chapter "Plate Tectonics."

Asthenosphere

The **asthenosphere** is solid upper mantle material that is so hot that it behaves plastically and can flow. The lithosphere rides on the asthenosphere.

Vocabulary

- **asthenosphere**: The layer below the lithosphere, made of a portion of the upper mantle, that is ductile.
- **lithosphere**: The layer of solid, brittle rock that makes up the Earth's surface; the crust and the uppermost mantle.

Summary

- The lithosphere is the brittle crust and uppermost mantle.
- The asthenosphere is a solid but it can flow, like toothpaste.
- The lithosphere rests on the asthenosphere.

Interactive Practice

Use this resource to answer the questions that follow.

http://www.windows2universe.org/earth/interior/earths_crust.html

1. What is the lithosphere?

2. How far does the lithosphere extend?

3. What makes up the lithosphere?

4. Why does the lithosphere move?

5. What is the asthenosphere?

6. What causes the asthenosphere to move?

Review

1. Where is the lithosphere? What layers does it include?

2. What is the asthenosphere?

3. How do the lithosphere and asthenosphere differ?

4. If the lithosphere is resting on the asthenosphere and you put a lot of weight on the lithosphere, say ice in a glacier, how would the lithosphere respond?

Summary

A planet must (1) orbit a star, (2) have enough mass to be nearly spherical, and (3) have cleared the area around its orbit of smaller objects. Earth is and does all these things! The planet rotates on its axis, so that one half is always facing the Sun and another half is always facing away from the Sun. This rotation creates the day-night cycle. Earth's axis of rotation is tilted relative to its plane of orbit, which creates the seasons. Like other planets, Earth also revolves around the Sun. Earth's trip takes a 365 day year. Earth has a magnetic field, due to convection in its liquid metal outer core. Besides an iron and nickel metal core, the planet has a mantle made of dense rock and a crust made of lighter rock, mostly mafic rock makes up the seafloor and a variety of rocks that have a less dense composition overall make up the crust. The crust and uppermost mantle make up the brittle lithosphere, which rides on the ductile asthenosphere, which is made up of the upper mantle below the lithosphere.

4.15 References

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Chapter 5 Plate Tectonics

Chapter Outline

Introduction

But it all seems so solid!

Besides flying around on a ball of rock — orbiting a giant ball of burning gas and spinning in circles about an axis — the ground you sit on is moving! Just as Copernicus, Kepler, and Galileo had trouble convincing people that Earth orbited the Sun when it clearly seemed that Earth was at the center of the universe and everything moved around it, early adherents to the idea that continents could move had to fight against, well, common sense. Over the past century the idea that continents could move was proposed, studied, abandoned, and finally accepted.

We'll start this concept with a field trip back in time to the scientists that developed plate tectonics theory. First, we'll visit Wegener, and then we'll get aboard ship to learn about seafloor spreading. Finally, we'll travel around western North America to see the features created by the different types of plate boundaries there.

5.1 Continental Drift

- Identify the evidence Wegener had in support of his continental drift hypothesis.
- Apply the steps of scientific method to Wegener's scientific investigation.

"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." - Alfred Wegener to his future wife, December, 1910.

We can't really get into Alfred Wegner's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it an accident that they do, or is there some geological reason?

Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents.

Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's most dogged supporter. Wegener amassed a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

Wegener's Evidence

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

- The continents appear to fit together.
- Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated (**Figure** 5.1). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.
  - Fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind.
  - *Mesosaurus* was a swimming reptile, but could only swim in fresh water.
  - *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.

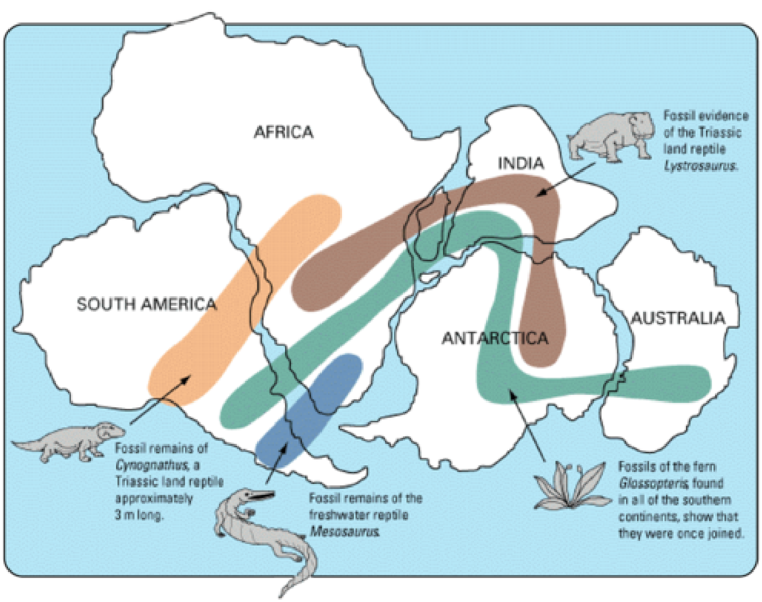


FIGURE 5.1

Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

- Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
- Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (**Figure** 5.2). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

FIGURE 5.2
The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

- Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
- Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents. An animation showing that Earth's climate belts remain in roughly the same position while the continents move is seen here: http://www.scotese.com/paleocli.htm.
- Wegener thought that mountains formed as continents ran into each other. This got around the problem of the leading hypothesis of the day, which was that Earth had been a molten ball that bulked up in spots as it cooled (the problem with this idea was that the mountains should all be the same age and they were known not to be). An animation showing how the continents split up can be found here: http://www.exploratorium.edu/origins/antarctica/ideas/gondwana2.html.

Summary

- Alfred Wegener did some background reading and made an observation.
- Wegener then asked an important question and set about to answer it.
- He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.

Practice

Use these resources to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Who was Alfred Wegener?
2. What evidence did Wegener find for Pangaea?
3. What was the response to Wegener's hypothesis?

MEDIA

Click image to the left for more content.

4. What is the continental drift hypothesis?
5. What do the continental plates consist of?
6. What were formed when Pangaea broke apart?
7. How long ago did the continents reach their present position?

Review

1. How did Wegener become interested in the idea that continents could move?
2. What did he need to do to explore the question and make it into a reasonably hypothesis?
3. How did Wegener use fossil evidence to support his hypothesis?
4. How did Wegener use climate evidence from rocks to support his hypothesis?

5.2 Wegener and the Continental Drift Hypothesis

- Define the continental drift hypothesis.
- Analyze why the continental drift hypothesis was not accepted by the majority of scientists in Wegener's day.

"Scientists still do not appear to understand sufficiently..."

"...that all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combing all this evidence. ... It is only by combing the information furnished by all the earth sciences that we can hope to determine 'truth' here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further, we have to be prepared always for the possibility that each new discovery, no matter what science furnishes it, may modify the conclusions we draw." - Alfred L. Wegener, *The Origins of Continents and Oceans*, first published in 1915.

Wegener put together a tremendous amount of evidence that the continents had been joined. He advocated using scientific evidence to find the "truth." As his colleague, are you convinced? Let's explore.

Wegener's Continental Drift Hypothesis

Wegener put his idea and his evidence together in his book *The Origin of Continents and Oceans*, first published in 1915. New editions with additional evidence were published later in the decade. In his book he said that around 300 million years ago the continents had all been joined into a single landmass he called Pangaea, meaning "all earth" in ancient Greek. The supercontinent later broke apart and the continents having been moving into their current positions ever since. He called his hypothesis **continental drift**.

The Problem with the Hypothesis

Wegener's idea seemed so outlandish at the time that he was ridiculed by other scientists. What do you think the problem was? To his colleagues, his greatest problem was that he had no plausible mechanism for how the continents could move through the oceans. Based on his polar experiences, Wegener suggested that the continents were like icebreaking ships plowing through ice sheets. The continents moved by centrifugal and tidal forces. As Wegener's colleague, how would you go about showing whether these forces could move continents? What observations would you expect to see on these continents?

FIGURE 5.3
Alfred Wegener suggested that continental drift occurred as continents cut through the ocean floor, in the same way as this icebreaker plows through sea ice.

FIGURE 5.4
Early hypotheses proposed that centrifugal forces moved continents. This is the same force that moves the swings outward on a spinning carnival ride.

Scientists at the time calculated that centrifugal and tidal forces were too weak to move continents. When one scientist did calculations that assumed that these forces were strong enough to move continents, his result was that if Earth had such strong forces the planet would stop rotating in less than one year. In addition, scientists also thought that the continents that had been plowing through the ocean basins should be much more deformed than they are.

Wegener answered his question of whether Africa and South America had once been joined. But a hypothesis is rarely accepted without a mechanism to drive it. Are you going to support Wegener? A very few scientists did, since his hypothesis elegantly explained the similar fossils and rocks on opposite sides of the ocean, but most did not.

Mantle Convection

Wegener had many thoughts regarding what could be the driving force behind continental drift. Another of Wegener's colleagues, Arthur Holmes, elaborated on Wegener's idea that there is thermal convection in the mantle.

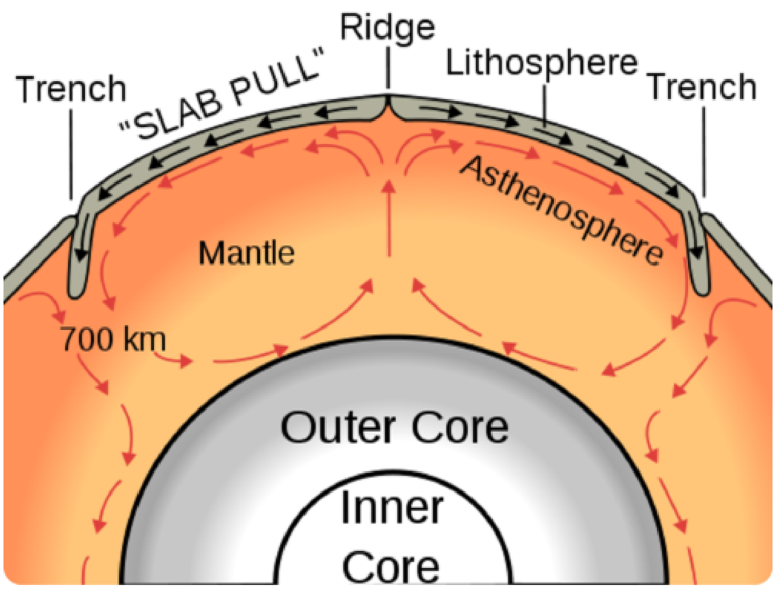


FIGURE 5.5
Thermal convection occurs as hot rock in the deep mantle rises towards the Earth's surface. This rock then spreads out and cools, sinking back towards the core, where it can be heated again. This circulation of rock through the mantle creates convection cells.

In a **convection cell**, material deep beneath the surface is heated so that its density is lowered and it rises. Near the surface it becomes cooler and denser, so it sinks. Holmes thought this could be like a conveyor belt. Where two adjacent convection cells rise to the surface, a continent could break apart with pieces moving in opposite directions. Although this sounds like a great idea, there was no real evidence for it, either.

Alfred Wegener died in 1930 on an expedition on the Greenland icecap. For the most part the continental drift idea was put to rest for a few decades, until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents. Since you're on a virtual field trip, you get to go along with them as well.

Vocabulary

- **continental drift**: The early 20th century hypothesis that the continents move about on Earth's surface.
- **convection cell**: A circular pattern of warm material rising and cool material sinking.

Summary

- Alfred Wegener published his idea that the continents had been joined as a single landmass, which he called Pangaea, about 300 million years ago.
- Wegener's idea was mostly ridiculed, in part because Wegener could not develop a plausible mechanism for continents moving through oceanic crust.

- Calculations showed that his idea about centrifugal and tidal forces powering the continents could not be right.
- Wegener also thought about mantle convection an idea expanded on by Arthur Holmes as the driving force for continental drift. There was no evidence available to support the idea at the time.

Practice

Use this resource to answer the questions that follow.

Review

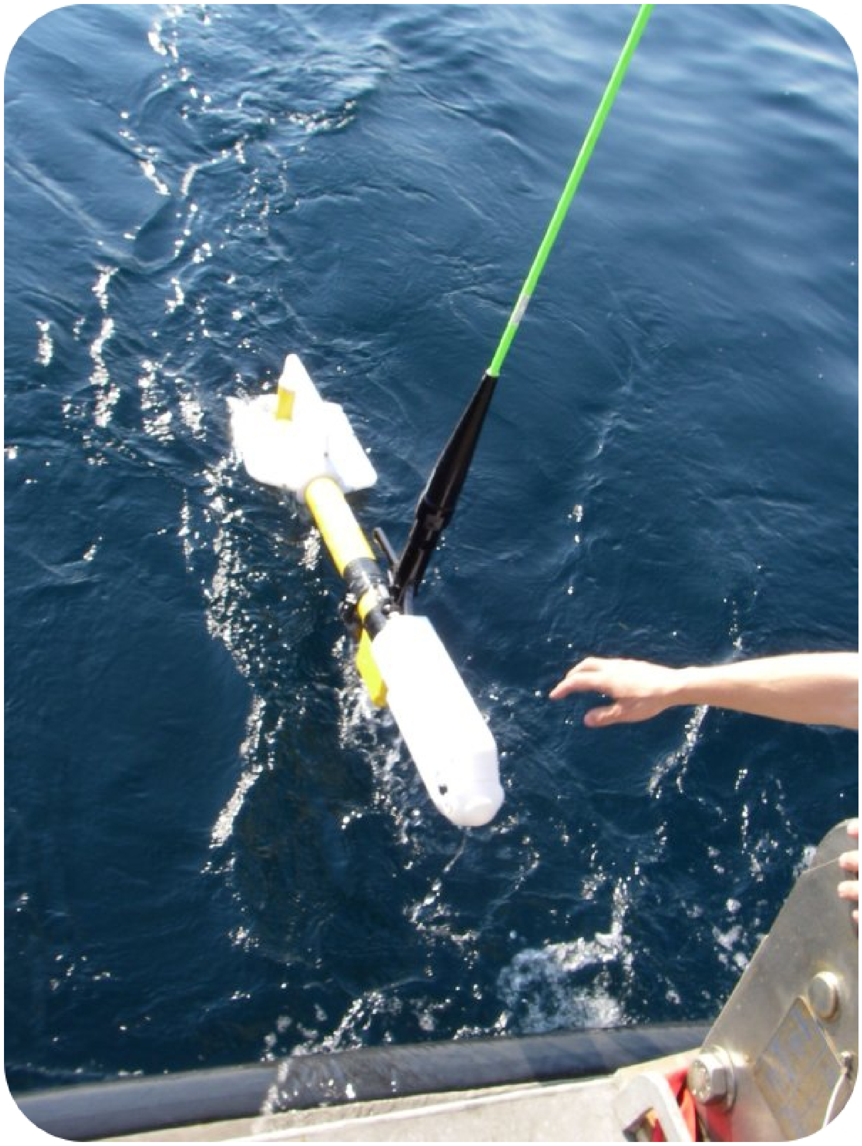
1. Describe the continental drift hypothesis.

2. Why did scientists reject Wegener's idea? What was needed for them to accept it?

3. Are there some ideas (hypotheses, theories) that have a great deal of evidence to support them, yet are not accepted by many people?

5.3 Magnetic Polarity Evidence for Continental Drift

- Identify how magnetic polarity evidence supports the continental drift hypothesis.



"The Wegener hypothesis has been so stimulating and has such fundamental implications in geology..."

"...as to merit respectful and sympathetic interest from every geologist. Some striking arguments in his favor have been advanced, and it would be foolhardy indeed to reject any concept that offers a possible key to the solution of profound problems in the Earth's history." - Chester R. Longwell, "Some Thoughts on the Evidence for Continental Drift," 1944

Wegener and his supporters did all they could do to find evidence to support continental drift. But without a mechanism the idea would not be accepted. What was needed was the development of technologies that would allow scientists to find more evidence for the idea and help them describe a mechanism. But first, they would find still more evidence that the continents had moved.

Magnetic Polarity Evidence

The next breakthrough in the development of the theory of plate tectonics came two decades after Wegener's death. **Magnetite** crystals are shaped like a tiny bar magnet. As basalt lava cools, the magnetite crystals line up in the magnetic field like tiny magnets. When the lava is completely cooled, the crystals point in the direction of magnetic north pole at the time they form. How do you expect this would help scientists see whether continents had moved or not?

FIGURE 5.6
Magnetite crystals.

As a Wegener supporter, (and someone who is omniscient), you have just learned of a new tool that may help you. A **magnetometer** is a device capable of measuring the magnetic field intensity. This allows you to look at the magnetic properties of rocks in many locations. First, you're going to look at rocks on land. Which rocks should you seek out for study?

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Geologists noted important things about the magnetic polarity of different aged rocks on the same continent:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole (**Figure** 5.7) no matter what continent or where on the continent the rocks are located.
- Older rocks that are the same age and are located on the same continent point to the same location, but that location is not the current north magnetic pole.
- Older rocks that are of different ages do not point to the same locations or to the current magnetic north pole.

In other words, although the magnetite crystals were pointing to the magnetic north pole, the location of the pole seemed to wander. Scientists were amazed to find that the north magnetic pole changed location over time (**Figure** 5.8).

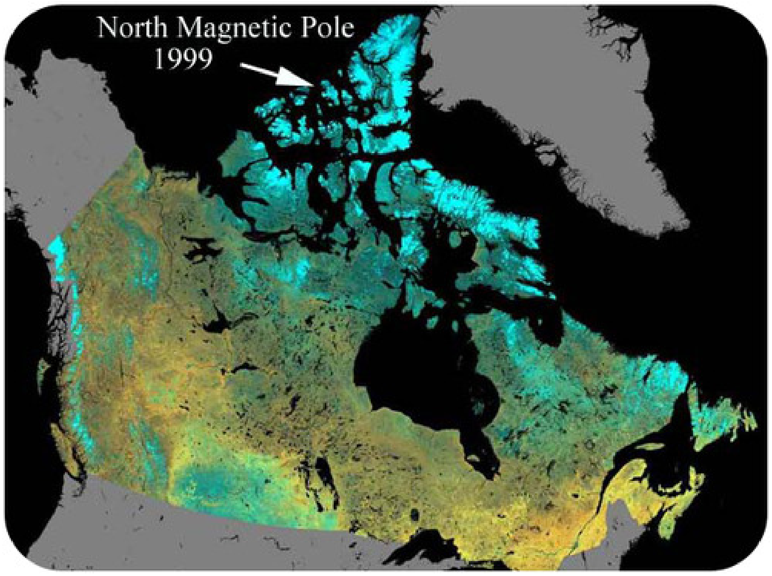


FIGURE 5.7
Earth's current north magnetic pole is in northern Canada.

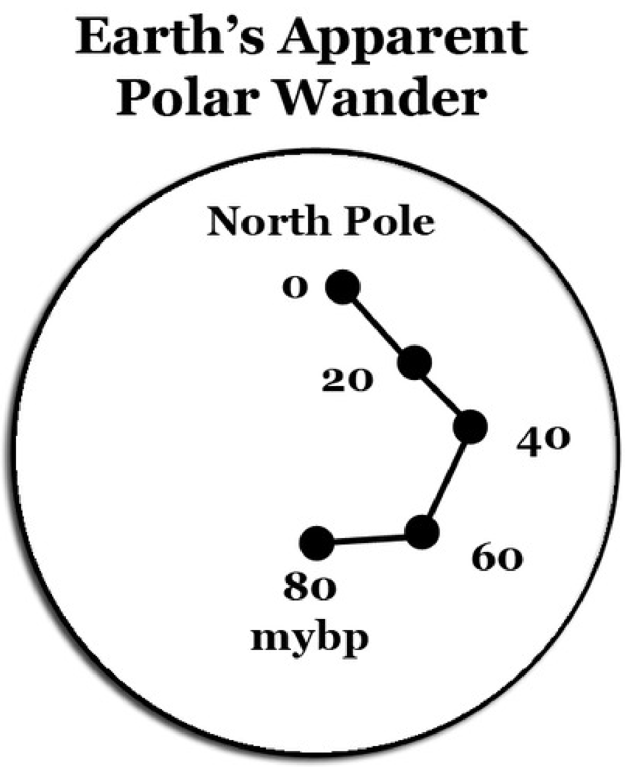


FIGURE 5.8
The location of the north magnetic north pole 80 million years before present (mybp), then 60, 40, 20, and now.

Can you figure out the three possible explanations for this? They are:

1. The continents remained fixed and the north magnetic pole moved.
2. The north magnetic pole stood still and the continents moved.
3. Both the continents and the north pole moved.

Magnetic Polarity on Different Continents with Rocks of the Same Age

How do you figure out which of those three possibilities is correct? You decide to look at magnetic rocks on different continents. Geologists noted that for rocks of the same age but on different continents, the little magnets pointed to different magnetic north poles.

- 400 million-year-old magnetite in Europe pointed to a different north magnetic pole than magnetite of the same age in North America.
- 250 million years ago, the north poles were also different for the two continents.

Now look again at the three possible explanations. Only one can be correct. If the continents had remained fixed while the north magnetic pole moved, there must have been two separate north poles. Since there is only one north pole today, what is the best explanation? The only reasonable explanation is that the magnetic north pole has remained fixed but that the continents have moved.

Wegener was Right!

How does this help you to provide evidence for continental drift? To test the idea that the pole remained fixed but the continents moved, geologists fitted the continents together as Wegener had done. It worked! There has only been one magnetic north pole and the continents have drifted (**Figure** 5.9). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander**.

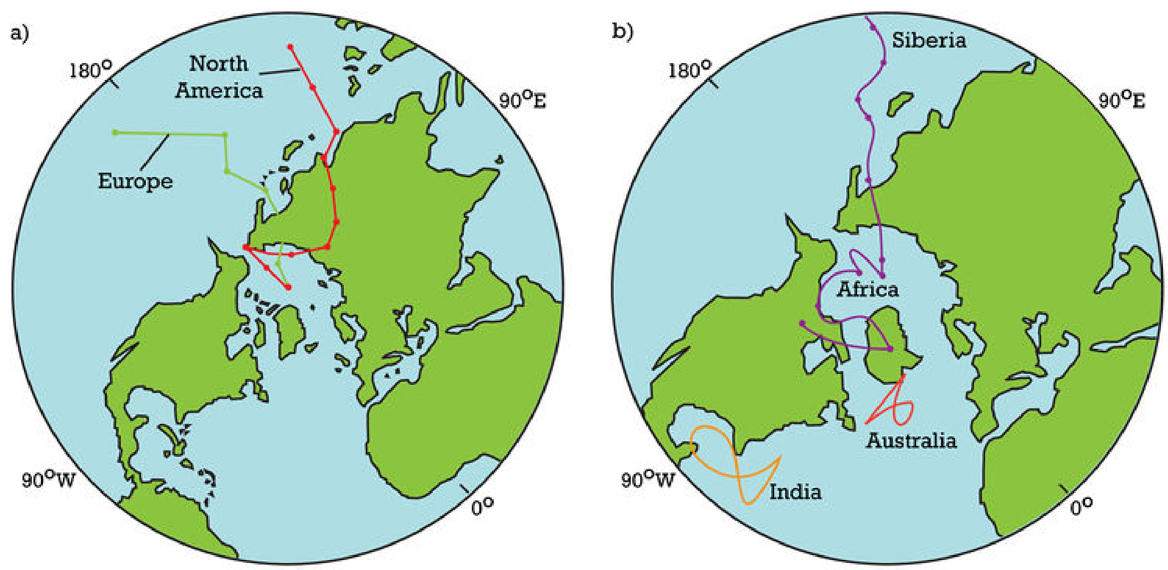


FIGURE 5.9

On the left: The apparent north pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.

Vocabulary

- **apparent polar wander**: The path on the globe showing where the magnetic pole appeared to move over time.
- **magnetite**: A magnetic mineral that takes on Earth's magnetic polarity as it crystallizes.
- **magnetometer**: An instrument that measures the magnetic field intensity.

Summary

- Using magnetic evidence found on a single continent in the 1950s, scientists showed that either the north magnetic pole was in a different spot in Earth's past or that the continents had moved.
- When they added magnetic evidence from a second continent, they showed that in the past there had either been two magnetic north poles or the continents had moved.
- Since there is only one magnetic north pole today, they concluded that the simplest explanation is that the continents have moved.

Practice

Use this resource to answer the questions that follow.

http://www.grossmont.edu/garyjacobson/animations.htm:

1. Explain what appears to be occurring at the north pole.

2. What direction is the pole moving?

3. Describe the movement of the south pole.

4. What direction is the south pole moving?

Review

1. What is apparent polar wander?

2. How does magnetic evidence from one continent show that either the north magnetic pole has moved or the continents have moved?

3. How does magnetic evidence from two continents show that the continents have moved?

5.4 Bathymetric Evidence for Seafloor Spreading

- Describe how seafloor bathymetry allows scientists to study features of the seafloor.
- Identify features of the seafloor and describe how they provide evidence for the theory of plate tectonics.

Let's go to sea!

To understand what came next, we need to go to sea aboard a research vessel. From the photo you can probably tell that a research vessel is no cruise ship. It's a lot smaller, and community spaces are filled with science labs, not swimming pools. The food ranges from barely edible to tasty and filling, but is rarely sumptuous. But with a research vessel we can gather data to explore the seafloor. Let's go on one now!

Life at Sea

We'll go out on the research vessel (R/V in ship-speak) Atlantis, owned by the US Navy and operated by the Woods Hole Oceanographic Institution for the oceanographic community.

The Atlantis has six science labs and storage spaces, precise navigation systems, seafloor-mapping sonar and satellite communications. Most importantly, the ship has all of the heavy equipment necessary to deploy and operate Alvin, the manned research submersible.

The ship has 24 bunks available for scientists, including two for the chief scientists. The majority of these bunks are below waterline, which makes for good sleeping in the daytime. Ship time is really expensive research, so vessels operate all night and so do the scientists. Your "watch", as your time on duty is called, may be 12-4, 4-8 or 8-12 – that's AM and PM. Alternately, if you're on the team doing a lot of diving in Alvin, you may just be up during the day. If you're mostly doing operations that don't involve Alvin, you may just be up at night. For safety reasons, Alvin is deployed and recovered only in daylight.

FIGURE 5.10
Alvin is deployed from the stern of the R/V Atlantis.

Scientists come from all over to meet a research ship in a port. An oceanographer these days doesn't need to be near the ocean, he or she just needs to have access to an airport!

Let's begin this cruise in Woods Hole, Massachusetts, Atlantis' home port. Our first voyage will be out to the Mid-Atlantic Ridge. Transit time to the research site can take days. By doing this virtually, we don't have to spend days in transit to our research site, and we don't have to get seasick!

As we head to the site, we will run the echo sounder. Let's see what we can find!

Echo Sounding

The people who first mapped the seafloor were aboard military vessels during World War II. As stated in the "Earth as a Planet" concept, echo sounders searching for submarines produced a map of seafloor depths. Depth sounding continued in earnest after the war. Scientists pieced together the ocean depths to produce bathymetric maps of the seafloor. During WWII and in the decade or so later, echo sounders had only one beam, so they just returned a line showing the depth beneath the ship. Later echo sounders sent out multiple beams and could create a bathymetric map of the seafloor below.

We will run a multi-beam echo sounder as we go from Woods Hole out to the Mid-Atlantic Ridge.

Features of the Seafloor

Although they expected an expanse of flat, featureless plains, scientists were shocked to find tremendous features like mountain ranges, rifts, and trenches. This work continues on oceanographic research vessels as they sail across the seas today. The map below is a modern map with data from several decades.

The major features of the ocean basins and their colors on the map in **Figure** 5.11 include:

- **mid-ocean ridges**: these features rise up high above the deep seafloor as a long chain of mountains, e.g. the light blue gash in middle of Atlantic Ocean.
- rift zones: in the middle of the mid-ocean ridges is a rift zone that is lower in elevation than the mountains surrounding it.

- deep sea **trenches**: these features are found at the edges of continents or in the sea near chains of active volcanoes, e.g. the very deepest blue, off of western South America.
- **abyssal plains**: these features are flat areas, although many are dotted with volcanic mountains, e.g. consistent blue off of southeastern South America.

See if you can identify each of these features on the map below.

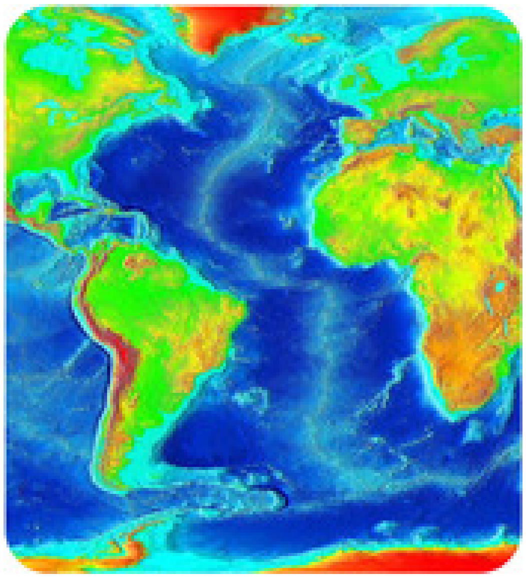


FIGURE 5.11
A modern map of the southeastern Pacific and Atlantic Oceans.

When they first observed these bathymetric maps, scientists wondered what had formed these features. It turns out that they were crucial for fitting together ideas about seafloor spreading.

Continental Margin

As we have seen, the ocean floor is not flat: mid-ocean ridges, deep sea trenches, and other features all rise sharply above or plunge deeply below the abyssal plains. In fact, Earth's tallest mountain is Mauna Kea volcano, which rises 10,203 m (33,476 ft.)meters) from the Pacific Ocean floor to become one of the volcanic mountains of Hawaii. The deepest canyon is also on the ocean floor, the Challenger Deep in the Marianas Trench, 10,916 m (35,814 ft).

The **continental margin** is the transition from the land to the deep sea or, geologically speaking, from continental crust to oceanic crust. More than one-quarter of the ocean basin is continental margin. (**Figure** 5.12).

Vocabulary

- **abyssal plain**: Very flat areas that make up most of the ocean floor.
- **continental margin**: Submerged, outer edge of the continent. It is the transition zone from land to deep sea where continental crust gives way to oceanic crust.
- **mid-ocean ridge**: A large, continuous mountain range found within an ocean basin. It is the location on the seafloor where magma upwells and forms new seafloor.
- **trench**: The deepest parts of the ocean basins.

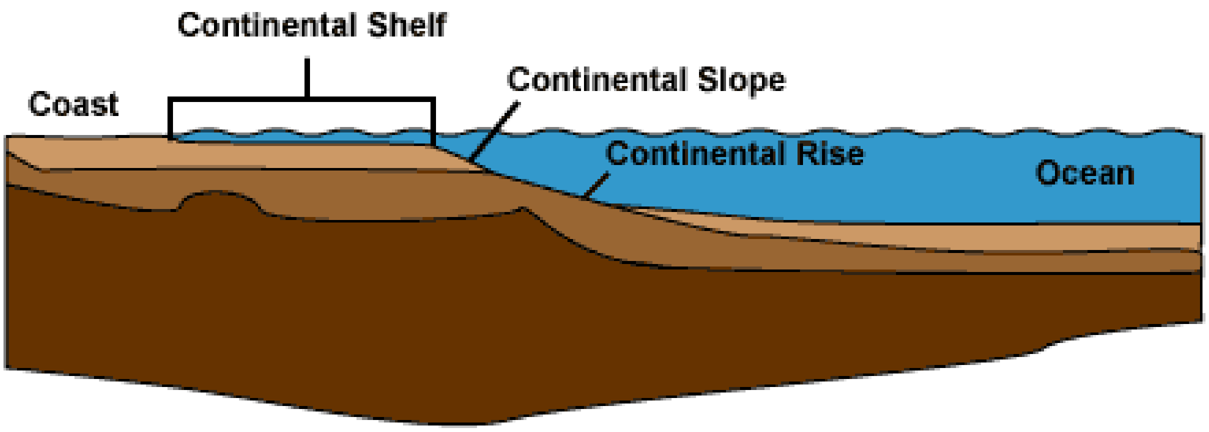


FIGURE 5.12
The continental margin is divided into the continental shelf, continental slope, and continental rise, based on the steepness of the slope.

Summary

- Much of what went into developing plate tectonics theory involved work done at sea.
- Echo sounders used to search for enemy submarines during World War II allowed scientists to piece together bathymetric maps of the seafloor. Multi-beam sounders work on research vessels today.
- These maps revealed amazing features like mid—ocean ridges, deep sea trenches, and abyssal plains.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What did Henry Hess use his sonar for?
2. What did Hess discover?
3. What was discovered in 1953?
4. What did Hess discover was occurring at the ridge?
5. What did Hess call his discovery?
6. What process recycles the crust?

Review

1. How does an echo sounder create a bathymetric map?
2. What are the important features located on the seafloor?
3. What do you think Alfred Wegener would have done with these bathymetric maps had he had access to them?

5.5 Magnetic Evidence for Seafloor Spreading

- Explain how seafloor magnetism and the ages of seafloor rocks provide evidence of seafloor spreading.

What causes the strange stripes on the seafloor?

This pattern of stripes could represent what scientists see on the seafloor. Note that the stripes are symmetrical about the central dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What could cause this? What could it possibly mean?

Seafloor Magnetism

On our transit to the Mid-Atlantic ridge, we tow a magnetometer behind the ship. Shipboard magnetometers reveal the magnetic polarity of the rock beneath them. The practice of towing a magnetometer began during WWII when navy ships towed magnetometers to search for enemy submarines.

When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern.

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.

- Stripes form mirror images on either side of the mid-ocean ridges (**Figure** 5.13).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** 5.14).

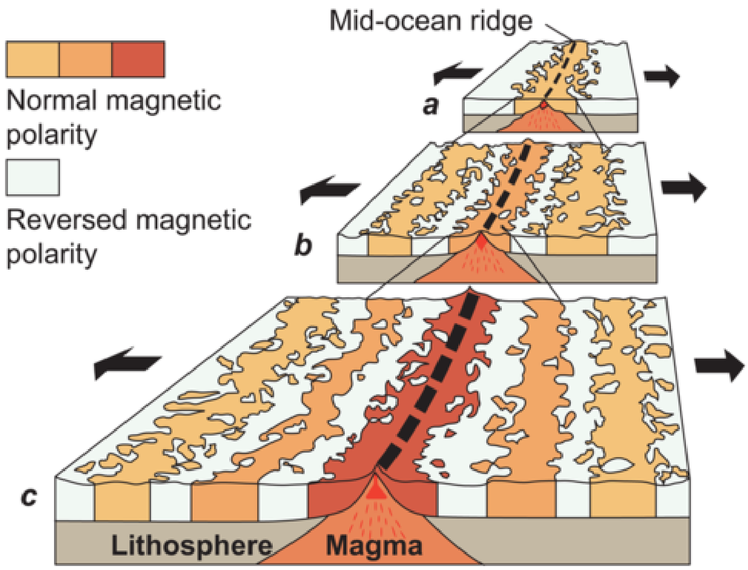


FIGURE 5.13
Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The magnetic stripes are what created the map above. Research cruises today tow magnetometers to add detail to existing magnetic polarity data.

Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with radiometric age dating and fossil ages, scientists came up with a time scale for the magnetic reversals. The first four magnetic periods are:

- Brunhes normal - present to 730,000 years ago.
- Matuyama reverse - 730,000 years ago to 2.48 million years ago.
- Gauss normal - 2.48 to 3.4 million years ago.
- Gilbert reverse – 3.4 to 5.3 million years ago.

The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, abutting continents.

Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in the **Table** 5.1.

TABLE 5.1:

	Rock ages	**Sediment thickness**	**Crust thickness**	**Heat flow**
At ridge axis	youngest	none	thinnest	hottest
With distance from axis	becomes older	becomes thicker	becomes thicker	becomes cooler

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates the warmth of a region, is highest at the ridge crest.

A map of sediment thickness is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sedimentthickness.html.

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (**Figure** 5.14). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

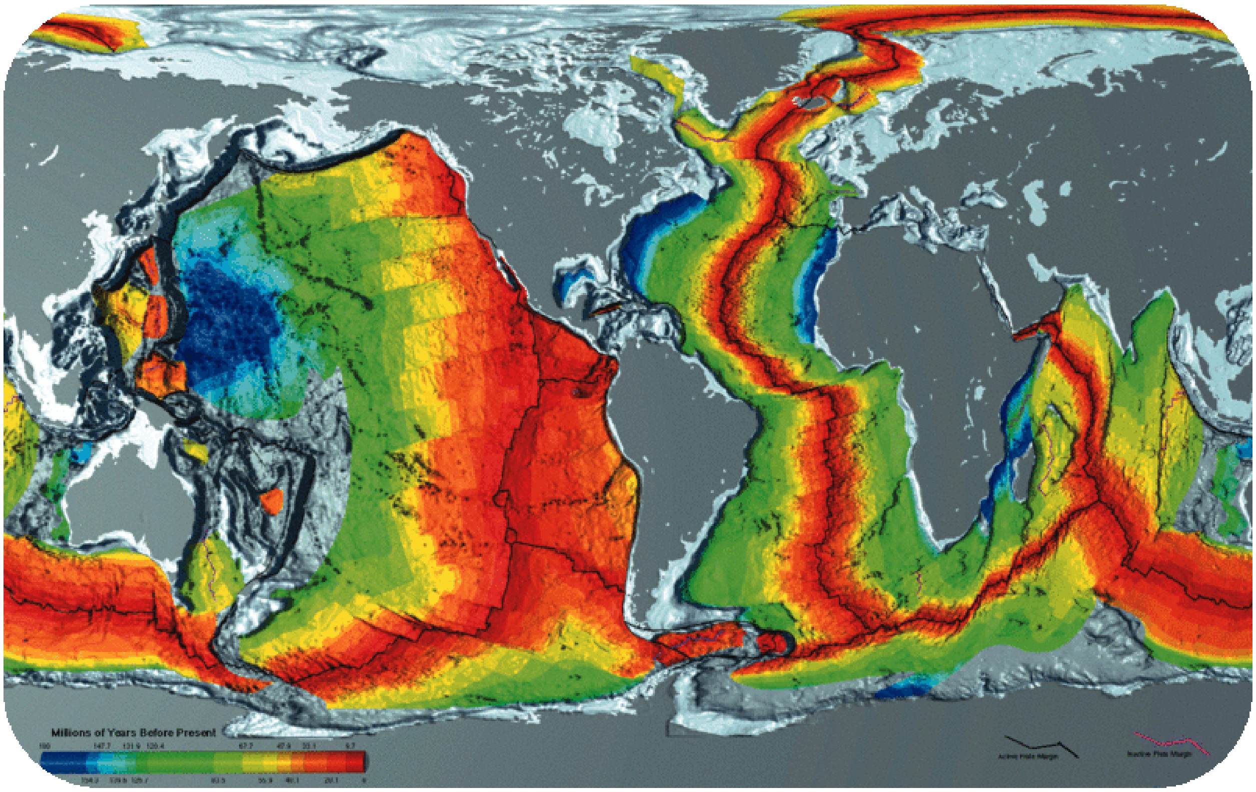


FIGURE 5.14
Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

How can you explain the observations that scientists have made in the oceans? Why is rock younger at the ridge and oldest at the farthest points from the ridge? The scientists suggested that seafloor was being created at the ridge. Since the planet is not getting larger, they suggested that it is destroyed in a relatively short amount of geologic time.

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory": http://online.wr.usgs.gov/calendar/2004/jul04.html.

Summary

- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered amazing magnetic patterns on the seafloor.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.
- The age of seafloor rocks increases from the ridge crest to rocks the farthest from the ridges. Still, the rocks of the ocean basins are much younger than most of the rocks of the continents.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-magnetic-field-reversal.html

MEDIA

Click image to the left for more content.

1. What is the purpose of our magnetic field?
2. Where was Bernard Burnhes doing his research?
3. What did Burnhes discover?
4. Explain what Burnhes concluded from his discovery.
5. How many times has the magnetic field reversed?
6. What seems to be occurring now?

Review

1. Describe the pattern the magnetic stripes make in the ocean floor.
2. How does magnetic polarity reveal the age of a piece of seafloor?
3. What other indications do scientists have regarding the age of the seafloor in various locations?

5.6 Seafloor Spreading Hypothesis

- Define the seafloor spreading hypothesis and describe how seafloor spreading works.

"I shall consider this paper an essay in geopoetry..."

"...In order not to travel any further into the realm of fantasy than is absolutely necessary I shall hold as closely as possibly to a uniformitarian approach. . . " - Harry Hammond Hess, "History of Ocean Basins," 1962

It all came together in the early 1960s. A number of scientists put the evidence together and concluded that mantle convection drove a process they called seafloor spreading. New seafloor was continually being created at mid-ocean ridges. Old seafloor was being destroyed at deep-sea trenches. This was the mechanism that drove continental drift.

An Essay in Geopoetry

Harry Hess was a geology professor and a naval officer who commanded an attack transport ship during WWII. Like other ships, Hess's ship had echo sounders that mapped the seafloor. Hess discovered hundreds of flat-topped mountains in the Pacific that he gave the name **guyot**. He puzzled at what could have formed mountains that appeared to be eroded at the top but were more than a mile beneath the sea surface. Hess also noticed trenches that were as much as 7 miles deep.

Meanwhile, other scientists like Bruce Heezen discovered the underwater mountain range they called the Great Global Rift. Although the rift was mostly in the deep sea, it occasionally came close to land. These scientists thought the rift was a set of breaks in Earth's crust. The final piece that was needed was the work of Vine and Matthews, who had discovered the bands of alternating magnetic polarity in the seafloor symmetrically about the rift.

Seafloor Spreading

The features of the seafloor and the patterns of magnetic polarity symmetrically about the mid-ocean ridges were the pieces that Hess needed. He resurrected Wegener's continental drift hypothesis and also the mantle convection idea of Holmes.

Hess wrote that hot magma rose up into the rift valley at the mid-ocean ridges. The lava oozed up and forced the existing seafloor away from the rift in opposite directions. Since magnetite crystals point in the direction of the magnetic north pole as the lava cools, the different stripes of magnetic polarity revealed the different ages of the seafloor. The seafloor at the ridge is from the Brunhes normal; beyond that is basalt from the Matuyama reverse; and beyond that from the Gauss normal. Hess called this idea **seafloor spreading**.

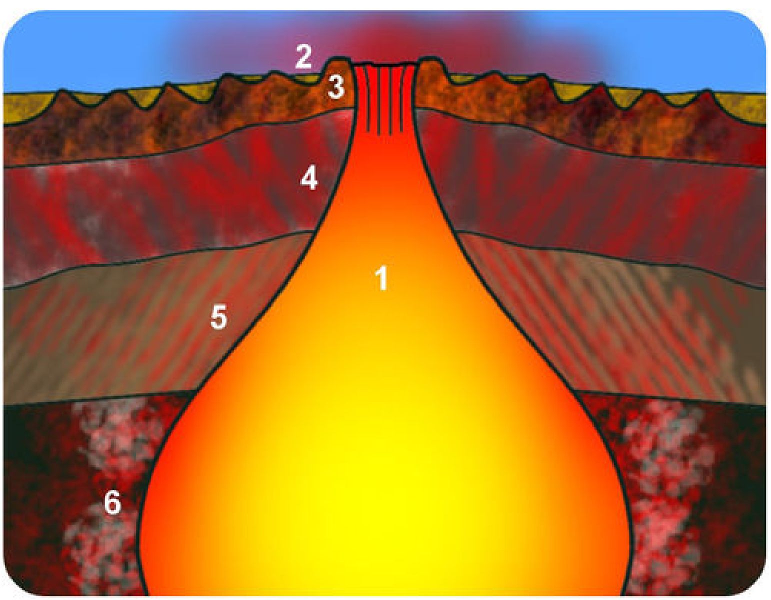


FIGURE 5.15
Magma at the mid-ocean ridge creates new seafloor.

These animations show the creation of magnetic stripes of normal and reversed polarity at a mid-ocean ridge: http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A49.gif and http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A55.gif.

Since new oceanic crust is created at the mid-ocean ridges, either Earth is getting bigger (which it is not) or oceanic crust must be destroyed somewhere. Since the oldest oceanic crust was found at the edges of the trenches, Hess hypothesized that the seafloor subducts into Earth's interior at the trenches to be recycled in the mantle.

- As oceanic crust forms and spreads, moving away from the ridge crest, it pushes the continent away from the ridge axis.
- If the oceanic crust reaches a deep sea trench, it sinks into the trench and is lost into the mantle.

- The oldest crust is coldest and lies deepest in the ocean because it is less buoyant than the hot new crust.

Hess could also use seafloor spreading to explain the flat topped guyots. He suggested that they were once active volcanoes that were exposed to erosion above sea level. As the seafloor they sat on moved away from the ridge, the crust on which they sat become less buoyant and the guyots moved deeper beneath sea level.

The Mechanism for Continental Drift

Seafloor spreading is the mechanism for Wegener's drifting continents. Convection currents within the mantle take the continents on a conveyor-belt ride of oceanic crust that, over millions of years, takes them around the planet's surface. The spreading plate takes along any continent that rides on it.

Seafloor spreading is the topic of this Discovery Education video: http://video.yahoo.com/watch/1595570/5390151.

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video **(3a)**: http://www.youtube.com/watch?v=6CsTTmvX6mc#38;feature=rec-LGOUT-exp_fresh+div-1r-2 (8:05).

MEDIA

Click image to the left for more content.

Vocabulary

- **guyot**: Flat-topped underwater mountain.
- **seafloor spreading**: The mechanism for moving continents. The formation of new seafloor at spreading ridges pushes lithospheric plates on the Earth's surface.

Summary

- Seafloor spreading wedded together the mantle convection idea of Holmes, the continental drift idea of Wegener, new bathymetric and magnetic data from the seafloor, and made a coherent single idea.
- Harry Hess called his idea "an essay in geopoetry," possibly because so many ideas fit together so well, or more likely because at the time he didn't have all the seafloor data he needed for evidence.
- Seafloor spreading is the mechanism for the drifting continents.

Practice

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_seafloorspreading.html

1. Where does seafloor spreading occur?

2. What is the average elevation of the ocean ridges?

3. What are the characteristics of the seafloor near these ridges?

4. Explain why a ridge exists.

5. How fast is the spreading occurring?

Review

1. How does the pattern of magnetic stripes give evidence for seafloor spreading?
2. How does the topography of the seafloor give evidence for seafloor spreading?
3. How does seafloor spreading fit into the idea that continents move about on Earth's surface?

5.7 Earth's Tectonic Plates

- Describe tectonic plates and how they move.

"With such wisdom has nature ordered things in the economy of this world, that the destruction of one continent is not brought about without the renovation of the earth in the production of another." — James Hutton, *Theory of the Earth, with Proofs and Illustrations, Vol. 1*, 1795.

Hutton's quote predates plate tectonics theory by about one-and-a-half centuries, but it seems as if he was talking about divergent and convergent plate boundaries. The next step in understanding the development of plate tectonics theory is to learn what it is that moves around on Earth's surface. It's not really a continent; it's a plate. What is a plate?

What is a Plate?

What portion of Earth makes up the "plates" in plate tectonics? Again, the answer came about in part due to war. In this case, the Cold War.

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's **epicenter**, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other.

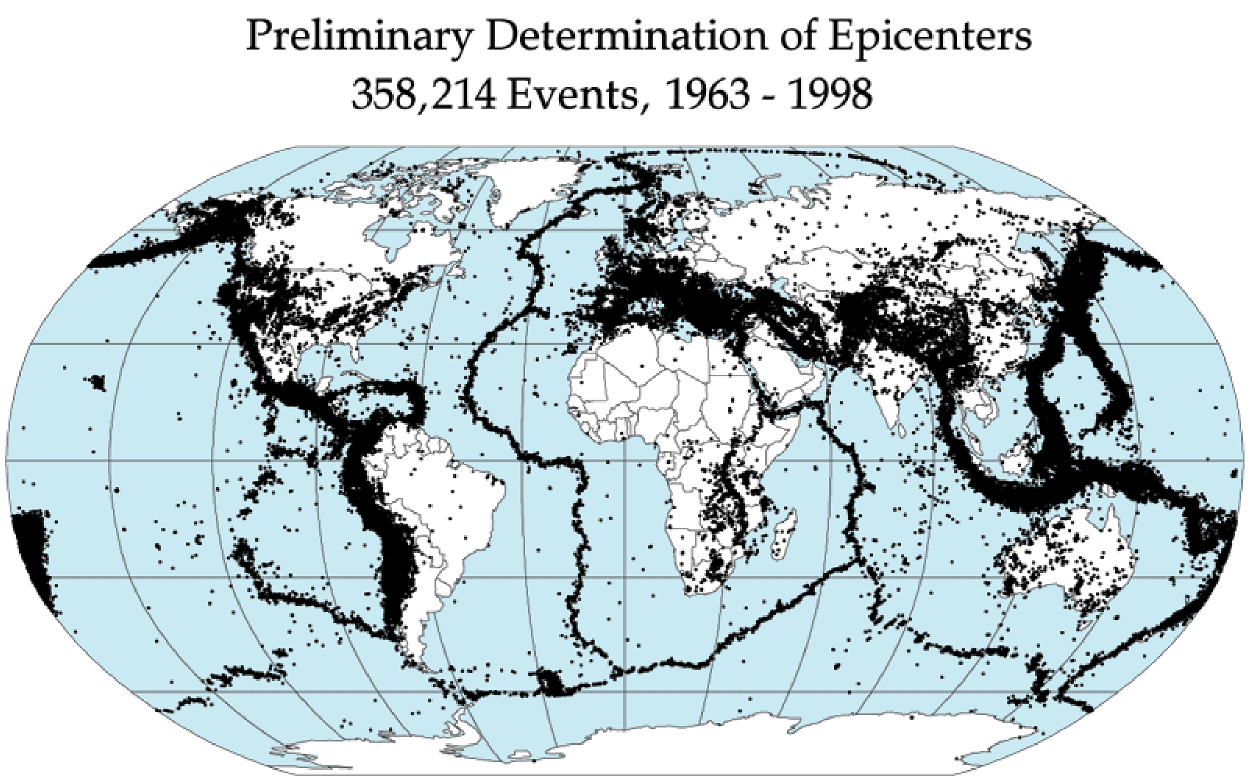


FIGURE 5.16
Earthquakes outline the plates.

The lithosphere is divided into a dozen major and several minor plates (**Figure** 5.18). A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.

The movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading?

This goes back to Arthur Holmes' idea of mantle convection. Picture two convection cells side by side in the mantle, similar to the illustration in **Figure** 5.17.

1. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
2. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
3. The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
4. The material sinks to the core and moves horizontally.
5. The material heats up and reaches the zone where it rises again.

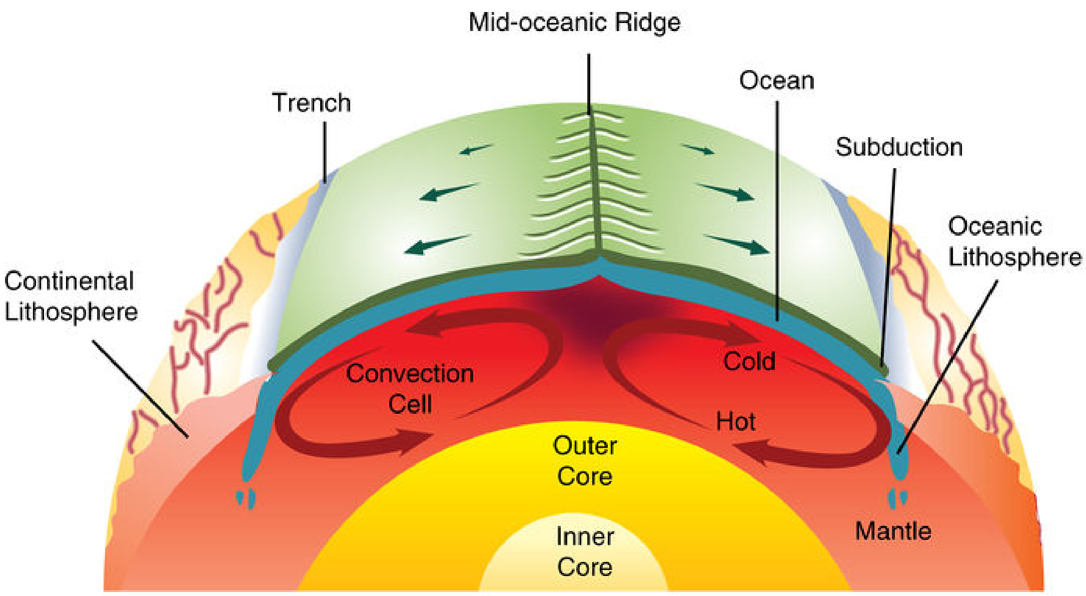


FIGURE 5.17
Mantle convection drives plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4
- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

Plate Boundaries

Plate boundaries are the edges where two plates meet. How can two plates move relative to each other? Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. The features found at these plate boundaries are the mid-ocean ridges, trenches, and large transform faults (**Figure** 5.16).

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

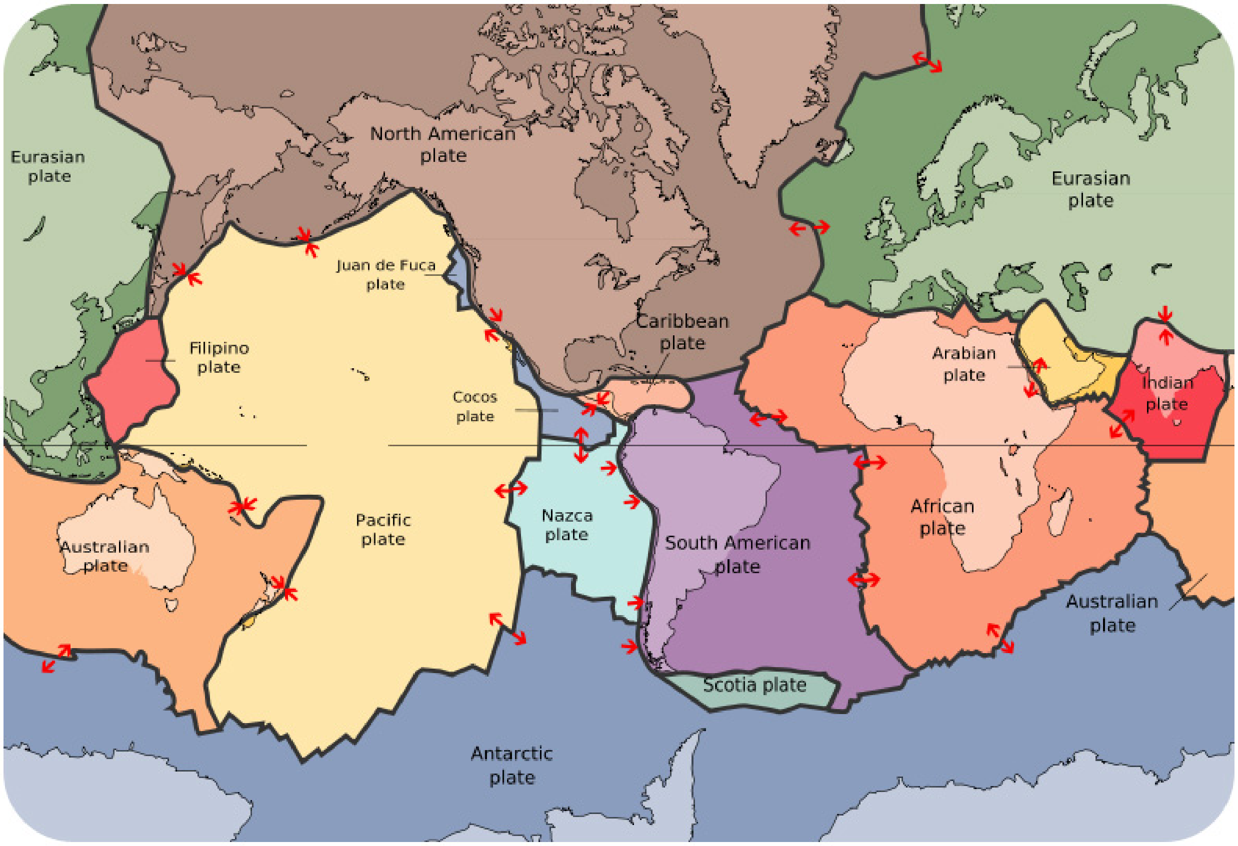


FIGURE 5.18
The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

- **Transform plate boundaries**: the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there. We can visit each of these types of plate boundaries on land or at sea.

Vocabulary

- **convergent plate boundary**: A location where two lithospheric plates come together.
- **divergent plate boundary**: A location where two lithospheric plates spread apart.
- **epicenter**: The point on the Earth's surface directly above the focus of the earthquake.
- **plate**: A slab of Earth's lithosphere that can move around on the planet's surface.
- **plate boundary**: A location where two plates come together.
- **transform plate boundary**: The type of plate boundary where two plates slide past one another.

Summary

- The plate in plate tectonics is a large chunk of lithosphere that can carry continental crust, oceanic crust, or some of each.
- Plates can be identified by the locations of earthquake epicenters. At the boundaries of plates are mid-ocean ridges, trenches, and large faults.
- Plates move by seafloor spreading, which is driven by mantle convection.
- Plates meet at plate boundaries. The three types are divergent, convergent, and transform.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-plate-tectonics.html

1. Which two plates meet in California?
2. What occurs where two plates meet?
3. What is an ocean ridge?
4. What is a strike-slip fault?
5. What occurs at strike-slip faults?
6. What evidence can be seen in California of the movement of the plates?

Review

1. How does the topography of the seafloor give evidence for seafloor spreading?
2. How does seafloor spreading fit into the idea that continents move about on Earth's surface?
3. How do convection cells drive the plates around Earth's surface?
4. What are the three types of plate boundaries?

5.8 Divergent Plate Boundaries in the Oceans

- Describe the activity and features of divergent plate boundaries in the ocean and on land.

How could you walk between two plates?

On a bridge! Let's get off the Atlantis in Iceland. It's good to feel solid ground beneath our feet again! While in Iceland we'll take a walk on Leif the Lucky Bridge. Why did we sail across the ocean for this? Iceland is one place where a mid-ocean ridge is found above sea level.

Plate Divergence in the Ocean

Iceland provides us with a fabulous view of a mid-ocean ridge above sea level (**Figure** 5.19) As you can see, where plates diverge at a mid-ocean ridge is a rift valley that marks the boundary between the two plates. Basalt lava erupts into that rift valley and forms new seafloor. Seafloor on one side of the rift is part of one plate and seafloor on the other side is part of another plate.

Leif the Lucky Bridge straddles the divergent plate boundary. Look back at the photo at the top. You may think that the rock on the left side of the valley looks pretty much like the rock on the right side. That's true – it's all basalt and it even all has the same magnetic polarity. The rocks on both sides are extremely young. What's different is that the rock one side of the bridge is the youngest rock of the North American Plate while the rock on the other side is the youngest rock on the Eurasian plate.

This is a block diagram of a divergent plate boundary. Remember that most of these are on the seafloor and only in Iceland do we get such a good view of a divergent plate boundary in the ocean.

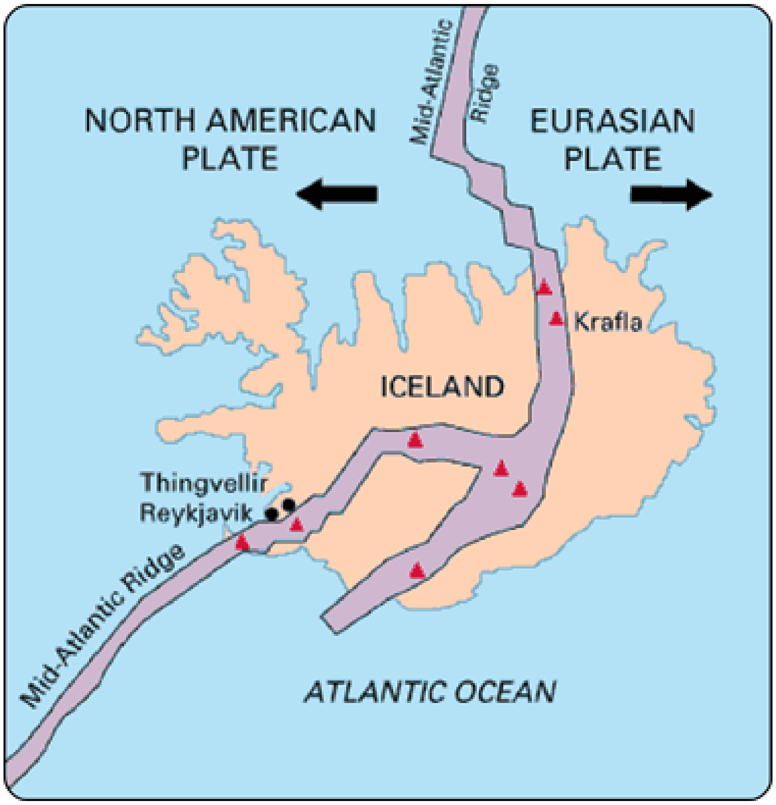


FIGURE 5.19
Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates

Convection Cells at Divergent Plate Boundaries

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking.

USGS animation of divergent plate boundary at mid-ocean ridge: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary#38;flash_file=divergent#38;flash_width=500#38;flash_height=200.

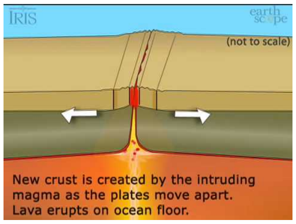
Divergent plate boundary animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov.

Summary

- Oceanic plates diverge at mid-ocean ridges. New seafloor is created in the rift valley between the two plates.
- Lava cools to form basalt at the top of the seafloor. Deeper in the crust the magma cools more slowly to form gabbro.
- Iceland is a location where we can see a mid-ocean ridge above sea level.

Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What causes divergence?
2. How is new crust created?
3. What erupts on the ocean floor?
4. How fast does divergence occur?
5. What is formed at a divergent boundary?

Review

1. What is the direction of plate motion at a divergent plate boundary?
2. Describe the relationship between the convection cell and volcanism at the mid-ocean ridge.
3. Why is the Leif the Lucky bridge so interesting?

5.9 Divergent Plate Boundaries

- Describe the activity and features of divergent plate boundaries on land.

What can we see in Western North America?

When we got off the Atlantis in Iceland a new batch of scientists got on for a different scientific investigation. We're now going to fly to western North America to see a different set of plate tectonic features. Western North America has all three of the different types of plate boundaries and the features that are seen at them.

Tectonic Features of Western North America

We're on a new trip now. We will start in Mexico, in the region surrounding the Gulf of California, where a divergent plate boundary is rifting Baja California and mainland Mexico apart. Then we will move up into California, where plates on both sides of a transform boundary are sliding past each other. Finally we'll end up off of the Pacific Northwest, where a divergent plate boundary is very near a subduction zone just offshore.

In this figure a red bar where seafloor spreading is taking place. A long black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

Plate Divergence on Land

A divergent plate boundary on land rips apart continents.

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.

FIGURE 5.20
This map shows the three major plate boundaries in or near California.

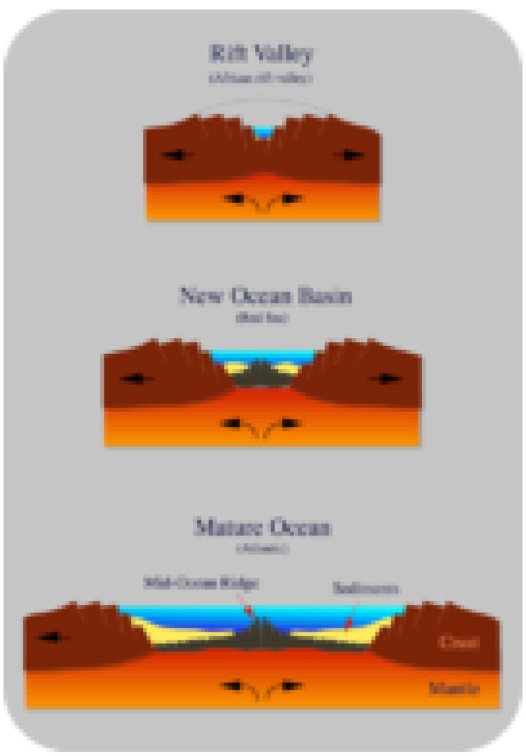


FIGURE 5.21
When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

Baja California

Baja California is a state in Mexico just south of California. In the image 5.22, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland

FIGURE 5.22
Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the image 5.23.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

Vocabulary

- **continental rifting**: A divergent plate boundary that breaks up a continent.

Summary

- Where continental rifting takes place, continents are split apart and an ocean may grow or be created between the two new plates.
- Baja California is rifting apart from mainland Mexico.
- Continental rifting can create major ocean basins, like the Atlantic.

Practice

Use this resource to answer the questions that follow.

http://www.cotf.edu/ete/modules/msese/earthsysflr/plates3.html

1. What are divergent boundaries?

2. What layer is pulled apart?

FIGURE 5.23
Volcanism in Baja California is evidence of rifting.

3. What occurs along the faults on land?
4. What results when the magma reaches the surface?
5. List examples of rift valleys on land.

Review

1. How is a divergent plate boundary on land different from one in the ocean?
2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

5.10 Transform Plate Boundaries

- Describe the activity and features of transform plate boundaries on land and in the ocean.

What could cause such an enormous scar on the land?

A transform plate boundary! As we continue up the West Coast, we move from a divergent plate boundary to a transform plate boundary. As in Iceland, where we could walk across a short bridge connecting two continental plates, we could walk from the Pacific Plate to the North American plate across this transform plate boundary. In this image, the San Andreas Fault across central California is the gash that indicates the plate boundary.

Transform Plate Boundaries

With transform plate boundaries, the two slabs of lithosphere are sliding past each other in opposite directions. The boundary between the two plates is a **transform fault**.

Transform Faults On Land

Transform faults on continents separate two massive plates of lithosphere. As they slide past each other, they may have massive earthquakes.

The San Andreas Fault in California is perhaps the world's most famous transform fault. Land on the west side is moving northward relative to land on the east side. This means that Los Angeles is moving northward relative to Palm Springs. The San Andreas Fault is famous because it is the site of many earthquakes, large and small. (**Figure** 5.24).

Transform plate boundaries are also found in the oceans. They divide mid-ocean ridges into segments. In the diagram of western North America, the mid-ocean ridge up at the top, labeled the Juan de Fuca Ridge, is broken

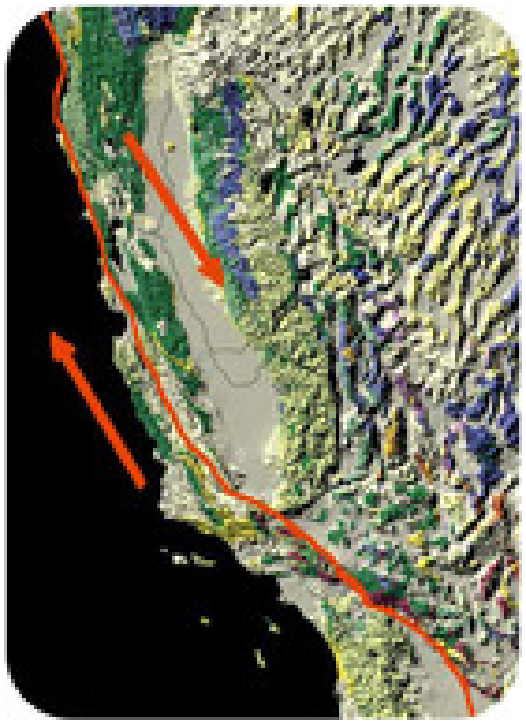


FIGURE 5.24
At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. At the northern end of the picture, the transform boundary turns into a subduction zone.

apart by a transform fault in the oceans. A careful look will show that different plates are found on each side of the ridge: the Juan de Fuca plate on the east side and the Pacific Plate on the west side.

Vocabulary

- **transform fault**: An earthquake fault; one plate slides past another.

Summary

- A transform plate boundary divides two plates that are moving in opposite direction from each other.
- On land, transform faults are the site of massive earthquakes because they are where large slabs of lithosphere slide past each other.
- Transform faults in the oceans break mid-ocean ridges into segments.

Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/slip3.html

1. Describe the motion of transform boundaries.

2. What is a fault?

3. What do transform boundaries produce?

4. Explain a strike-slip fault.

5. What is the best studied fault?

6. What two plates make this boundary?
7. Which direction are each of these plates moving?

Review

1. What is the direction of plate motion at a transform plate boundary?
2. Why are transform faults on continents prone to massive earthquakes?
3. How do transform faults in the oceans compare with those on land?

5.11 Ocean-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where an oceanic plate meets a continental plate.

What do you see at an ocean-continent convergent boundary?

We continue our field trip up the West Coast. Just offshore from Washington, Oregon, and Northern California is a subduction zone, where the Juan de Fuca Plate is sinking into the mantle. The Juan de Fuca Plate is being created at a spreading center, the Juan de Fuca Ridge. Let's see the results of subduction of the Juan de Fuca Plate.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. The three possibilities are oceanic crust to oceanic crust, oceanic crust to continental crust, or continental crust to continental crust. If at least one of the slabs of lithosphere is oceanic, that oceanic plate will plunge into the trench and back into the mantle. The meeting of two enormous slabs of lithosphere and subduction of one results in magma generation and earthquakes. If both plates meet with continental crust, there will be mountain building. Each of the three possibilities is discussed in a different lesson.

In this lesson we look at subduction of an oceanic plate beneath a continental plate in the Pacific Northwest.

Ocean-Continent Convergence

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches. The entire region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (**Figure ??**). The volcanoes are known as a **continental arc**.

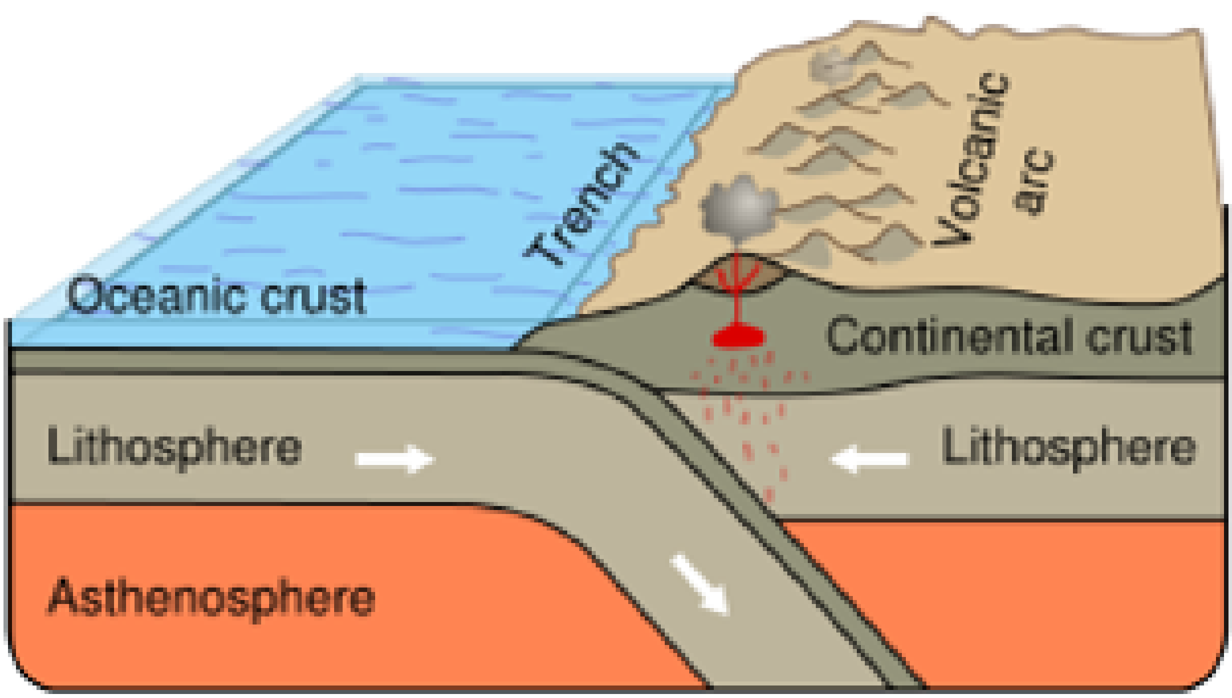


FIGURE 5.25

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

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html.

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc: http://e arthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html.

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Cascades Volcanoes

The volcanoes of northeastern California — Lassen Peak, Mount Shasta, and Medicine Lake volcano — along with the rest of the Cascade Mountains of the Pacific Northwest, are the result of subduction of the Juan de Fuca plate beneath the North American plate (**Figure** 5.26). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

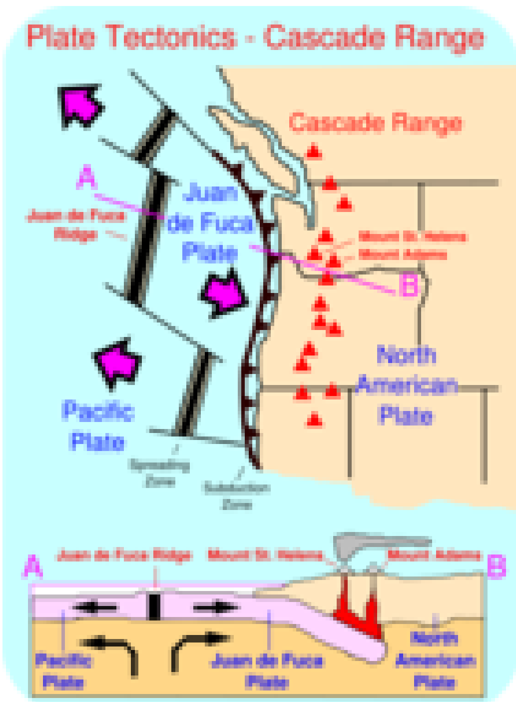


FIGURE 5.26
The Cascade Mountains of the Pacific Northwest are a continental arc.

Intrusions at a Convergent Boundary

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range. California has an ancient set of batholiths that make up the Sierra Nevada mountains (**Figure** 5.27).

An animation of an ocean continent plate boundary is seen here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov.

Vocabulary

- **batholith**: An enormous body of igneous intrusive rock, usually granitic.

FIGURE 5.27
The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

- **continental arc**: A line of volcanoes on a continent resulting from subduction beneath the continent.
- **subduction**: The sinking of one lithospheric plate beneath another.
- **subduction zone**: The area where two lithospheric plates come together and one sinks beneath the other.

Summary

- When two plates come towards each other they create a convergent plate boundary.
- The plates can meet where both have oceanic crust or both have continental crust, or they can meet where one has oceanic and one has continental.
- Dense oceanic crust will subduct beneath continental crust or a less dense slab of oceanic crust.
- The oceanic plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.
- If the magma is too viscous to rise to the surface it will become stuck in the crust to create intrusive igneous rocks.

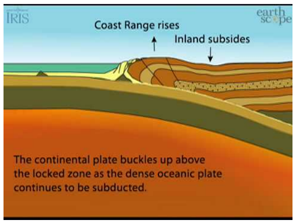
Practice

Use these resources to answer the questions that follow.

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. Describe a subduction zone.

2. What forms this subduction zone?
3. How far does the subducting oceanic plate descend?
4. What is formed on the continental plate?
5. Where can an example of this plate boundary be found?



MEDIA
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6. What is a locked zone?
7. What is produced when the locked zone is released?

Review

1. What is the direction of plate motion at a convergent plate boundary?
2. Describe the relationship between the convection cell and subduction at a trench.
3. Subduction is sometimes called crustal recycling. Why do you think this is the case?
4. What happens if magma is too viscous to rise through the crust to erupt at the surface?

5.12 Ocean-Ocean Convergent Plate Boundaries

- Learn the activity and features of convergent plate boundaries where one oceanic plate subducts beneath another oceanic plate.

What do you see in this satellite photo?

We continue our trip up western North America to find a convergent plate boundary where oceanic crust subducts beneath oceanic crust. North of the contiguous U.S. lies Canada, and north of Canada lies Alaska. A line of volcanoes, known as the Aleutian Islands, is the result of ocean-ocean convergence. In this satellite image is an erupting volcano, topped by snow or ice, and surrounded by seawater - a member of the Aleutian chain. Let's take a look at this boundary and the volcanic arc.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. We explored what happens when oceanic crust meets continental crust. Another type of convergent plate boundary is found where two oceanic plates meet. In this case the older, denser slab of oceanic crust will plunge beneath the less dense one.

Ocean-Ocean

The features of a subduction zone where an oceanic plate subducts beneath another oceanic plate are the same as a continent-ocean subduction zone. An ocean trench marks the location where the plate is pushed down into the mantle. In this case, the line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (**Figure** 5.28)?

In the north Pacific, the Pacific Plate is subducting beneath the North American Plate just as it was off of the coast of the Pacific Northwest. The difference is that here the North American plate is covered with oceanic crust. Remember

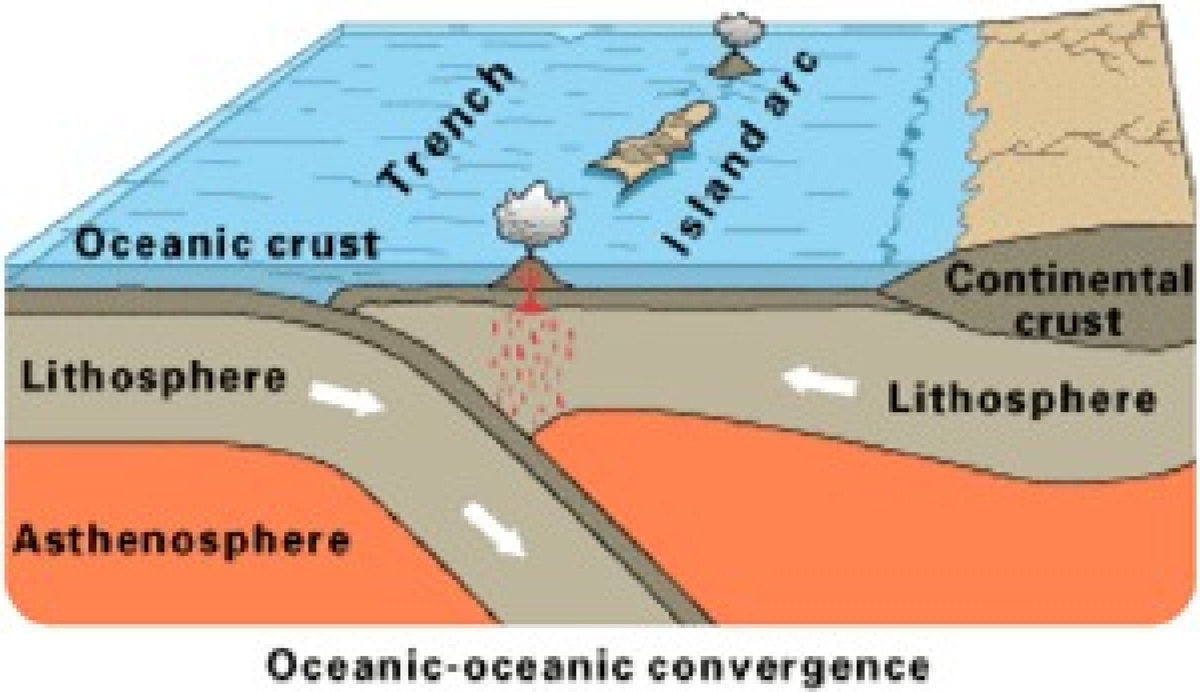


FIGURE 5.28
Subduction of an ocean plate beneath other oceanic crust results in a volcanic island arc, an ocean trench, and many earthquakes

that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active. Airplanes sometimes must avoid flying over these volcanoes for fear of being caught in an eruption.

Vocabulary

- **island arc**: A line of ocean island volcanoes resulting from subduction beneath oceanic lithosphere.

Summary

- If the two plates that meet at a convergent plate boundary both are of oceanic crust, the older, denser plate will subduct beneath the less dense plate.
- The features of an ocean-ocean subduction zone are the same as those of an ocean-continent subduction zone, except that the volcanic arc will be a set of islands known as an island arc.
- The older plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.

Practice

Use this resource to answer the questions that follow.

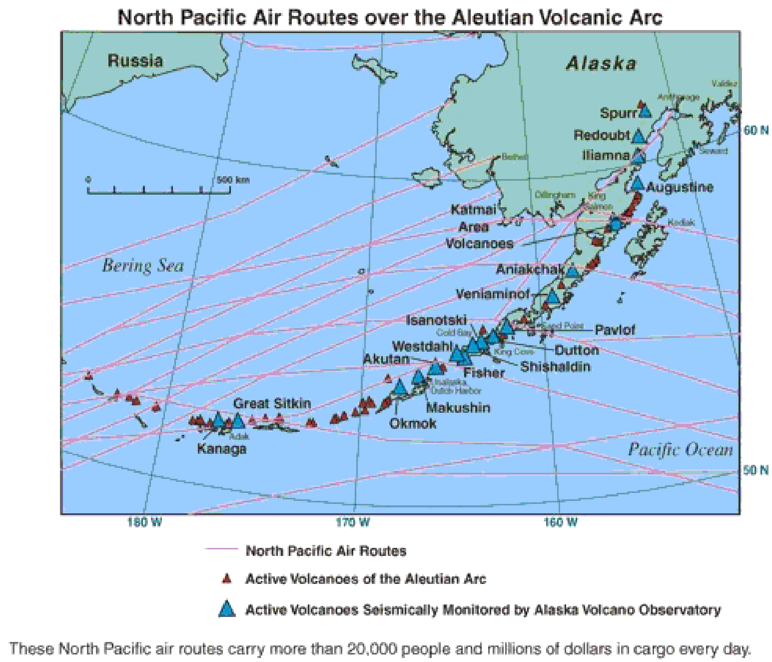


FIGURE 5.29
The arc of the island arc that is the Aleutian Islands is easily seen in this map of North Pacific air routes over the region.

http://science7.com/ES-PlateTect-PlateMove.htm

1. What forms where two oceanic plates converge?
2. Explain how an island volcano forms.
3. What is an island arc?
4. Give two examples of island arcs.
5. How is magma produced?

Review

1. Compare and contrast the features of an ocean-ocean convergent plate boundary with the features of an ocean-continent convergent plate boundary.
2. How do the Aleutian volcanoes differ from the Cascades volcanoes?
3. How do island arcs get their name?

5.13 Continent-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where two continental plates come together.

What do you see at a continent-continent convergent plate boundary?

Nowhere along the west coast of North America is there a convergent plate boundary of this type at this time. Why are there no continent-continent convergent boundaries in western North America? The best place to see two continental plates converging is in the Himalaya Mountains, the mountains that are the highest above sea level on Earth.

Continent-Continent Convergence

Continental plates are too buoyant to subduct. What happens to continental material when it collides? It has nowhere to go but up!

Continent-continent convergence creates some of the world's largest mountains ranges. Magma cannot penetrate this thick crust, so there are no volcanoes, although the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

A short animation of the Indian Plate colliding with the Eurasian Plate: http://www.scotese.com/indianim.htm.

An animation of the Himalayas rising: http://www.youtube.com/watch?v=ep2_axAA9Mw#38;NR=1.

The Appalachian Mountains along the eastern United States are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago. This was part of the formation of Pangaea.

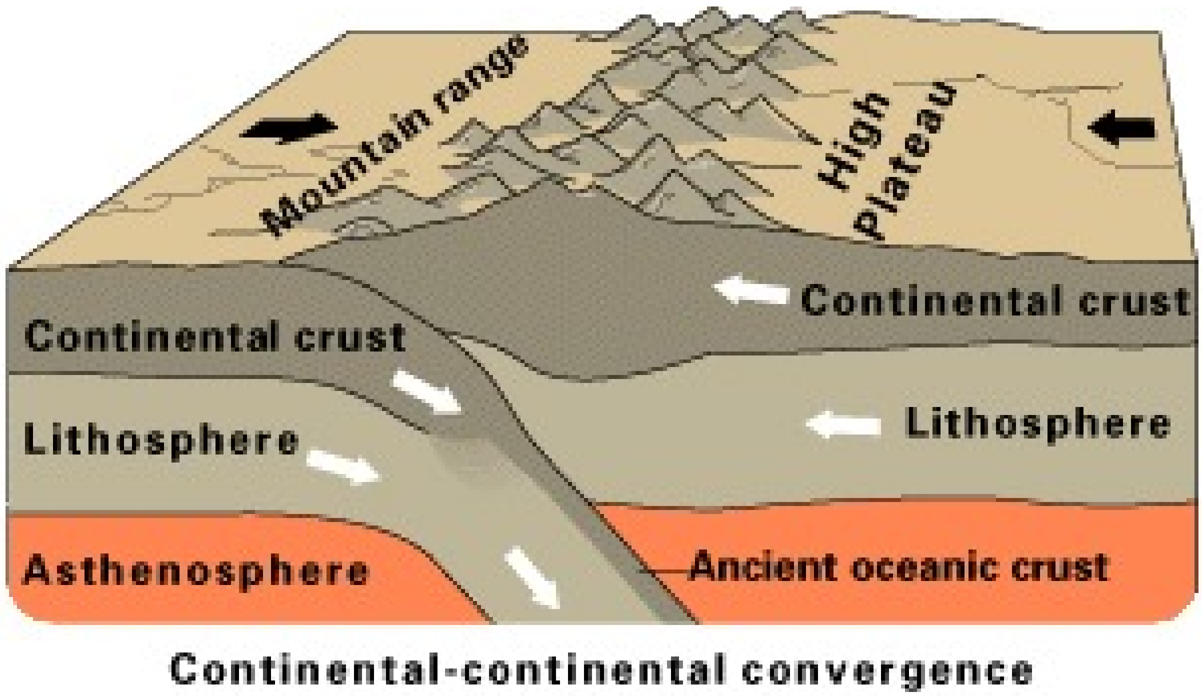


FIGURE 5.30
A diagram of two sections of continental crust converging.

Summary

- Continental crust is too buoyant to subduct. If the two plates that meet at a convergent plate boundary both consist of continental crust, they will smash together and push upwards to create mountains.
- Large slabs of lithosphere smashing together create large earthquakes.
- The activity at continent-continent convergences does not take place in the mantle, so there is no melting and therefore no volcanism.
- The amazing Himalaya Mountains are the result of this type of convergent plate boundary.
- Old mountain ranges, such as the Appalachian Mountains, resulted from ancient convergence when Pangaea came together.

Practice

Use these resources to answer the questions that follow.

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. What happens when two continental plates converge?

2. What is the result of this convergence?

http://pubs.usgs.gov/gip/dynamic/himalaya.html

3. Where are the Himalaya Mountains?

4. When were the Himalayas formed?

5. When did India ram into Asia?

6. How fast are the Himalayas rising?

Review

1. Compare and contrast the features of a continent-continent convergent plate boundary with the features of an ocean-continent convergent plate boundary.

2. What causes mountain ranges to rise in this type of plate boundary?

3. Why are there earthquakes but not volcanoes in this type of plate boundary?

5.14 Plate Tectonics through Earth History

- Explain the relationship between plate tectonics theory and the existence of supercontinents such as Pangaea.

That map is sort of familiar, but what is it?

Wegener's persistent search for evidence that the continents had been joined paid off. Scientists who came after him developed an understanding of seafloor spreading, which was the mechanism for Wegener's continental drift. Geologists know that Wegener was right because the movements of continents explain so much about the geological activity we see.

The existence of Wegener's supercontinent Pangaea is completely accepted by geologists today. But did it all begin with Pangaea? Or were there other supercontinents that came before?

Plate Tectonics Theory

First, let's review plate tectonics theory. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.
- some places are prone to earthquakes while others are not.

- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and fossil species are found where they are.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Supercontinent Cycle

Remember that Wegener used the similarity of the mountains on the west and east sides of the Atlantic as evidence for his continental drift hypothesis. Those mountains rose at the convergent plate boundaries where the continents were smashing together to create Pangaea. As Pangaea came together about 300 million years ago, the continents were separated by an ocean where the Atlantic is now. The proto-Atlantic ocean shrank as the Pacific Ocean grew.

The Appalachian mountains of eastern North America formed at a convergent plate boundary as Pangaea came together (**Figure ??**). About 200 million years ago, the they were probably as high as the Himalayas, but they have been weathered and eroded significantly since the breakup of Pangaea.

FIGURE 5.31
The Appalachian Mountains in New Hampshire.

Pangaea has been breaking apart since about 250 million years ago. Divergent plate boundaries formed within the continents to cause them to rift apart. The continents are still moving apart, since the Pacific is shrinking as the Atlantic is growing. If the continents continue in their current directions, they will come together to create a supercontinent on the other side of the planet in around 200 million years.

If you go back before Pangaea there were earlier supercontinents, such as Rodinia, which existed 750 million to 1.1 billion years ago, and Columbia, at 1.5 to 1.8 billion years ago. This **supercontinent cycle** is responsible for most of the geologic features that we see and many more that are long gone (**Figure** 5.32).

This animation shows the movement of continents over the past 600 million years, beginning with the breakup of Rodinia: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html.

Vocabulary

- **supercontinent cycle**: The cycle in which the continents join into one supercontinent and then move apart to

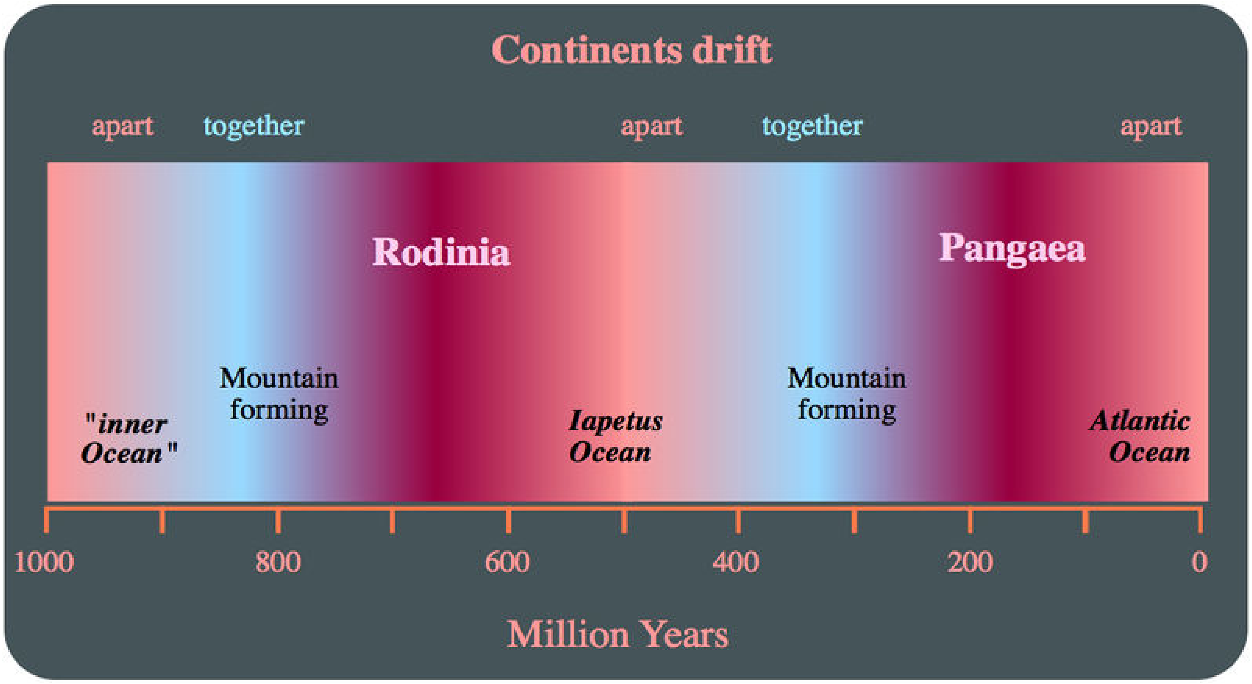


FIGURE 5.32
Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years. The supercontinent before Pangaea was Rodinia. A new continent will form as the Pacific ocean disappears.

join together at the other side of the planet as another supercontinent.

Summary

- Pangaea came together as a set of continent-continent convergent plate boundaries.
- Pangaea is still breaking up as the continents move apart. The Atlantic Ocean is getting bigger and the Pacific Ocean is getting smaller.
- Pangaea was not the first supercontinent and it won't be the last. The continents come together and break apart about every 500 million years in a process called the supercontinent (or Wilson) cycle.

Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/drift.html

1. What did Alfred Wegener notice?
2. What did he discover from his research?
3. What did he call the original supercontinent?
4. What happened 200 million years ago?
5. What landmasses split up 135 million years ago?

6. List the events that occurred 65 million years ago.
7. When did Greenland separate from North America?
8. Explain the plate tectonics theory.

Review

1. Describe the plate tectonics processes that brought Pangaea together.
2. Describe the plate tectonics processes that split Pangaea up.
3. Why do scientists think that there will be another supercontinent in the future?

5.15 Intraplate Activity

- Describe and explain volcanic activity that occurs within oceanic and continental plates.

What would you think if you heard that all geological activity does NOT take place at plate boundaries?

These photos of fabulous geological activity are going to rock your world. Why? After all of these lessons in which you learned that volcanoes and earthquakes are located around plate boundaries, this last lesson in "Concept Plate Tectonics" doesn't quite fit. These volcanoes are located away from plate boundaries. Two such locations are Hawaii and Yellowstone. Yellowstone is in the western U.S. and Hawaii is in the central Pacific.

Intraplate Activity

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. The release of pressure causes melting near the surface to form a **hotspot**. Eruptions at the hotspot create a volcano.

Hotspot volcanoes are found in a line (**Figure** 5.33). Can you figure out why? *Hint*: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot.

An animation of the creation of a hotspot chain is seen here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/

p_hawaii.html.

Intraplate Activity in the Oceans

The first photo above is of a volcanic eruption in Hawaii. Hawaii is not in western North America, but is in the central Pacific ocean, near the middle of the Pacific Plate.

The Hawaiian Islands are a beautiful example of a hotspot chain in the Pacific Ocean. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a slower rate. The islands get progressively older to the northwest because they are further from the hotspot. This is because the Pacific Plate is moving toward the northwest over the hotspot. Loihi, the youngest volcano, is still below the sea surface.

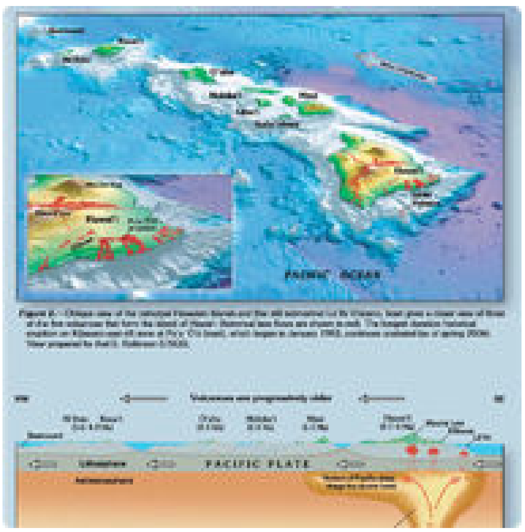


FIGURE 5.33
The Hawaiian Islands have formed from volcanic eruptions above the Hawaii hotspot.

Since many hotspots are stationary in the mantle, geologists can use some hotspot chains to tell the direction and the speed a plate is moving (**Figure** 5.34). The Hawaiian chain continues into the Emperor Seamounts. The bend in the chain was caused by a change in the direction of the Pacific Plate 43 million years ago. Using the age and distance of the bend, geologists can figure out the speed of the Pacific Plate over the hotspot.

Intraplate Activity on the Continents

The second photo in the introduction is of a geyser at Yellowstone National Park in Wyoming. Yellowstone is in the western U.S. but is inland from the plate boundaries offshore.

Hotspot magmas rarely penetrate through thick continental crust, so hotspot activity on continents is rare. One exception is the Yellowstone hotspot (**Figure** 5.35). Volcanic activity above the Yellowstone hotspot on can be traced from 15 million years ago to its present location on the North American Plate.

Vocabulary

- **hotspot**: A plume of hot material that rises through the mantle and can cause volcanoes.
- **intraplate activity**: Geologic activity that takes place away from plate boundaries.

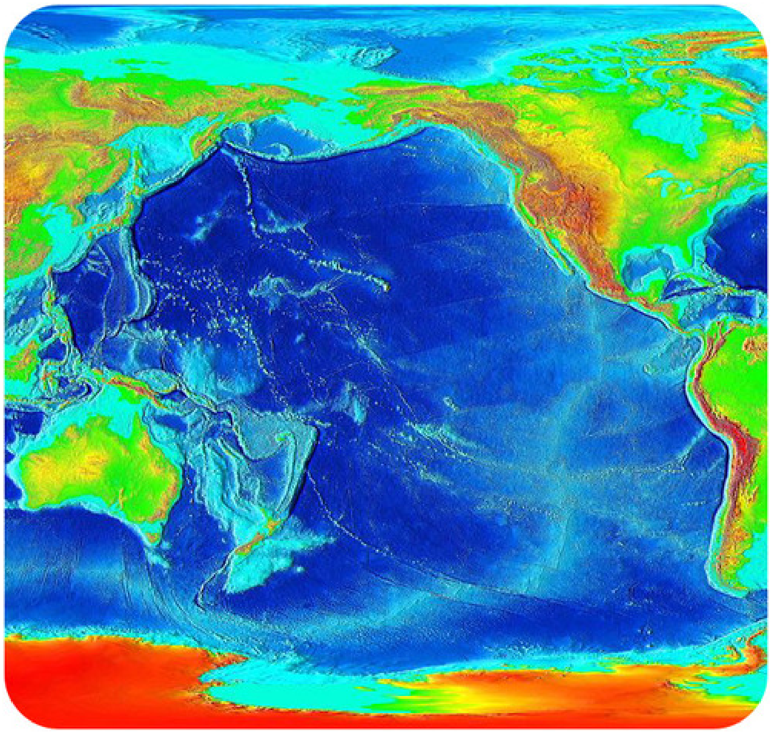


FIGURE 5.34
The Hawaiian-Emperor chain can be traced from Hawaii in the central Pacific north of the equator into the Aleutian trench, where the oldest of the volcanoes is being subducted. It looks like a skewed "L".

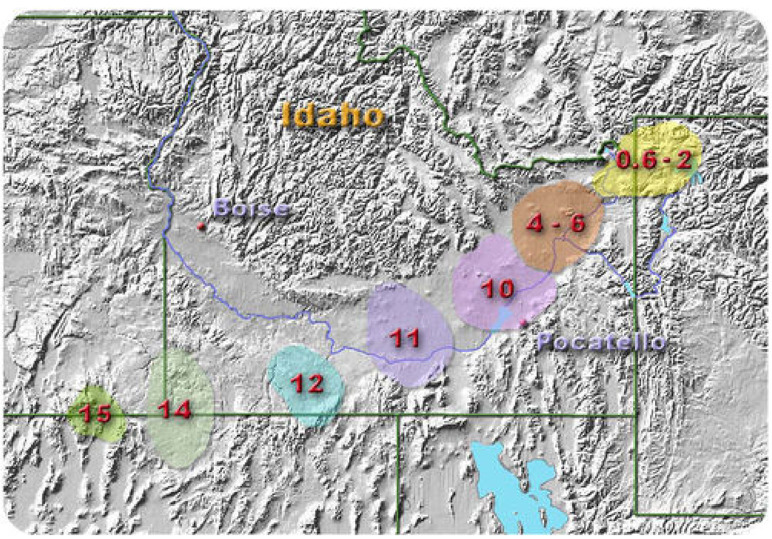


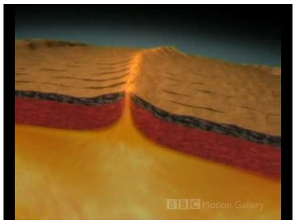
FIGURE 5.35
The ages of volcanic activity attributed to the Yellowstone hotspot.

Summary

- Not all geological activity is found at plate boundaries. Some volcanic activity, with accompanying earthquakes, is located within a plate. This is called intraplate activity.
- Intraplate activity occurs above mantle plumes that cause melting at a hotspot.
- Hotspots erupt mostly on oceanic crust. Hawaii is an example. A few hotspots, like Yellowstone, erupt on continental crust. The difference is due to the thickness of the crust.
- Hotspots can be used to tell the speed and direction that a plate is moving, since the hotspots are stationary within the mantle.

Practice

Use these resources to answer the questions that follow.



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1. Where is Iceland located?
2. What causes the mantle to be forced up?
3. What does a constructive plate boundary form?
4. Where are most volcanoes found?
5. What are hotspots?
6. How do hotspots form volcanoes?
7. Where can a hotspot be seen today?

http://www.nps.gov/yell/naturescience/tracking_hotspot.htm

8. What direction is the North American Plate moving? How fast is it moving?
9. When did the McDermmit Volcanic Field erupt?
10. What was the most recent eruption of this hotspot? Where?

Review

1. What is a mantle plume and how is it related to a hotspot?
2. How do scientists use hotspot volcanism to tell the direction and speed of a plate?
3. Why are hotspot volcanoes much more common in the oceans than on continents?

Summary

In the early 20th century, Alfred Wegener was the first persistent scientist to propose the idea that continents move around on Earth's surface. The meteorologist amassed a tremendous amount of evidence but could not think of a mechanism that others would accept to explain how solid continents could plow through ocean basins. Wegener's idea was abandoned. His continental drift idea was resurrected after World War II when scientists started to put together data about the seafloor. The astonishing features of the seafloor, the strange pattern of rock ages across the seafloor, and the history of the magnetic north pole on land, gave scientists in the early 1960s a great deal to mull over. From this work Harold Hess propose seafloor spreading as a mechanism for drifting continents. The resulting theory of plate tectonics is the explanation of what happens as plates of Earth's lithosphere interact at different types of plate boundaries.

5.16 References

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CHAPTER 6 Geological Activity from Plate Tectonics Processes

Chapter Outline

Introduction

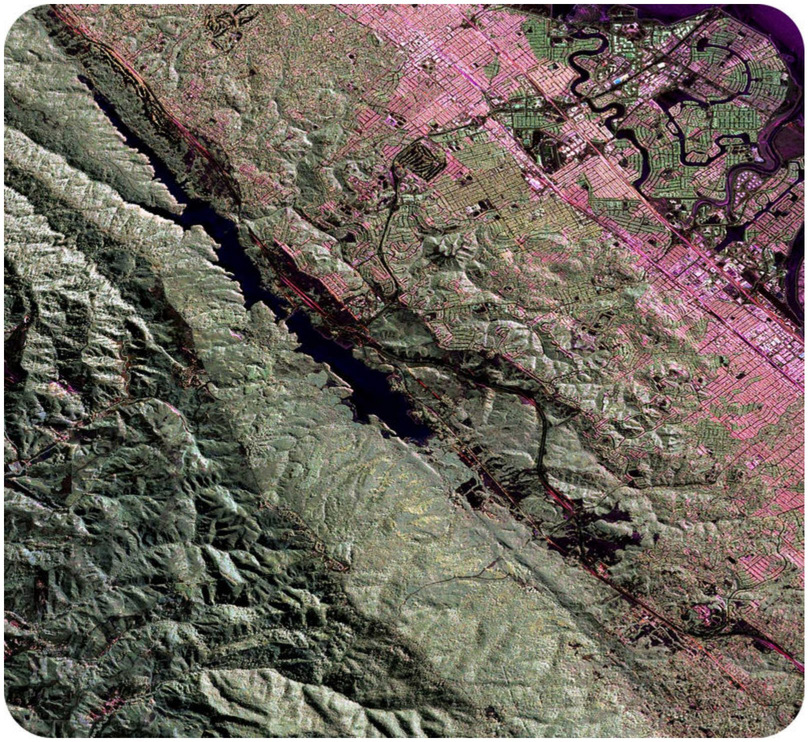


Plate tectonics = natural disasters - weather disasters

So many natural disasters occur because of plate tectonics processes. By using what we know about plate tectonics we can understand where most earthquakes and volcanic eruptions will strike. We can know where to look for many types of mineral deposits.

The scar in this satellite image is of the San Andreas Fault as it runs through the San Francisco Bay Area. The fault is seen from the upper left to the lower right of this image. The fault forms a trough that is filled with water at Crystal Springs Reservoir. The development in pink and green is San Mateo and Burlingame. Foster City, which is built on fill, has curved streets extending into the bay. Scientists will use space-based radar along this same flight path over the next years to look for changes in the ground surface along the fault.

6.1 Geological Stresses

- Define the types of geological stress and describe their affect on various types of rock under a range of conditions.

When people have too much stress they may break. What happens if a rock gets too much stress?

With all the movement occurring on Earth's surface — slabs of crust smashing into each other, sideways movements along faults, magma rising through solid rock — it's no wonder that rocks experience stress. Rocks respond differently to different types of stress and under different conditions.

Causes and Types of Stress

Stress is the force applied to an object. In geology, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform. This is called **confining stress.**
- **Compression** squeezes rocks together, causing rocks to fold or fracture (break) (**Figure** 6.1). Compression is the most common stress at convergent plate boundaries.

FIGURE 6.1
Stress caused these rocks to fracture.

- Rocks that are pulled apart are under **tension**. Rocks under tension lengthen or break apart. Tension is the major type of stress at divergent plate boundaries.
- When forces are parallel but moving in opposite directions, the stress is called **shear** (**Figure** 6.2). Shear stress is the most common stress at transform plate boundaries.

When stress causes a material to change shape, it has undergone **strain** or **deformation**. Deformed rocks are common in geologically active areas.

A rock's response to stress depends on the rock type, the surrounding temperature, the pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

Responses to Stress

Rocks have three possible responses to increasing stress (illustrated in **Figure** 6.3):

- **elastic deformation**: the rock returns to its original shape when the stress is removed.
- **plastic deformation**: the rock does not return to its original shape when the stress is removed.
- **fracture**: the rock breaks.

Under what conditions do you think a rock is more likely to fracture? Is it more likely to break deep within Earth's crust or at the surface? What if the stress applied is sharp rather than gradual?

- At the Earth's surface, rocks usually break quite quickly, but deeper in the crust, where temperatures and pressures are higher, rocks are more likely to deform plastically.
- Sudden stress, such as a hit with a hammer, is more likely to make a rock break. Stress applied over time often leads to plastic deformation.

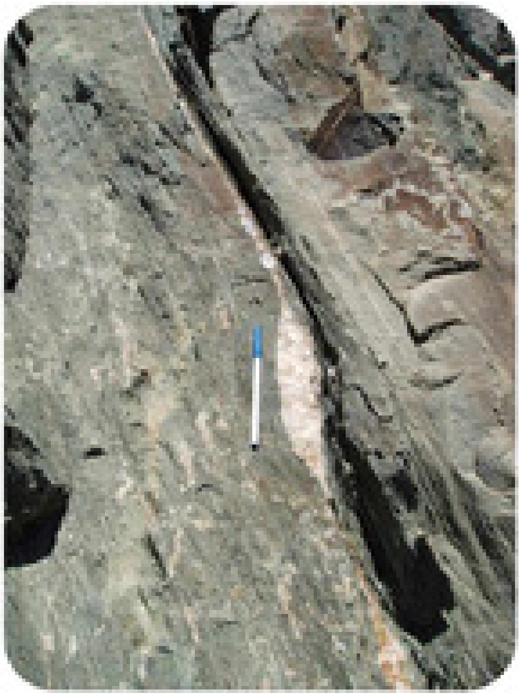


FIGURE 6.2
Shearing in rocks. The white quartz vein has been elongated by shear.

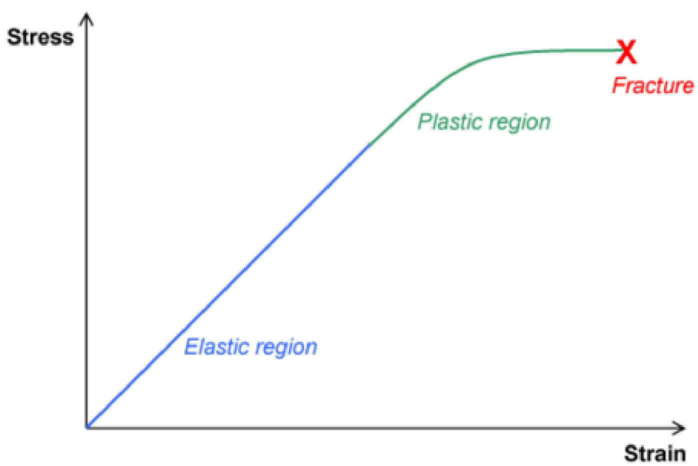


FIGURE 6.3
With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

Vocabulary

- **compression**: Stresses that push toward each other, causing a decrease in the space a rock takes up.
- **confining stress**: Stress from the weight of material above a buried object; reduces volume.
- **deformation**: Strain. The change of shape that a rock undergoes whe it has been altered by stresses.
- **elastic deformation**: Strain that alters the shape of a rock but that is not permanent.
- **fracture**: A break in rock caused by stresses, with or without movement of material.
- **plastic deformation**: Strain in which the rock deforms but does not return to its original shape when the strain is removed.
- **shear**: Parallel stresses that move past each other in opposite directions.

- **strain**: Deformation in a rock because of a stress that exceeds the rock's internal strength.
- **stress**: Force per unit area in a rock.
- **tension**: Stresses that pull material in opposite directions.

Summary

- Stress is the force applied to an object. Stresses can be confining, compression, tension, or shear.
- Rocks under stress may show strain or deformation. Deformation can be elastic or plastic, or the rock may fracture.
- Rocks respond to stress differently under different conditions.

Practice

Use this resource to answer the questions that follow.

https://www.as.uky.edu/sites/default/files/elearning/module10swf.swf

Select Overview.

1. What is stress?

2. What are the three directions in which stress can be applied?

3. What does tension cause?

4. What does compression cause?

5. What is shearing?

Review

1. What type of stress would you find at a transform fault? At a subduction zone? What type of stress at a continental rift zone?

2. Compare and contrast fracture, plastic deformation, and elastic deformation.

3. What do you think happens with stressed rocks in an earthquake zone?

6.2 Principle of Horizontality

- Identify rules for the formation and deformation of sedimentary rock.
- Explain how sedimentary rock helps scientists study geological history.

Why does the Grand Canyon resemble these cakes?

If you go to the Grand Canyon, you'll see a layer cake of geological formations. Some people call this "layer cake geology." Just like the cake, the bottom layer is put down first and then subsequent layers moving upward. If a layer is not horizontal it must have been deformed. We'll learn about deformation in the next several concepts.

Sedimentary Rock Rules

Sedimentary rocks follow certain rules.

1. Sedimentary rocks are formed with the oldest layers on the bottom and the youngest on top.
2. Sediments are deposited horizontally, so sedimentary rock layers are originally horizontal, as are some volcanic rocks, such as ash falls.
3. Sedimentary rock layers that are not horizontal are deformed.

Since sedimentary rocks follow these rules, they are useful for seeing the effects of stress on rocks. Sedimentary rocks that are not horizontal must have been deformed.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses.

Geologic History

You're standing in the Grand Canyon and you see rocks like those below. Using the rules listed above, try to figure out the geologic history of the geologic column. The Grand Canyon is full mostly of sedimentary rocks, which are important for deciphering the geologic history of a region.

In the Grand Canyon, the rock layers are exposed like a layer cake. Each layer is made of sediments that were deposited in a particular environment - perhaps a lake bed, shallow offshore region, or a sand dune.

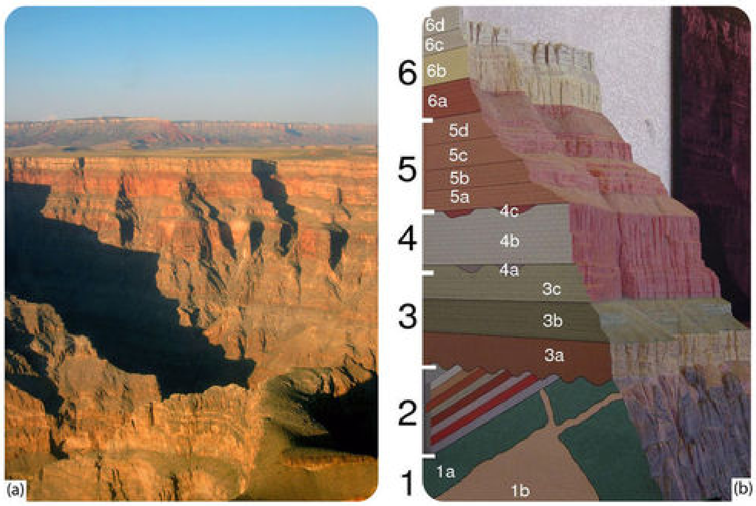


FIGURE 6.4

(a) The rocks of the Grand Canyon are like a layer cake. (b) A geologic column showing the rocks of the Grand Canyon.

In this geologic column of the Grand Canyon, the sedimentary rocks of groups 3 through 6 are still horizontal. Group 2 rocks have been tilted. Group 1 rocks are not sedimentary. The oldest layers are on the bottom and youngest are on the top.

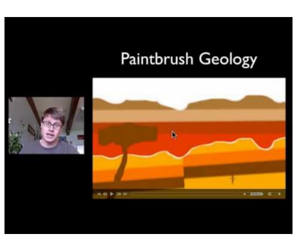
The ways geologists figure out the geological history of an area will be explored more in "Concept Earth History."

Summary

- Sedimentary rocks are laid down horizontally.
- Rocks are laid down from oldest to youngest.
- Sedimentary rocks that are not horizontal have been deformed.
- Sedimentary rocks are very useful for deciphering the geological history of an area.

Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What is the law of superposition?
2. How us rock laid down?
3. How can you determine the oldest rock?
4. What can happen to disturb the layers?
5. What does erosion do?
6. What is an intrusion?

Review

1. In the Grand Canyon section, what do you think caused 4a and 4c?
2. What may have happened in to the rocks in 2? What type of rocks are they?
3. What could have happened between 1 & 2 and 3?

6.3 Folds

- Identify and define types of folds and related structures.

Can you see the anticline at Anticline Overlook?

Moving around the desert Southwest, we see a lot of folds. This view is from the Anticline Overlook at Canyonlands National Park. Look up what an anticline is below and then see if you can spot this one. Remember you may only be able to see part of it in the photo. All of the folds (not the basin) pictured below are found in the arid Southwest.

Folds

Rocks deforming plastically under compressive stresses crumple into **folds**. They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.

You can see three types of folds.

Monocline

A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure** 6.5 for an example).

FIGURE 6.5
At Utah's Cockscomb, the rocks plunge downward in a monocline.

What you see in the image appears to be a monocline. Are you certain it is a monocline? What else might it be? What would you have to do to figure it out?

Anticline

Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** 6.6). The oldest rocks are at the center of an anticline and the youngest are draped over them.

When rocks arch upward to form a circular structure, that structure is called a **dome**. If the top of the dome is sliced off, where are the oldest rocks located?

Syncline

A **syncline** is a fold that bends downward. The youngest rocks are at the center and the oldest are at the outside (**Figure** 6.7).

When rocks bend downward in a circular structure, that structure is called a **basin** (**Figure** 6.8). If the rocks are exposed at the surface, where are the oldest rocks located?

FIGURE 6.6
Anticlines are formations that have folded rocks upward.

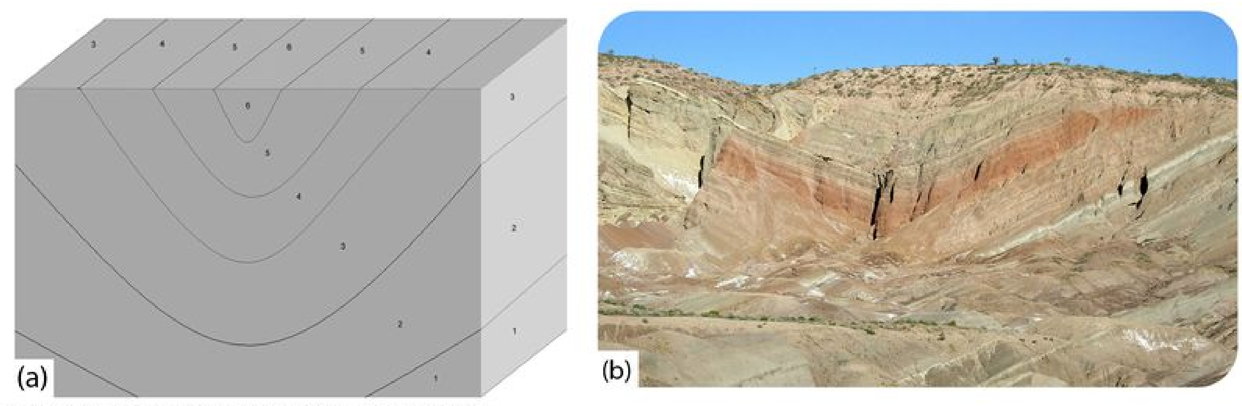


FIGURE 6.7
(a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

Vocabulary

- **anticline**: A fold that arches upward; older rocks are in the center and younger rocks are at the outside.
- **basin**: A circular anticline; oldest rocks are in the center and the youngest are on the outside.
- **dome**: A circular anticline; oldest rocks are in the center and youngest are on the outside.
- **fold**: A bend in a set of rocks caused be compression.
- **monocline**: A bend in a set of rocks that causes them to be inclined relative to the horizontal.

FIGURE 6.8

Basins can be enormous. This is a geologic map of the Michigan Basin, which is centered in the state of Michigan but extends into four other states and a Canadian province.

FIGURE 6.9

Some folding can be fairly complicated. What do you see in the photo above?

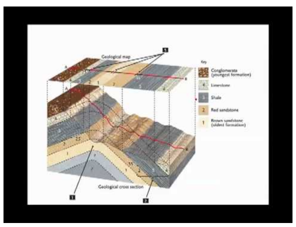
- **syncline**: A fold in the rocks that bends downward, in which the youngest rocks are at the center.

Summary

- Rocks deform by compressive stress into folds.
- A monocline is a simple bend.
- In anticline, rocks arch upward. A three-dimensional anticline is a dome.
- In a syncline, rocks arch downward. A three-dimensional syncline is a basin.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What causes folds?
2. What are the folds called?
3. What is a dip?
4. What is a strike?
5. What does a block diagram show you?
6. What is the strike and dip symbol?
7. What do the arrows on the diagram tell you?
8. Describe the effects of erosion.

Review

1. Draw a picture to show how compressive stresses lead to the formation of anticlines and synclines.
2. Do you think that anticlines and synclines are ordinarily found separately or adjacent to each other?
3. If you found a bulls-eye of rock on the flat ground with no structure to guide you, how could you tell if the structure had been a syncline or an anticline?

4. What folds can you find in this photo of Monument Valley in Arizona? Notice the rock layers at the top of the ridge. What is the geologic history of this region?

6.4 Faults

- Describe the results of rocks fracturing under stress, forming joints or faults.
- Identify types of faults.

Why is this called a fault?

The word "fault" refers to a defect. There may be no greater defect than the scar of the San Andreas Fault across California. Rocks on either side of the fault are estimated to have originated in locations about 350 miles apart! We're still in the arid western United States, but now our searching for geological features is more dangerous!

Fractures

A rock under enough stress will fracture. There may or may not be movement along the fracture.

Joints

If there is no movement on either side of a fracture, the fracture is called a **joint**. Granite rocks in Joshua Tree National Park show horizontal and vertical jointing. These joints formed when the confining stress was removed from the granite as shown in (**Figure** 6.10).

Faults

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** 6.11). Sudden motions along faults cause rocks to break and move suddenly. The energy released is an earthquake.

How do you know there's a fault in this rock? Try to line up the same type of rock on either side of the lines that cut across them. One side moved relative to the other side, so you know the lines are a fault.

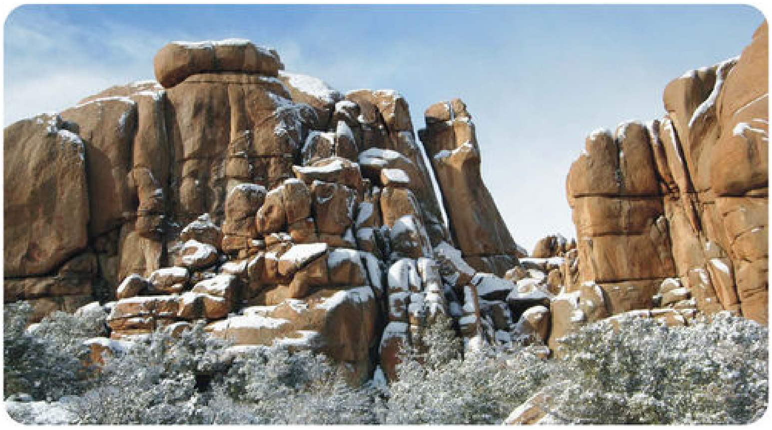


FIGURE 6.10
Joints in granite rocks at Joshua Tree National Park, in California.

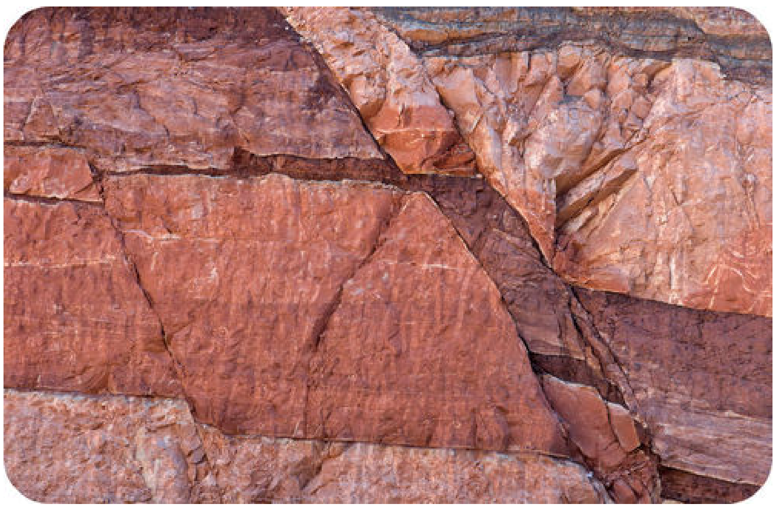


FIGURE 6.11
Faults are easy to recognize as they cut across bedded rocks.

Slip is the distance rocks move along a fault. Slip can be up or down the fault plane. Slip is relative, because there is usually no way to know whether both sides moved or only one. Faults lie at an angle to the horizontal surface of the Earth. That angle is called the fault's **dip.** The dip defines which of two basic types a fault is. If the fault's dip is inclined relative to the horizontal, the fault is a **dip-slip fault** (**Figure** 6.12).

Dip-Slip Faults

There are two types of dip-slip faults. In a **normal fault**, the hanging wall drops down relative to the footwall. In a **reverse fault**, the footwall drops down relative to the hanging wall.

An animation of a normal fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Normal+Fault#38;flash_file=normalfault#38;flash_width=220#38;flash_height=320.

A **thrust fault** is a type of reverse fault in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults (**Figure** 6.13).

An animation of a thrust fault is seen here: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Thrust+Fault#38;flash_file=thrustfault#38;flash_width=220#38;flash_height=320.

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional

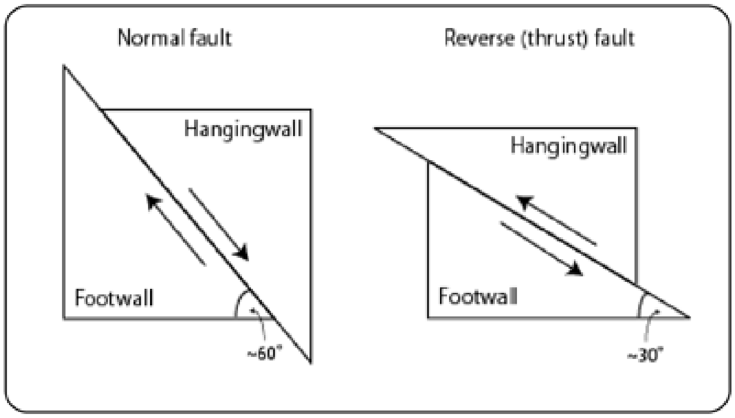


FIGURE 6.12
This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

FIGURE 6.13
At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

stress (**Figure** 6.14).

Strike-Slip Faults

A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. Imagine placing one foot on either side of a strike-slip fault. One block moves toward you. If that block moves toward your right foot, the fault is a right-lateral strike-slip fault; if that block moves toward your left foot, the fault is a left-lateral strike-slip fault (**Figure** 6.15).

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (See opening image).

A strike-slip fault animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Strike-Slip+Fault#38;flash_file=strikeslip#38;flash_width=240#38;flash_height=310.

People sometimes say that California will fall into the ocean someday, which is not true. This animation shows movement on the San Andreas into the future: http://visearth.ucsd.edu/VisE_Int/aralsea/bigone.html.

FIGURE 6.14
The rocks are different on each side of a normal fault.

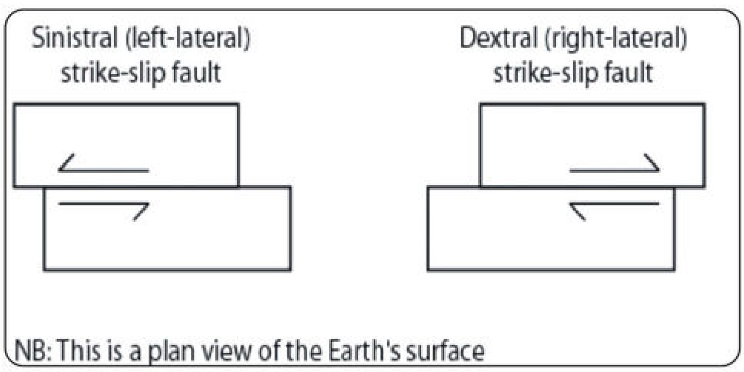


FIGURE 6.15
Strike-slip faults.

Vocabulary

- **dip**: The angle of a fault relative to horizontal.
- **dip-slip fault**: A fault in which the dip of the fault plain is inclined relative to the horizontal.
- **fault**: A fracture along which one side has moved relative to the other.
- **joint**: A break in rock along which there is no movement.
- **normal fault**: A dip-slip fault in which the hanging wall drops down relative to the footwall.
- **reverse fault**: A dip-slip fault in which the hanging wall pushes up relative to the footwall.
- **slip**: The distance rocks move along a fault.
- **strike-slip fault**: A fault in which the dip of the fault plane is vertical.
- **thrust fault**: A reverse fault in which the dip of the fault plane is nearly horizontal.

Summary

- A fracture with no movement on either side is a joint.
- Dip-slip faults show vertical movement. In a normal fault, the hanging wall drops down relative to the footwall. The reverse is true of a reverse fault.
- Strike-slip faults have horizontal motions due to shear stress.

Practice

Use this resource to answer the questions that follow.

http://www.iris.edu/gifs/animations/faults.htm

1. What causes normal fault motion?

2. What type of motion results from a normal fault?

3. Explain a reverse fault. What type of motion results from this fault?

4. Describe a strike-slip fault.

5. What causes an oblique-slip fault?

Review

1. Imagine you're looking at an outcrop. What features would you see to indicate a fault?

2. If the San Andreas Fault has had 350 miles of displacement, where did the rocks in San Francisco (on the west side of the fault) originate? How do scientists know?

3. How do you imagine the Grand Teton mountain range rose? In one earthquake? Along one fault? Or is there a more complex geological history?

6.5 Mountain Building

- Explain how converging or diverging plates can create mountain ranges.

How do plate motions create mountains?

Plate tectonic processes create some of the world's most beautiful places. The North Cascades Mountains in Washington State are a continental volcanic arc. The mountains currently host some glaciers and there are many features left by the more abundant ice age glaciers. Changes in altitude make the range a habitable place for many living organisms.

Converging Plates

Converging plates create the world's largest mountain ranges. Each combination of plate types — continent-continent, continent-ocean, and ocean-ocean — creates mountains.

Converging Continental Plates

Two converging continental plates smash upwards to create gigantic mountain ranges (**Figure** 6.16). Stresses from this **uplift** cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards. As was stated previously there is currently no mountain range of this type in the western U.S., but we can find one where India is pushing into Eurasia.

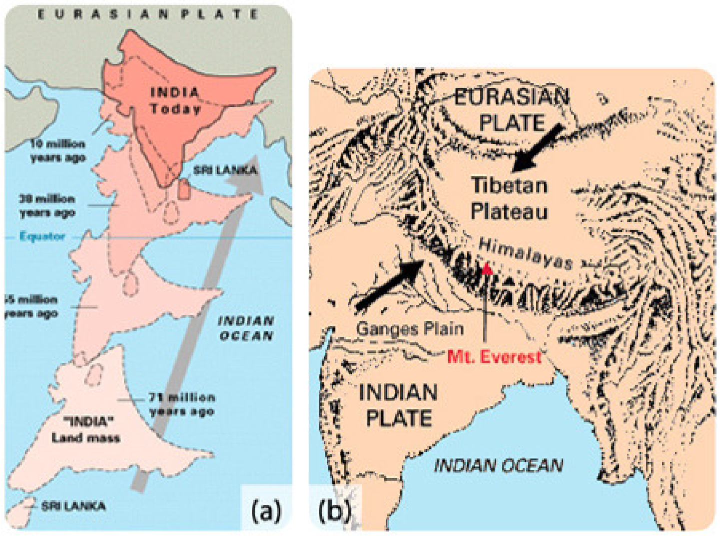


FIGURE 6.16
(a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

Subducting Oceanic Plates

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges. This happens on continental crust, as in the Andes Mountains(**Figure** 6.17), or on oceanic crust, as with the Aleutian Islands, which we visited earlier. The Cascades Mountains of the western U.S. are also created this way.

FIGURE 6.17
The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

Diverging Plates

Amazingly, even divergence can create mountain ranges. When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along normal faults. The result is alternating mountains and valleys, known as a basin-and-range (**Figure** 6.18). In basin-and-range, some blocks are uplifted to form ranges, known as horsts, and some are down-dropped to form basins, known as grabens.

This is a very quick animation of movement of blocks in a basin-and-range setting: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Horst+%26amp%3B+Graben#38;flash_file=horstandgraben#38;flash_width=380#38;flash_height=210.

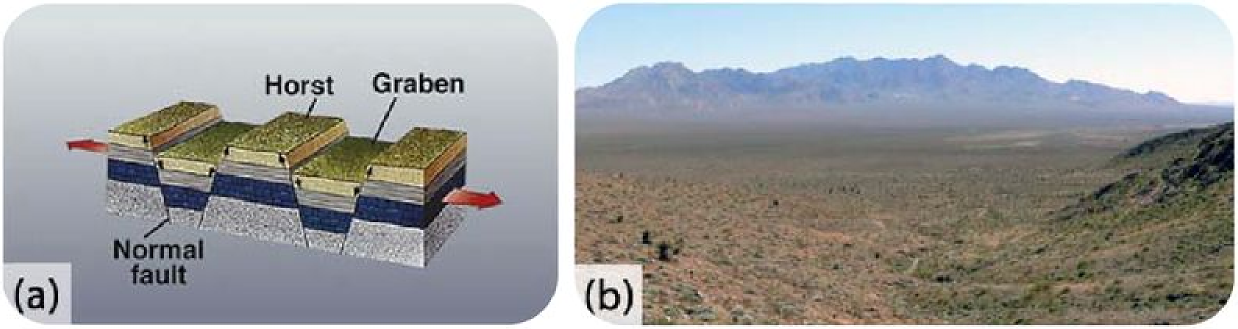


FIGURE 6.18
(a) Horsts and grabens. (b) Mountains in Nevada are of classic basin-and-range form. The photographer is in the Nopah Range and is looking across a basin to the Kingston Range beyond.

Vocabulary

- **uplift**: The upward rise of rock material.

Summary

- Converging or diverging plates cause mountains to grow.
- Subduction of oceanic crust beneath a continental or oceanic plate creates a volcanic arc.
- Tensional forces bring about block faulting, which creates a basin-and-range topography.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What created the landscape we see today on Earth?
2. What can cause mountains to form?
3. How tall are the Alps?
4. How were the Alps formed?
5. Explain the forces that caused the Alps to form.

Review

1. Describe how plate interactions create mountain ranges like the Himalayas.

2. Diagram how pulling apart continental crust could create mountains and basins. What are the mountains and basins called?

3. How are the Andes Mountains similar to the Aleutian Islands? How are they different?

6.6 Earthquake Characteristics

- Define earthquakes, and explain how they occur.

Does ground shaking cause the greatest damage in an earthquake?

This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is often not from the ground shaking but from the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes so that when the gas caught fire there was no way to put it out. Do you wonder why the people standing in the street are looking toward the fire rather than running in the opposite direction?

Earthquake!

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Earthquakes can be so small they go completely unnoticed, or so large that it can take years for a region to recover.

Elastic Rebound Theory

The description of how earthquakes occur is called **elastic rebound theory** (**Figure** 6.19).

Elastic rebound theory in an animation: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Elastic+Rebound#38;flash_file=elasticrebound#38;flash_width=300#38;flash_height=350.

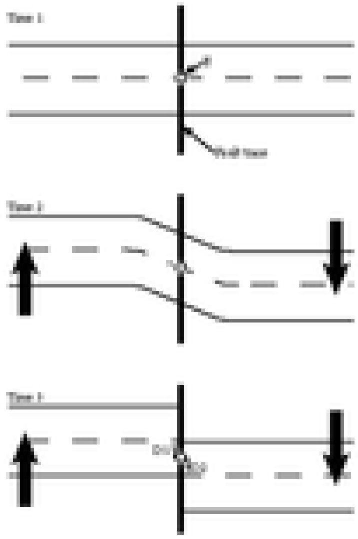


FIGURE 6.19
Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

Focus and Epicenter

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The **epicenter** is the point on the land surface that is directly above the focus (**Figure** 6.20).

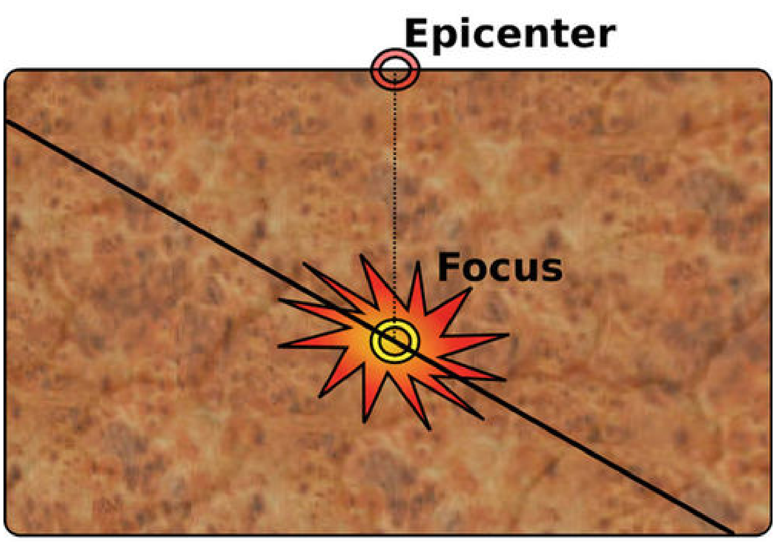


FIGURE 6.20
In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

In about 75% of earthquakes, the focus is in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media.

Vocabulary

- **earthquake**: Ground shaking caused by the release of energy stored in rocks.
- **elastic rebound theory**: How earthquakes are generated. Stresses cause strain to build up in rocks until they can no longer bend elastically and they break, causing an earthquake.
- **epicenter**: The point on the Earth's surface directly above the focus of the earthquake.
- **focus**: The point where rocks rupture during an earthquake.

Summary

- A sudden release of energy stored in rocks causes an earthquake.
- The focus is where the rocks rupture. The epicenter is the point on the ground directly above the focus.
- Most earthquakes are shallow; these do the most damage.

Practice

Use this resource to answer the questions that follow.

http://www.pbs.org/wnet/savageearth/animations/earthquakes/main.html

1. What causes an earthquake?

2. What is the focus?

3. Which waves travel the fastest?

4. Which waves cannot travel through the core?

5. What happens to the waves as distance increases?

Review

1. How does elastic rebound theory describe how an earthquake takes place?

2. Where is an earthquake's focus? Where is its epicenter?

3. Why do shallow earthquakes cause the most damage?

6.7 Earthquake Zones

- Explain the relationship between plate boundaries and earthquakes.

What caused the earthquake in Northridge, CA in 1994?

Northridge, California experienced a 6.7 magnitude earthquake in 1994. Roads, bridges and elevated highways, like this one, were damaged and 72 people died. Northridge lies on a blind thrust fault that was only discovered as a result of the quake. The fault is part of the San Andreas Fault system, which is part of the Pacific Ring of Fire (and ground shaking).

Annual Earthquakes

In a single year, on average, more than 900,000 earthquakes are recorded and 150,000 of them are strong enough to be felt. Each year about 18 earthquakes are major, with a Richter magnitude of 7.0 to 7.9, and on average one earthquake has a magnitude of 8 to 8.9.

Magnitude 9 earthquakes are rare. The United States Geological Survey lists five since 1900 (see **Figure** 6.21 and **Table** 6.1). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.

TABLE 6.1: **Earthquakes of magnitude 9 or greater**

Location	Year	Magnitude
Valdivia, Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Great Indian Ocean Earthquake	2004	9.1
Kamchatka, Alaska	1952	9.0
Tōhoku, Japan	2011	9.0

FIGURE 6.21
The 1964 Good Friday Earthquake centered in Prince William Sound, Alaska released the second most amount of energy of any earthquake in recorded history.

Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries.

- About 80% of all earthquakes strike around the Pacific Ocean basin because it is lined with convergent and transform boundaries (**Figure** 6.22).
- About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate.
- The remaining 5% are scattered around other plate boundaries or are intraplate earthquakes.

Summary

- Small earthquakes are extremely common, but the largest earthquakes are extremely rare.
- The vast majority of earthquakes happen at plate boundaries.
- The Pacific Ocean basin has the most earthquakes due to the plate boundaries that line it; the Himalaya region has the second most due to the convergence of India and Asia.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What was the magnitude of the Chilean earthquake?

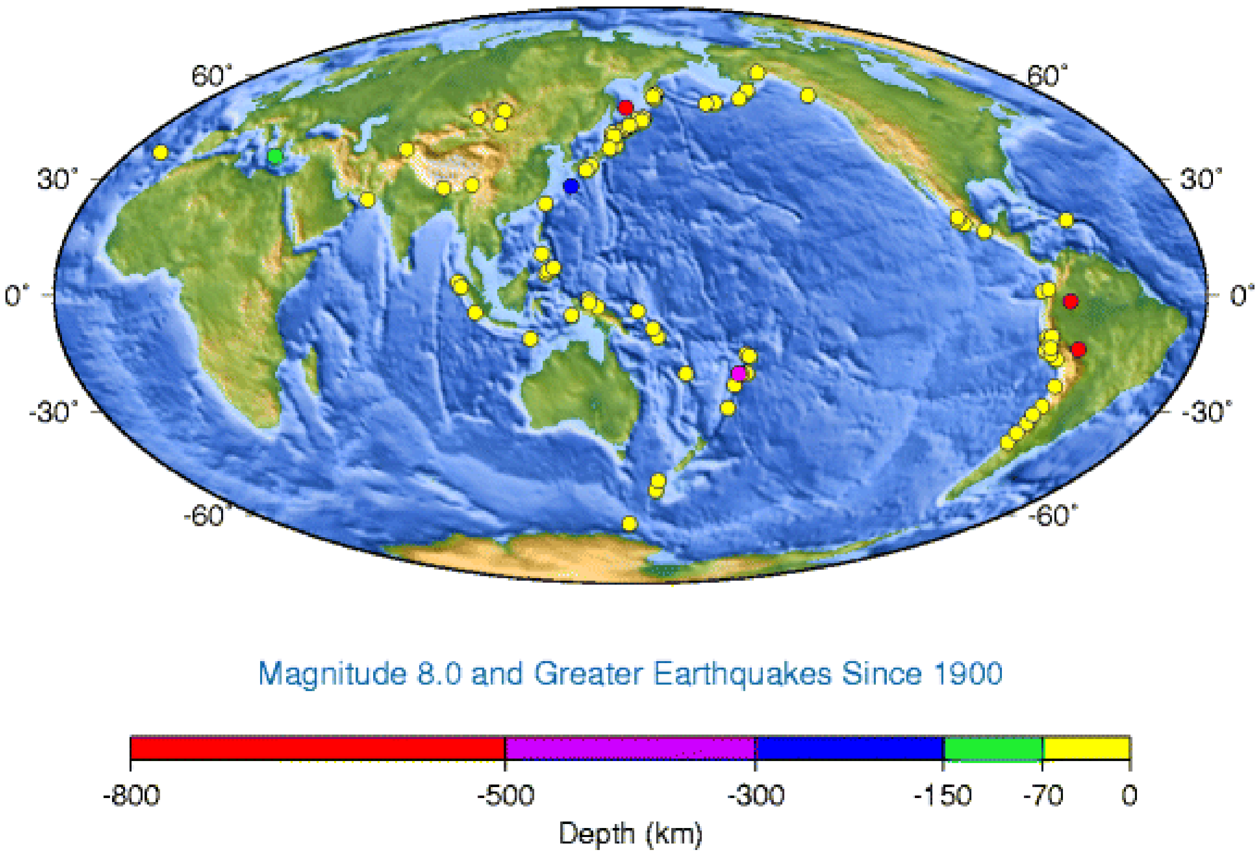


FIGURE 6.22

Earthquake epicenters for magnitude 8.0 and greater events since 1900. The earthquake depth shows that most large quakes are shallow focus, but some subducted plates cause deep focus quakes.

2. What two plates are converging near Chile that caused the earthquake?
3. What is the ring of fire? What occurs along this ring of fire?
4. What was the strongest earthquake every recorded? When did it occur?
5. Why are scientists urging Memphis to adopt building codes similar to Chile's?

Review

1. Diagram the western United States with different types of plate boundaries.
2. Why are most earthquakes at plate boundaries?
3. Why are some earthquakes away from plate boundaries?
4. What two types of plate motions occur along the Pacific Rim? Where would you find each type along western North America?
5. What type of plate motions cause the Mediterranean-Asiatic quakes?
6. Why do earthquakes occur away from plate boundaries?

6.8 Earthquakes at Transform Plate Boundaries

- Describe earthquakes that take place at transform plate boundaries.

Would you like to live in San Francisco?

Lots of people live in California for the weather. Transplants from snowy climates think they've found paradise in the state's warm sunshine. What if you got your dream job in San Francisco? Would you take it? Are you afraid enough of the region's potential for large earthquakes that you wouldn't? Look at the map of faults in the Bay Area below before you decide.

Transform Plate Boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. Why do you think this is so?

California

As you learned in Concept Plate Tectonics, the boundary between the Pacific and North American plates runs through much of California as the San Andreas Fault zone. As you can see below, there is more than just one fault running through the area. There is really a fault zone. The San Andreas Fault runs from south to north up the peninsula, through San Francisco, gets through part of Marin north of the bay, and then goes out to sea. The other faults are part of the fault zone, and they too can be deadly.

The faults along the San Andreas Fault zone produce around 10,000 earthquakes a year. Most are tiny, but occasionally one is massive. In the San Francisco Bay Area, the Hayward Fault was the site of a magnitude 7.0 earthquake in 1868. The 1906 quake on the San Andreas Fault had a magnitude estimated at about 7.9 (**Figure** 6.23). About 3,000 people died and 28,000 buildings were lost, mostly in the fire that followed the earthquake.

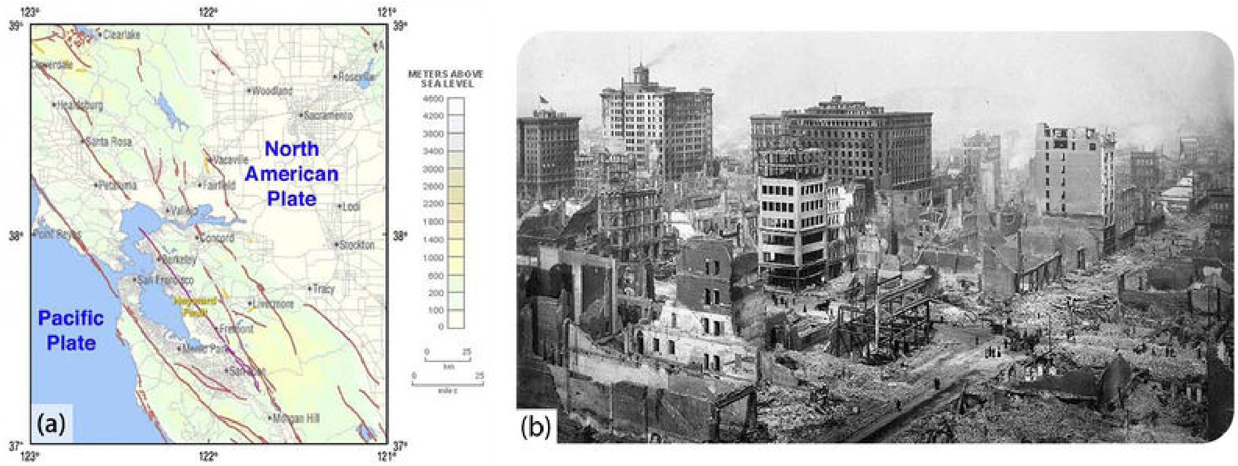


FIGURE 6.23
(a) The San Andreas Fault zone in the San Francisco Bay Area. (b) The 1906 San Francisco earthquake is still the most costly natural disaster in California history.

Recent California earthquakes occurred in:

- 1989: Loma Prieta earthquake near Santa Cruz, California. Magnitude 7.1 quake, 63 deaths, 3,756 injuries, 12,000+ people homeless, property damage about $6 billion.
- 1994: Northridge earthquake on a blind thrust fault near Los Angeles. Magnitude 6.7, 72 deaths, 12,000 injuries, damage estimated at $12.5 billion.

In this video, the boundaries between three different tectonic plates and the earthquakes that result from their interactions are explored **(9b)**: http://www.youtube.com/watch?v=upEh-1DpLMg (1:59).

MEDIA
Click image to the left for more content.

New Zealand

New Zealand also has a transform fault with strike-slip motion, causing about 20,000 earthquakes a year! Only a small percentage of those are large enough to be felt. A 6.3 quake in Christchurch in February 2011 killed about 180 people.

Summary

- Transform fault earthquakes have shallow focus because the plates meet near the surface.

- The San Andreas Fault is actually a fault zone made up of a number of other active faults.
- New Zealand also has a transform plate boundary.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Transform Plates**

1. What is a transform boundary?
2. Give an example of where a transform boundary is found.

MEDIA

Click image to the left for more content.

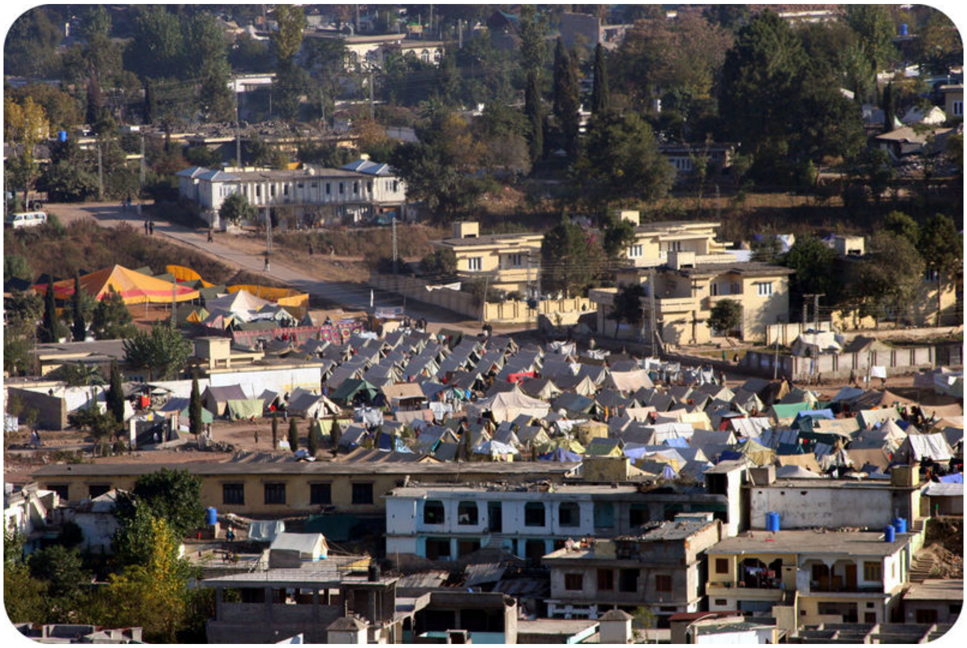
3. How far does the San Andreas Fault extend?
4. What two plates form the fault?
5. What type of fault is it?
6. What causes an earthquake?
7. What is a creepmeter?
8. How many earthquakes occur at the San Andreas fault each year?

Review

1. Why are earthquakes at convergent plate boundaries sometimes deep, while those at transform plate boundaries are always shallow?
2. Are the earthquakes that take place along the other faults in the San Andreas Fault Zone always smaller than the earthquakes that take place on the San Andreas Fault itself?
3. Do you expect that the quiet along the San Andreas Fault near San Francisco since 1906 means that earthquake activity is calming down along that plate boundary?

6.9 Earthquakes at Convergent Plate Boundaries

- Describe earthquakes that take place at convergent plate boundaries.



How do earthquakes create refugees?

People who've lost their homes in a large earthquake in Pakistan live in a refugee camp, which appears as tents in the photo. Despite suffering the loss of their homes, material possessions, and sometimes loved ones, refugees are often most damaged by the fear that another earthquake could strike. With many people, each aftershock brings renewed terror.

Convergent Plate Boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle (**Figure** 6.24). Eventually the plate heats up enough deform plastically and earthquakes stop.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin.

Ocean-Ocean: Japan

Earthquakes in Japan are caused by ocean-ocean convergence. The Philippine Plate and the Pacific Plate subduct beneath oceanic crust on the North American or Eurasian plates. This complex plate tectonics situation creates a chain of volcanoes, the Japanese islands, and as many as 1,500 earthquakes annually.

In March 2011 an enormous 9.0 earthquake struck off of Sendai in northeastern Japan. This quake, called the 2011 Tōhoku earthquake, was the most powerful ever to strike Japan and one of the top five known in the world. Damage from the earthquake was nearly overshadowed by the tsunami it generated, which wiped out coastal cities and towns (**Figure** 6.25). Several months after the earthquake, about 22,000 people were dead or missing, and 190,000

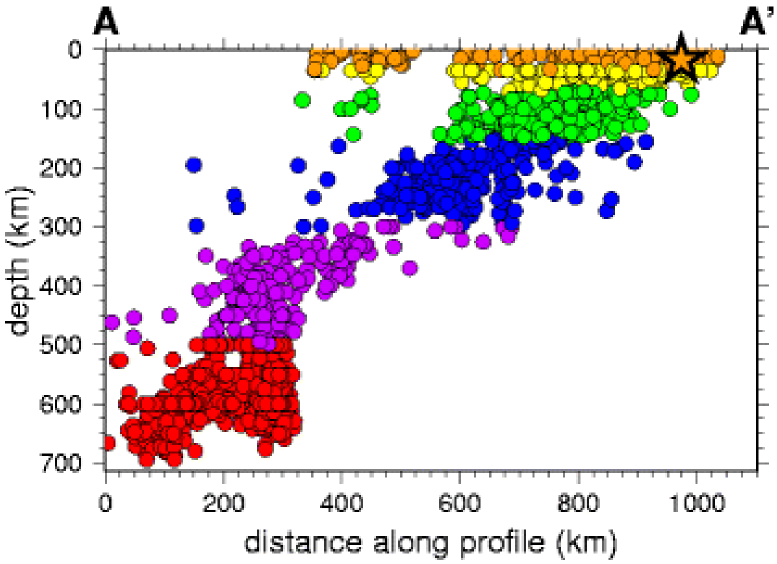


FIGURE 6.24

This cross section of earthquake epicenters with depth outlines the subducting plate with shallow, intermediate, and deep earthquakes.

buildings had been damaged or destroyed. Aftershocks, some as large as major earthquakes, have continued to rock the region.

A map of aftershocks is seen here: http://earthquake.usgs.gov/earthquakes/seqs/events/usc0001xgp/.

Here is an interactive feature article about the earthquake: http://www.nytimes.com/interactive/2011/03/11/world/asia/maps-of-earthquake-and-tsunami-damage-in-japan.html.

FIGURE 6.25

Destruction in Ofunato, Japan, from the 2011 Tōhoku Earthquake.

Ocean-Continent: Cascades

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. The subduction of three small plates beneath North America produces active volcanoes, the Cascades. As with an active subduction zone, there are also earthquakes. Surprisingly, large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9. A quake of that magnitude today could produce an incredible amount of destruction and untold fatalities.

An image of earthquakes beneath the Pacific Northwest and the depth to the epicenter is shown here: http://pubs.usgs.gov/ds/91/.

Elastic rebound at a subduction zone generates an earthquake in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/5/AOTF5_Subduction_ElasticRebound480.mov.

Continent-Continent: Asia

Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge (**Figure** 6.26). The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.

FIGURE 6.26
Damage from the 2005 Kashmir earthquake.

In Understanding Earthquakes: From Research to Resilience, scientists try to understand the mechanisms that cause earthquakes and tsunamis and the ways that society can deal with them **(3d)**: http://www.youtube.com/watch?v=W5Qz-aZ2nUM (8:06).

MEDIA
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Summary

- Earthquakes occur all along the subducting plate as it plunges into the mantle.
- All three types of convergent plate boundaries produce massive earthquakes.
- Subduction zones around the Pacific Rim are responsible for many of the world's earthquakes.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Convergent Plates**

1. How do convergent plate boundaries occur?
2. What is formed by the continental-continental plate boundaries?
3. Where are these type of boundaries found?
4. What is formed at oceanic-continental plate boundaries?
5. Where are active volcanoes found?

Review

1. Why does a subducting plate produce so many earthquakes and what type of quakes does it produce?
2. What caused the most destruction from the 2011 Japan earthquake and why?
3. Why do you think the Pacific Northwest has such infrequent but exceptionally massive earthquakes? There are several possible reasons.

6.10 Intraplate Earthquakes

- Identify the causes of intraplate earthquakes.

What caused an earthquake in Virginia? It's not near a plate boundary.

Everyone expects earthquakes in California, but no one expects a large (okay, medium) earthquake in Virginia, but that's what happened in August 2011. This earthquake was one of the intraplate earthquakes that do not occur along plate boundaries but within plates. This crack is in the Washington Monument in the District of Columbia, which remains closed while the damage is being repaired.

Intraplate Earthquakes

Intraplate earthquakes are the result of stresses caused by plate motions acting in solid slabs of lithosphere. The earthquakes take place along ancient faults or rift zones that have been weakened by activity that may have taken place hundreds of millions of years ago.

2011 Virginia Earthquake

In August 2011 the eastern seaboard of the U.S. was rocked by a magnitude 5.8 earthquake. While not huge, most of the residents had never experienced a quake and many didn't know what it was. Some people thought the shaking might have been the result of a terrorist attack.

This region is no longer part of an active plate boundary. But if you went back in time to the late Paleozoic, you would find the region being uplifted into the ancestral Appalachian mountains as continent-continent convergence brought Pangaea together. The Piedmont Seismic Zone is an area of several hundred million year-old faults that sometimes reactivate.

New Madrid Earthquake

In 1812, a magnitude 7.5 earthquake struck near New Madrid, Missouri. The earthquake was strongly felt over approximately 50,000 square miles and altered the course of the Mississippi River. Because very few people lived there at the time, only 20 people died. Many more people live there today (**Figure** 6.27). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

Like the Piedmont Seismic Zone, the New Madrid Seismic Zone is a set of reactivated faults. These faults are left from the rifting apart of the supercontinent Rodinia about 750 million years ago. The plates did not rift apart here but left a weakness in the lithosphere that makes the region vulnerable to earthquakes.

Summary

- Intraplate earthquakes occur because solid slabs of lithosphere traveling on a round planet must make some adjustments.
- Intraplate earthquakes strike at ancient fault or rift zones that are reactivated.
- Intraplate earthquakes can do a great deal of damage even though they are not usually as large as quakes along plate boundaries.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. How many earthquakes are there in the United States?
2. What is the second most active fault in the United States?

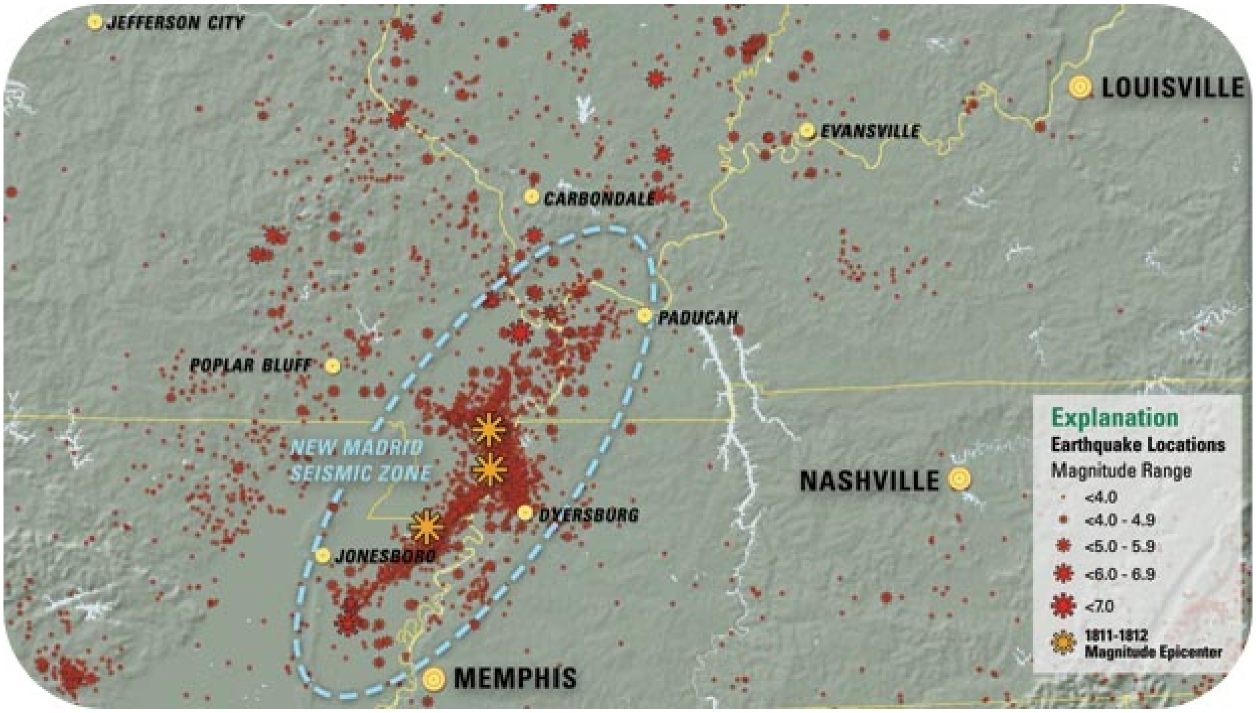

FIGURE 6.27

The New Madrid seismic zone is located in the interior of the North American plate (near Missouri, Arkansas, Tennessee, Kentucky, and Illinois), but many earthquakes occur there.

3. When did the New Madrid earthquake occur?
4. What was the magnitude of the New Madrid earthquake?
5. How many aftershocks occurred?
6. How long is the New Madrid fault?
7. How many people would be affected by another quake?
8. Where is the Ramapo fault?

Review

1. Why do intraplate earthquakes tend to be less frequent and smaller than earthquakes at plate boundaries?
2. Why do intraplate earthquakes take place at all?
3. What causes intraplate earthquakes?

6.11 Predicting Earthquakes

- Explain how scientists attempt to predict earthquakes.

What if you could predict an earthquake?

What would make a good prediction? Knowing where, when, and the magnitude of the quake would make it possible for people to evacuate. If you were right, you would be famous! but if you were wrong, many people would be angry with you.

A Good Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be detailed and accurate. Where will the earthquake occur? When will it occur? What will be the magnitude of the quake? With a good prediction authorities could get people to evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

Where?

Where an earthquake will occur is the easiest feature to predict. How would you predict this? Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before (**Figure** 6.28). Fault segments behave consistently. A segment with frequent small earthquakes or one with infrequent huge earthquakes will likely do the same thing in the future.

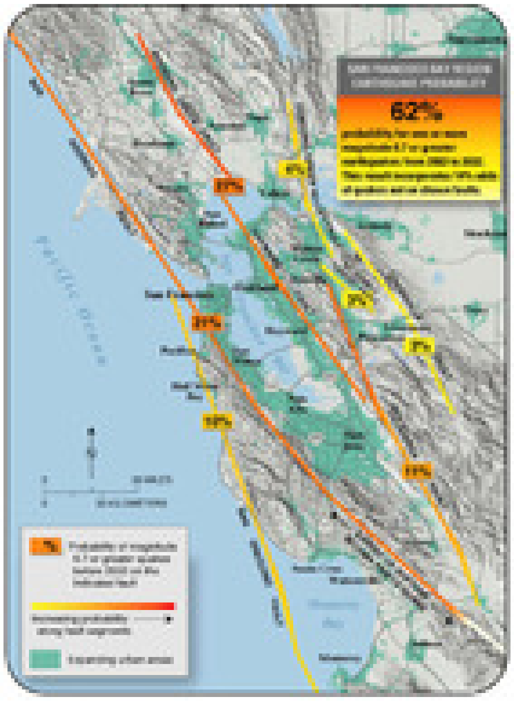

FIGURE 6.28
The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

When?

When an earthquake will occur is much more difficult to predict. Since stress on a fault builds up at the same rate over time, earthquakes should occur at regular intervals (**Figure** 6.29). But so far scientists cannot predict when quakes will occur even to within a few years.

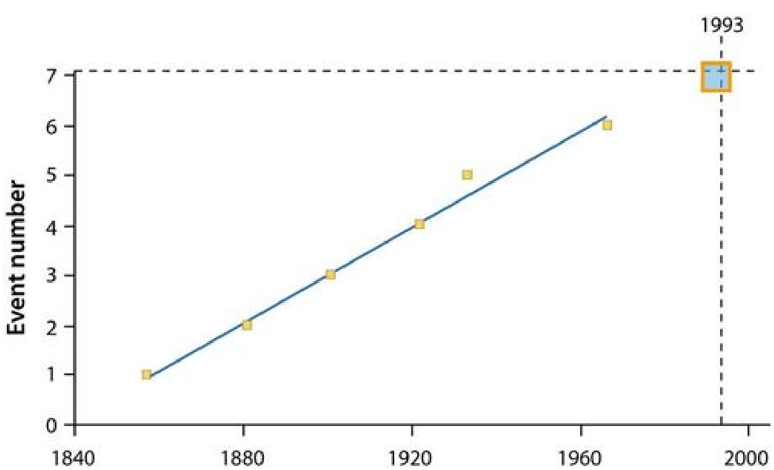

FIGURE 6.29
Around Parkfield, California, an earthquake of magnitude 6.0 or higher occurs about every 22 years. So seismologists predicted that one would strike in 1993, but that quake came in 2004 - 11 years late.

Earthquake Signs

Signs sometimes come before a large earthquake. Small quakes, called **foreshocks**, sometimes occur a few seconds to a few weeks before a major quake. However, many earthquakes do not have foreshocks, and small earthquakes are not necessarily followed by a large earthquake. Ground tilting, caused by the buildup of stress in the rocks, may precede a large earthquake, but not always. Water levels in wells fluctuate as water moves into or out of fractures before an earthquake. This is also an uncertain predictor of large earthquakes. The relative arrival times of P-waves and S-waves also decreases just before an earthquake occurs.

Folklore tells of animals behaving erratically just before an earthquake. Mostly, these anecdotes are told after the earthquake. If indeed animals sense danger from earthquakes or tsunami, scientists do not know what it is they could be sensing, but they would like to find out.

Earthquake prediction is very difficult and not very successful, but scientists are looking for a variety of clues in a variety of locations and to try to advance the field.

See more at http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/.

MEDIA
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It's been twenty years since the Loma Prieta Earthquake ravaged downtown Santa Cruz and damaged San Francisco's Marina District and the Bay Bridge. QUEST looks at the dramatic improvements in earthquake prediction technology since 1989. But what can be done with ten seconds of warning?

Find out more by listening to this audio report at http://science.kqed.org/quest/audio/predicting-the-next-big-one/.

MEDIA
Click image to the left for more content.

Vocabulary

- **foreshock**: One or more small earthquakes that come before a large earthquake.

Summary

- A good prediction must indicate when and where an earthquake will take place with detail and accuracy.
- Fault segments tend to behave the same way over time.
- Signs that an earthquakes may occur include foreshocks, ground tilting, water levels in wells and the relative arrival times of P and S waves.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What magnitude was the 2010 Haiti earthquake?
2. How did scientists recognize that the fault was active?
3. What evidence led to the prediction?
4. What can not be predicted?
5. What type of fault is at the Hayward Fault?

Review

1. Why are earthquakes so hard to predict?
2. Why is it easier to predict where a quake will occur than when?
3. Describe some of the signs that scientists use to predict earthquakes.
4. It's now nine years after the map of earthquake probabilities in the San Francisco Bay area was made. What do you think the fact that no large earthquakes have struck those faults yet does to the probability that one will strike by 2032?

6.12 Tsunami

- Describe the wave features of tsunami.

What is a tsunami?

"Tsunami" is a Japanese word meaning "harbor wave." Some people call them tidal waves. But these deadly waves are not related to tides and they are not restricted to harbors. Few words can express the horror these waves can bring.

Tsunami as Waves

Tsunami are deadly ocean waves from the sharp jolt of an undersea earthquake. Less frequently, these waves can be generated by other shocks to the sea, like a meteorite impact. Fortunately, few undersea earthquakes, and even fewer meteorite impacts, generate tsunami.

Wave Height

Tsunami waves have small wave heights relative to their long wavelengths, so they are usually unnoticed at sea. When traveling up a slope onto a shoreline, the wave is pushed upward. As with wind waves, the speed of the bottom of the wave is slowed by friction. This causes the wavelength to decrease and the wave to become unstable. These factors can create an enormous and deadly wave.

How a tsunami forms is shown in this animation: http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::640::480::/sites/dl/free/0072402466/30425/16_19.swf::Fig.%2016.19%20-%20Formation%20of%20a%20Tsunami.

Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami. Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

A video explanation of tsunami is here: http://www.youtube.com/watch?v=StdqGoezNrY#38;feature=channel.

Wavelength

Since tsunami are long-wavelength waves, a long time can pass between crests or troughs. Any part of the wave can make landfall first.

In 1755 in Lisbon, Portugal, a tsunami trough hit land first. A large offshore earthquake did a great deal of damage on land. People rushed out to the open space of the shore. Once there, they discovered that the water was flowing seaward fast and some of them went out to observe. What do you think happened next? The people on the open beach drowned when the crest of the wave came up the beach.

Large tsunami in the Indian Ocean and more recently Japan have killed hundreds of thousands of people in recent years. The west coast is vulnerable to tsunami since it sits on the Pacific Ring of Fire. Scientists are trying to learn everything they can about predicting tsunamis before a massive one strikes a little closer to home.

See more at http://science.kqed.org/quest/video/scary-tsunamis/.

Adobe Flash

MEDIA
Click image to the left for more content.

Vocabulary

- **tsunami**: An enormous wave generated by vertical movement of the ocean floor during an underwater earthquake; tsunamis can also be caused by volcanic eruptions, landslides, or meteorite impacts. A deadly set of waves can rise high on a beach and travel far inland.

Summary

- Tsunami have relatively low wave heights, so they are not noticeable until they move up a shore.
- Tsunami have long wavelengths. The time between two crests or two troughs can be many minutes.
- Tsunami warning systems have been placed in most locations where tsunami are possible.

Practice

Use this resource to answer the questions that follow.

Adobe Flash

MEDIA
Click image to the left for more content.

1. What does the word tsunami mean?
2. Why has Japan had so many tsunamis?

3. What causes a tsunami?
4. How fast do the waves travel?
5. What happens to the tsunami as it reaches the continental shelf?
6. How do tsunamis differ from regular waves?
7. What was the deadliest tsunami ever recorded?
8. What does the Pacific Tsunami Warning Center do?

Review

1. Why is a wave that is so powerful and tall on land unnoticeable at sea?

2. What should you do if you are at the beach and the water suddenly is sucked offshore?

3. Describe tsunami as waves in the way they travel up a shoreline and may strike as crests or troughs.

6.13 21st Century Tsunami

- Describe the consequences of major 21st-century tsunami.

Why should you pay attention in school?

Tilly Smith, an 11-year old English schoolgirl, was vacationing with her family in Phuket, Thailand on December 26, 2004. Walking along the beach Tilly noticed that the bubbling sea in Phuket resembled a video taken just before a tsunami in Hawaii in 1946. She'd seen the video in geography class two weeks earlier and insisted to her parents that a tsunami was coming. Her warning saved the approximately 100 tourists and others who were on that beach.

Boxing Day Tsunami 2004

Not everyone had the same warning the people on Tilly's beach had. The Boxing Day Tsunami of December 26, 2004 was by far the deadliest of all time (**Figure** 6.30). The tsunami was caused by the 2004 Indian Ocean Earthquake. With a magnitude of 9.2, it was the second largest earthquake ever recorded.

The extreme movement of the crust displaced trillions of tons of water along the entire length of the rupture. Several tsunami waves were created with about 30 minutes between the peaks of each one. The waves that struck nearby Sumatra 15 minutes after the quake reached more than 10 meters (33 feet) in height. The size of the waves decreased with distance from the earthquake and were about 4 meters (13 feet) high in Somalia.

The tsunami did so much damage because it traveled throughout the Indian Ocean. About 230,000 people died in eight countries. There were fatalities even as far away as South Africa, nearly 8,000 kilometers (5,000 miles) from the earthquake epicenter. More than 1.2 million people lost their homes and many more lost their ways of making a living.

FIGURE 6.30
The countries that were most affected by the 2004 Boxing Day tsunami.

Japan Tsunami 2011

The Japanese received a one-two punch in March 2011. The 2011 Tōhoku earthquake offshore was a magnitude 9.0 and damage from the quake was extensive. People didn't have time to recover before massive tsunami waves hit the island nation. As seen in **Figure** 6.31, waves in some regions topped 9 meters (27 feet).

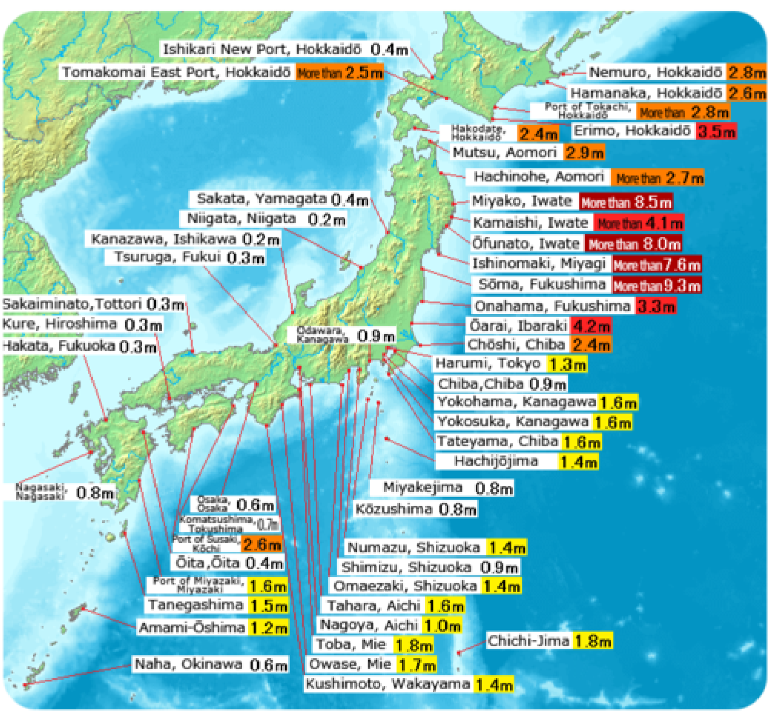


FIGURE 6.31
This map shows the peak tsunami wave heights.

The tsunami did much more damage than the massive earthquake (**Figure** 6.32).

FIGURE 6.32
An aerial view shows the damage to Sendai, Japan caused by the earthquake and tsunami. The black smoke is coming from an oil refinery, which was set on fire by the earthquake. The tsunami prevented efforts to extinguish the fire until several days after the earthquake.

Worst was the damage done to nuclear power plants along the northeastern coast. Eleven reactors were automatically shut down. Power and backup power were lost at the Fukushima plant, leading to equipment failures, meltdowns, and the release of radioactive materials. Control and cleanup of the disabled plants will go on for many years.

Tsunami Warning Systems

As a result of the 2004 tsunami, an Indian Ocean warning system was put into operation in June 2006. Prior to 2004, no one had thought a large tsunami was possible in the Indian Ocean.

FIGURE 6.33
A sign in Thailand shows an evacuation route.

In comparison, a warning system has been in effect around the Pacific Ocean for more than 50 years. The system was used to warn of possible tsunami waves after the Tōhoku earthquake, but most were too close to the quake to get to high ground in time. Further away, people were evacuated along many Pacific coastlines, but the waves were not that large.

Summary

- The Boxing Day Tsunami of 2004 came from a massive earthquake and traveled across the Indian Ocean, causing death and destruction in 12 nations.
- In Japan, the tsunami struck very quickly after the 9.0 earthquake in the subduction zone offshore. Many more people died from the tsunami than the quake.
- Tsunami warning systems are important but are not useful in locations that are very close to the earthquake that generated them.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What was the magnitude of the Japan Tsunami?

2. How tall was the sea wall?

3. How many people died or were missing?

4. How does a tsunami move in deep water?

5. How far inland did some waves reach?

6. How fast were the waves moving?

Review

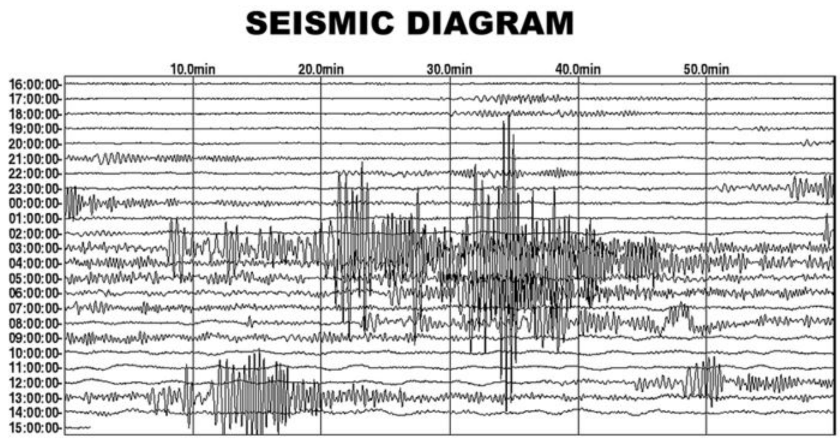
1. How does an earthquake generate a tsunami?

2. What was the Indian Ocean tsunami like in Indonesia and Thailand relative to Somalia and South Africa? Why the discrepancy?

3. Why do you think there was more damage from the tsunami in Japan than from the earthquake that caused it?

6.14 Measuring Earthquake Magnitude

- Describe instruments scientists use to measure earthquakes.



Can you read a seismogram?

What information can you pick out of this seismograph? Can you see arrival of the P- and S-waves? How many earthquakes were there? Were there foreshocks or aftershocks? At what times do all of these things happen?

Measuring Magnitude

A **seismograph** produces a graph-like representation of the seismic waves it receives and records them onto a **seismogram** (**Figure** 6.34). Seismograms contain information that can be used to determine how strong an earthquake was, how long it lasted, and how far away it was. Modern **seismometers** record ground motions using electronic motion detectors. The data are then kept digitally on a computer.

If a seismogram records P-waves and surface waves but not S-waves, the seismograph was on the other side of the Earth from the earthquake. The amplitude of the waves can be used to determine the magnitude of the earthquake, which will be discussed in a later section.

- This animation shows how a seismogram works: http://www.wwnorton.com/college/geo/egeo/flash/8_3.swf.
- A seismograph records an earthquake 50 miles away: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/17/Seismogram_RegionalEarthquake.mov.
- This animation shows three different stations picking up seismic waves: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/10/4StationSeismoNetwork480.mov.

Interpreting a Seismogram

The seismogram in the introduction shows:

- foreshocks.

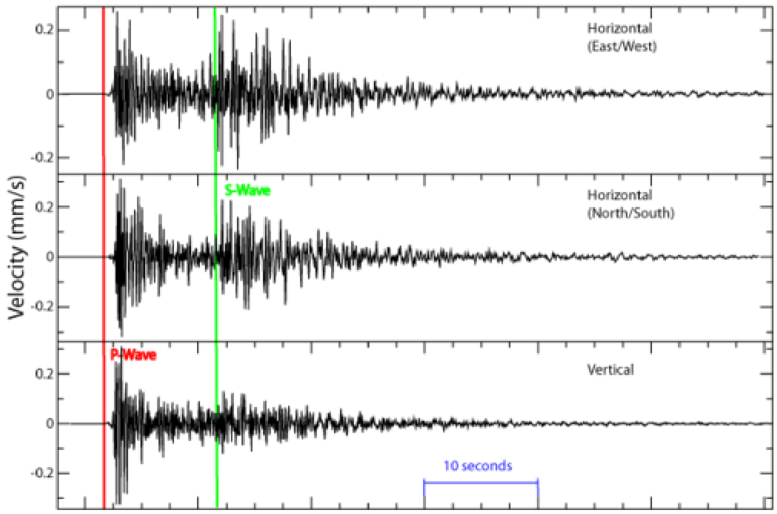


FIGURE 6.34
These seismograms show the arrival of P-waves and S-waves. The surface waves arrive just after the S-waves and are difficult to distinguish. Time is indicated on the horizontal portion (or x-axis) of the graph.

- the arrival of the P-waves.
- the arrival of the S-waves.
- the arrival of the surface waves (very hard to pick out).
- aftershocks.
- the times when all of these things occur.

Vocabulary

- **seismograph**: An older type of seismometer in which a suspended, weighted pen wrote on a drum that moved with the ground.
- **seismogram**: A seismogram is the printed record of seismic activity produced by a seismometer.
- **seismometer**: A seismometer is a machine that measures seismic waves and other ground motions.

Summary

- A seismograph records seismic waves on a seismogram. A seismometer is a digital seismic wave recorder.
- Since S-waves do not travel through liquids, a seismogram with no S-waves is on the other side of the planet.
- Seismographs yield a tremendous amount of information about an earthquake.

Practice

Use this resource to answer the questions that follow.

http://news.medill.northwestern.edu/chicago/news.aspx?id=190188

1. What was the largest earthquake in history?

2. What is Earthscope doing?

3. Why are the seismometers being installed?

4. How many instruments are being installed with this project?

5. How far apart are the seismometers being distributed?

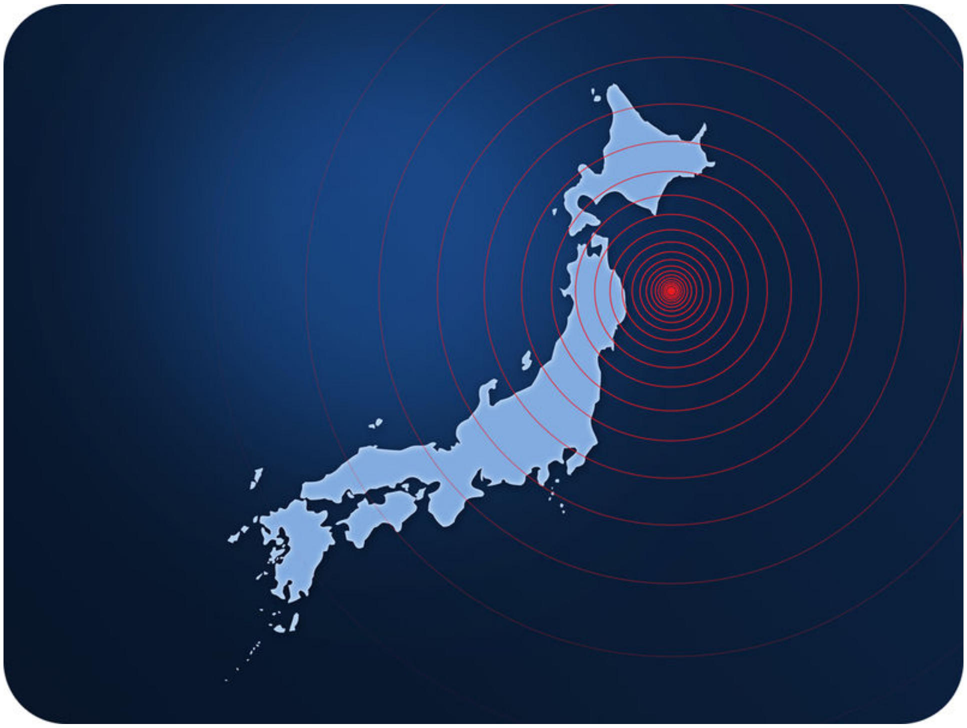
6. what do researchers hope to do with the data?

Review

1. Define seismograph, seismogram, and seismometer.
2. What does a seismogram with P-waves but not S-waves mean?
3. How can you tell a main earthquake from foreshocks and afterschocks?

6.15 Locating Earthquake Epicenters

- Explain how to find an earthquake epicenter.



Can you find an earthquake epicenter?

The epicenter of the 2011 Japan earthquake was just offshore of Sendai where the Pacific Plate plunges into a subduction zone. The quake had a relatively shallow depth of 20 miles (32 km). Remember that shallow quakes typically cause the most damage. How do scientists find an earthquake epicenter?

Finding the Epicenter

Here are the steps to finding an earthquake epicenter using three seismograms:

1. Determine the epicenter distance from three different seismographs. The longer the time between the arrival of the P-wave and S-wave, the farther away is the epicenter. So the difference in the P- and S-wave arrival times determines the distance between the epicenter and a seismometer.

This animation shows how to determine distance using P, S, and surface waves: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/IRIStravelTime_Bounce_480.mov.

2. Draw a circle with a radius equal to the distance from the epicenter for that seismograph. The epicenter is somewhere along that circle. Do this for three locations. Using data from two seismographs, the two circles will intercept at two points. A third circle will intercept the other two circles at a single point. This point is the earthquake epicenter (**Figure** 6.35).

Seismic stations record ten earthquakes in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/12/TravelTime_Sphere_10Stn_480.mov.

FIGURE 6.35
Three circles drawn from three seismic stations each equal to the radius from the station to the epicenter of the quake will intercept at the actual epicenter.

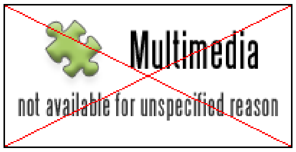
Of course, it's been a long time since scientists drew circles to locate an earthquake epicenter. This is all done digitally now. but it's a great way to learn the basics of how locating an epicenter works.

Summary

- To find an earthquake epicenter you need at least three seismographs.
- Find the distance from each seismograph to the earthquake epicenter.
- The interception of the three circles is the epicenter.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is a seismogram?
2. What waves does a seismogram show?
3. What is the S-P interval?
4. How many data stations are required to determine the epicenter?
5. What is triangulation?

Review

1. How do you determine the distance from the seismograph to the earthquake epicenter?
2. How do you find the epicenter from three seismographs? What if you have more seismographs involved?
3. In what circumstance would three seismographs not give you enough information to find an earthquake epicenter?

6.16 Scales that Represent Earthquake Magnitude

- Describe how scientists express the size and intensity of an earthquake.

How do scientists measure earthquakes?

This 6.3 magnitude earthquake in Christchurch New Zealand in 2011 caused 181 deaths and thousands of injuries. Earthquakes and the damage they cause can be measured in a few different ways based on the damage they cause or the energy of the quake.

Measuring Earthquakes

People have always tried to quantify the size of and damage done by earthquakes. Since early in the 20^{th} century, there have been three methods. What are the strengths and weaknesses of each?

Mercalli Intensity Scale

Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures. What factors would go into determining the damage that was done and what the residents felt in a region?

Richter Magnitude Scale

Developed in 1935 by Charles Richter, this scale uses a seismometer to measure the magnitude of the largest jolt of energy released by an earthquake.

Moment Magnitude Scale

This scale measures the total energy released by an earthquake. Moment magnitude is calculated from the area of the fault that is ruptured and the distance the ground moved along the fault.

Log Scales

The Richter scale and the moment magnitude scale are **logarithmic scales**.

- The amplitude of the largest wave increases ten times from one integer to the next.
- An increase in one integer means that thirty times more energy was released.
- These two scales often give very similar measurements.

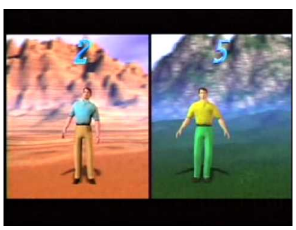
How does the amplitude of the largest seismic wave of a magnitude 5 earthquake compare with the largest wave of a magnitude 4 earthquake? How does it compare with a magnitude 3 quake? The amplitude of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake and 100 times that of a magnitude 3 quake.

How does an increase in two integers on the moment magnitude scale compare in terms of the amount of energy released? Two integers equals a 900-fold increase in released energy.

Moment Magnitude Scale is Best

Which scale do you think is best? With the Richter scale, a single sharp jolt measures higher than a very long intense earthquake that releases more energy. The moment magnitude scale more accurately reflects the energy released and the damage caused. Most seismologists now use the moment magnitude scale.

The way scientists measure earthquake intensity and the two most common scales, Richter and moment magnitude, are described along with a discussion of the 1906 San Francisco earthquake in *Measuring Earthquakes* video **(3d)**: http://www.youtube.com/watch?v=wtlu_aDteCA (2:54).



MEDIA

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Vocabulary

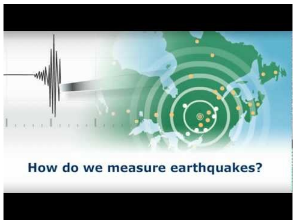
- **logarithmic scale**: A scale in which each unit is an exponential increase over the previous unit.

Summary

- Mercalli Intensity Scale depends on many factors besides the amount of energy released in the earthquake including the type of basement rock and the quality of the structures built in the area.
- The Richter scale is a logarithmic scale that measures the largest jolt of energy released by an earthquake.
- The moment magnitude scale is a logarithmic scale that measures the total amount of energy released by an earthquake.

Practice

Use this resource to answer the questions that follow.



MEDIA

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1. How is earthquake strength measured?
2. What is magnitude?
3. What do scientists use to measure earthquakes?
4. How is magnitude calculated?
5. What is intensity?
6. What does intensity depend upon?
7. How does geology affect intensity?

Review

1. Under what circumstances might the Mercalli Intensity Scale be useful today? Why was it replaced by the Richter and then the moment magnitude scales?
2. Why do scientists prefer the moment magnitude scale to the Richter scale?
3. How much difference is there between the 5.8 magnitude quake that struck Virginia and the 9.0 quake that struck Japan, both in 2011, in their energy released and largest wave amplitude?

6.17 Earthquake Damage

- Identify factors that make an earthquake damaging and deadly.

Is magnitude all that matters for determining earthquake damage?

The type and quality of construction has a tremendous effect on what happens during an earthquake. Damage and fatalities are directly affected by the construction in an earthquake. For example, many more people died in the 1988 Armenia earthquake, where people live in mud houses, than in the 1989 earthquake in Loma Prieta. Most buildings in California's earthquake country are designed to be earthquake-safe.

Damage from Earthquakes

We know that earthquakes kill lots of people. However, the ground shaking almost never kills people, and the ground does not swallow someone up. Fatalities depend somewhat on an earthquake's size and the type of ground people inhabit. But much of what determines the number of fatalities depends on the quality of structures. People are killed when structures fall on them. More damage is done and more people are killed by the fires that follow an earthquake than the earthquake itself.

What Makes an Earthquake Deadly?

- Population density. The magnitude 9.2 Great Alaska Earthquake, near Anchorage, of 1964 resulted in only 131 deaths. At the time few people lived in the area (**Figure** 6.36).

- Not size. Only about 2,000 people died in the 1960 Great Chilean earthquake, the largest earthquake ever recorded. The Indian Ocean earthquake of 2004 was one of the largest ever, but most of the 230,000 fatalities were caused by the tsunami, not the earthquake itself.
- Ground type. Solid bedrock vibrates less than soft sediments, so there is less damage on bedrock. Sediments that are saturated with water undergo **liquefaction** and become like quicksand (**Figure** 6.37). Soil on a hillside may become a landslide.

FIGURE 6.36
A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake.

FIGURE 6.37
Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

Earthquake effects on buildings are seen in this animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/6/SeismicBuilding-Narrated480.mov.

City Planning

In earthquake-prone areas, city planners try to reduce hazards. For example, in the San Francisco Bay Area, maps show how much shaking is expected for different ground types (**Figure** 6.38). This allows planners to locate new hospitals and schools more safely.

Vocabulary

- **liquefaction**: Clay, silt, and sand saturated with water become like quicksand, lose their strength, and behave more like a liquid than a solid.

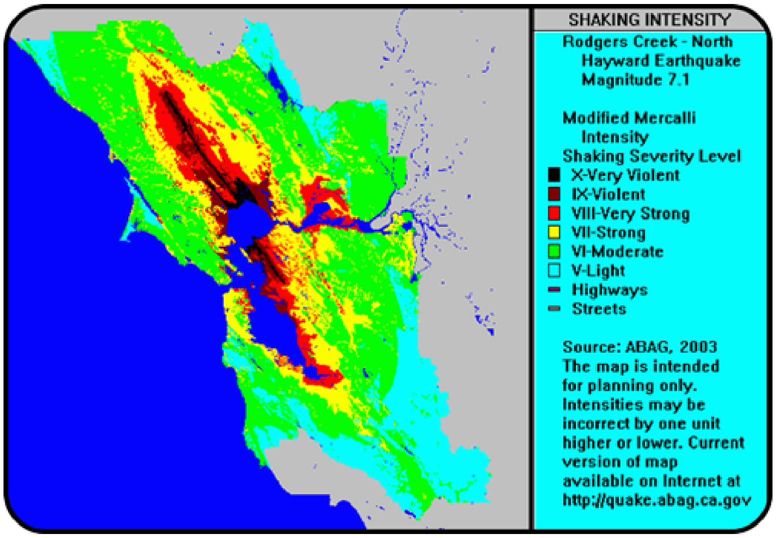


FIGURE 6.38

The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault.

Summary

- Seismic waves rarely kill anyone. Structures falling on people and fires or tsunamis after the earthquake cause many more fatalities.
- City planning can lessen the damage done by earthquakes.
- Population density and ground type affect the number of fatalities.

Practice

Use this resource to answer the questions that follow.

Chile Assesses Earthquake Damage

http://abcnews.go.com/GMA/video/chile-earthquake-9969105

1. How many people were killed?

2. How many people have been displaced?

3. How large was the earthquake?

4. What damage could be seen?

5. How capable is Chile in dealing with an earthquake?

6. Why is Chile better prepared for an earthquake than Haiti?

Review

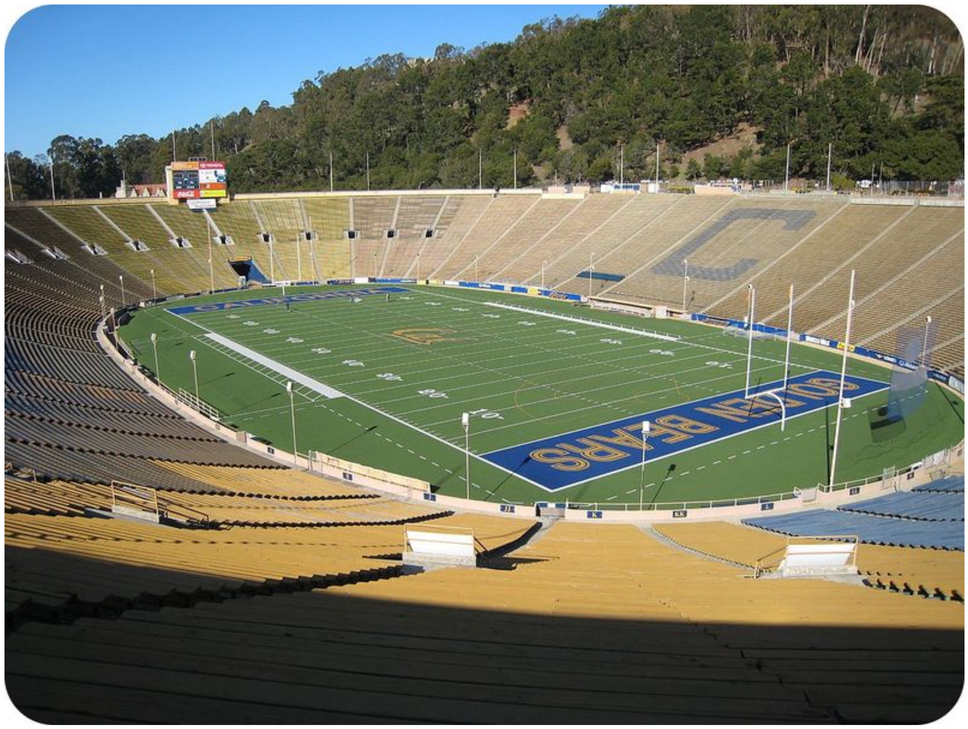
1. In the map of expected Modified Mercalli Intensity for the Bay Area of a hypothetical earthquake on the Hayward Fault, why do you think there is red and black north of the bay and up the Sacramento River? Why do you think there are much safer areas in rings around the bay?

2. What causes liquefaction and why is it damaging?

3. If a 9.2 earthquake struck near Anchorage, Alaska today, what do you think the fatalities would be compared with the quake in 1964?

6.18 Earthquake Safe Structures

- Identify steps that can be taken to make buildings safer and avoid fires in earthquake-prone areas.



Why is California Memorial Stadium called a "tectonic time bomb"?

The Hayward Fault passes directly beneath both end zones at California Memorial Stadium, the home of football at the University of California, Berkeley. The site probably looked flat and easy to build on in 1922 before knowledge of earthquake faults was very advanced. Now, in the over-built East Bay, the land is worth an incredible amount of money. To make the stadium safe for workers, players, and fans, the stadium is being renovated in a $321 million project involving 10 miles of steel cables, silicone fluid-filled shock absorbers, concrete piers, 3 feet of sand, plastic sheeting, and stone columns. Go Bears!

New Construction

New construction can be made safer in many ways:

- Skyscrapers and other large structures built on soft ground must be anchored to bedrock, even if it lies hundreds of meters below the ground surface.
- The correct building materials must be used. Houses should bend and sway. Wood and steel are better than brick, stone, and adobe, which are brittle and will break.
- Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams are used to hold down sway.
- Large buildings can be placed on rollers so that they move with the ground.
- Buildings may be placed on layers of steel and rubber to absorb the shock of the waves.
- Connections, such as where the walls meet the foundation, must be made strong.

- In a multi-story building, the first story must be well supported (**Figure** 6.39).

FIGURE 6.39
The first floor of this San Francisco building is collapsing after the 1989 Loma Prieta earthquake.

Retrofitting

To make older buildings more earthquake safe, **retrofitting** with steel or wood can reinforce a building's structure and its connections (**Figure** 6.40). Elevated freeways and bridges can also be retrofitted so that they do not collapse.

Preventing Fire Damage

Fires often cause more damage than the earthquake. Fires start because seismic waves rupture gas and electrical lines, and breaks in water mains make it difficult to fight the fires (**Figure** 6.41). Builders zigzag pipes so that they bend and flex when the ground shakes. In San Francisco, water and gas pipelines are separated by valves so that areas can be isolated if one segment breaks.

Cost Considerations

Why aren't all structures in earthquakes zones constructed for maximum safety? Cost, of course. More sturdy structures are much more expensive to build. So communities must weigh how great the hazard is, what different building strategies cost, and make an informed decision.

In 1868 marked the Hayward Fault erupted in what would be a disastrous earthquake today. Since the fault erupts every 140 years on average, East Bay residents and geologists are working to prepare for the inevitable event.

See more at http://science.kqed.org/quest/video/the-hayward-fault-predictable-peril/.

Adobe Flash

MEDIA
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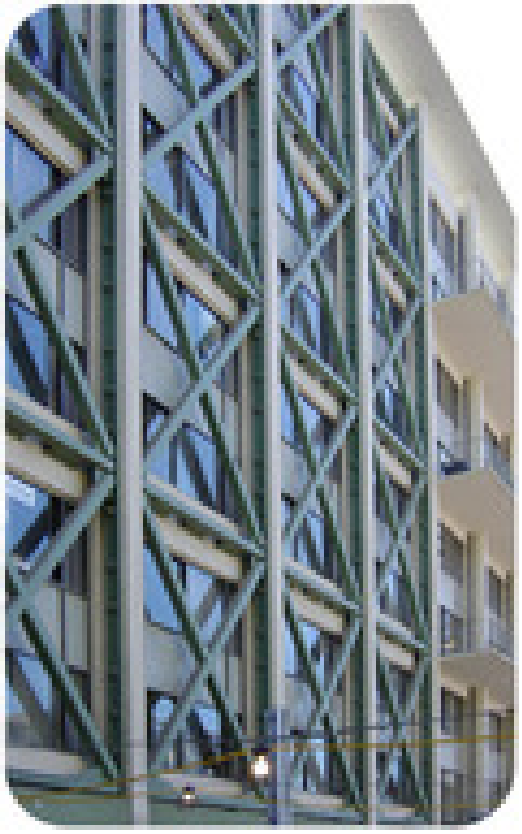

FIGURE 6.40
Steel trusses were built in an x-pattern to retrofit a dormitory at the University of California, Berkeley. The building is very near the Hayward Fault.

FIGURE 6.41
In the 1906 San Francisco earthquake, fire was much more destructive than the ground shaking.

Vocabulary

- **retrofit**: Adding new technology to older systems.

Summary

- New structures that are built to meet earthquake safety codes do much better in earthquakes.

- Old buildings can be retrofitted for better safety.
- Cost is an important factor in deciding how safe to make the structures in an area.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is LA's most earthquake proof building?
2. Why is it called a floating building?
3. How many suspension points are in the building?
4. What size earthquake should the building be able to withstand?
5. How far is it designed to move?

Review

1. Why do people build structures in earthquake-prone areas like the San Francisco or Los Angeles areas?
2. Why do fires do so much damage after an earthquake?
3. How do people weigh the costs and benefits to determining how earthquake safe to make structures in an area?

6.19 Staying Safe in an Earthquake

- Identify the preparations for and actions during and after an earthquake that increase safety.

How can you prepare for an earthquake?

If you live in earthquake country the actions you take before, during, and after a quake could make the difference in your comfort for several days or even your survival.

Protecting Yourself in an Earthquake

There are many things you can do to protect yourself before, during, and after an earthquake.

Before the Earthquake

- Have an engineer evaluate the house for structural integrity. Make sure the separate pieces — floor, walls, roof, and foundation — are all well-attached to each other.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places.
- 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 that 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.
- Prepare an earthquake kit with three days supply of water and food, a radio, and batteries.
- Place flashlights all over the house and in the glove box of your car.

- Keep several fire extinguishers around the house to fight small fires.
- Be sure to have a first aid kit. Everyone should know basic first aid and CPR.
- Plan in advance how you will evacuate 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, get beneath a sturdy table, cover your head, and hold on.
- Stay away from windows, mirrors, and large furniture.
- If the building is structurally unsound, get outside as fast as possible.
- If you are outside, run to an open area away from buildings and power lines that may fall.
- If you are in a car, stay in the car and stay away from structures that might collapse, such as 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 and power to your home.
- Use your phone only if there is an emergency. Many people will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

Summary

- Before an earthquake, be sure that your home is secure and that you have supplies to last a few days.
- During an earthquake, get to a safe place.
- After an earthquake, avoid dangerous situations, wait for instructions, and assist as necessary.

Practice

Use these resources to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is California's 4th season?
2. What should you do to prepare your home?
3. What should an emergency plan include?
4. What should you have in you disaster preparedness kit?

Earthquake Safety at http://www.ehow.com/video_5112721_earthquake-safety.html

5. What should you do when an earthquakes hits and you are in your home?
6. What should you do if you are outside when an earthquake hits?

7. How should you organize your home?

Review

1.What should you do to prepare for an earthquake?

2. What should you do during an earthquake?

3. What should you do after an earthquake?

6.20 Volcano Characteristics

- Define volcanoes, their locations, and their stages.

Do you think volcanoes are cool?

Active volcanoes are found on all continents except Australia. Volcanoes even erupt under the ice on Antarctica! Do you live near a volcano? What are the chances that it will erupt in your lifetime? If you don't live near one, could a volcanic eruption elsewhere cloud the skies above where you live?

Volcanoes

A volcano is a vent from which the material from a magma chamber escapes. Volcanic eruptions can come from peaky volcanic cones, fractured domes, a vent in the ground, or many other types of structures.

Where They Are

Volcanoes are a vibrant manifestation of plate tectonics processes. Volcanoes are common along convergent and divergent plate boundaries. Volcanoes are also found within lithospheric plates away from plate boundaries. Wherever mantle is able to melt, volcanoes may be the result.

What is the geological reason for the locations of all the volcanoes in the figure? Does it resemble the map of earthquake epicenters? Are all of the volcanoes located along plate boundaries? Why are the Hawaiian volcanoes located away from any plate boundaries?

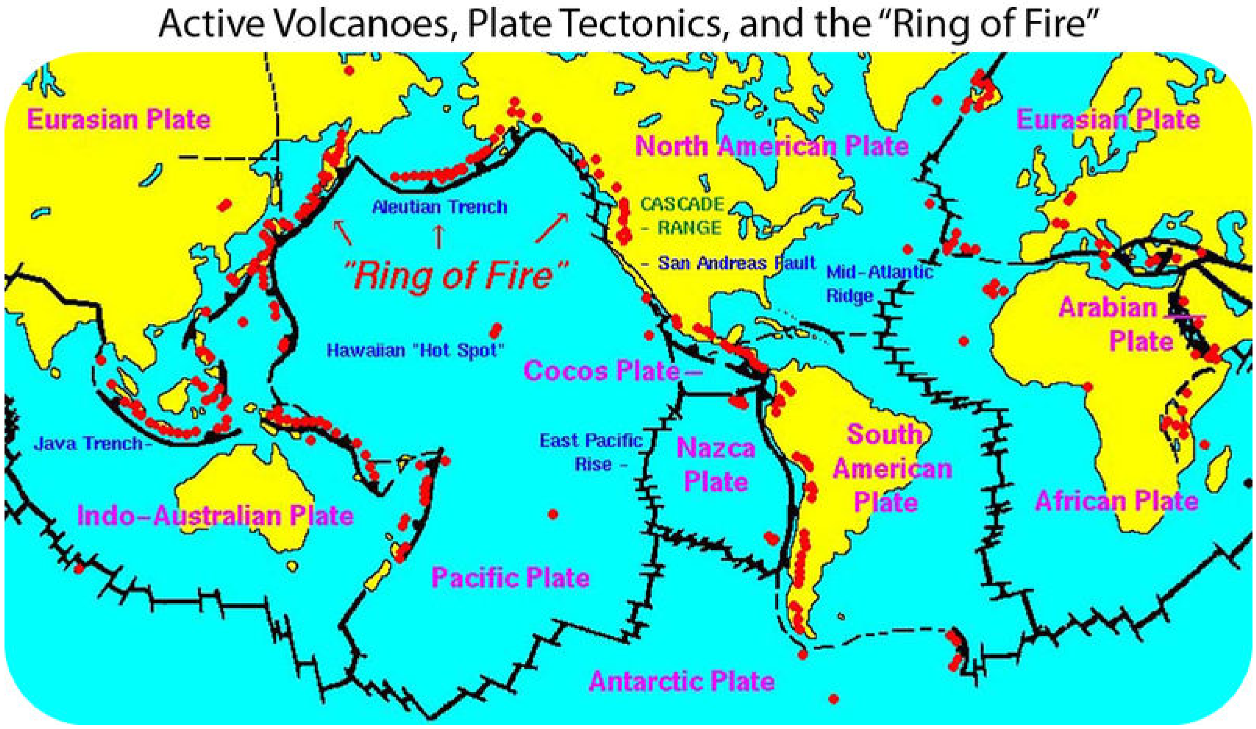

FIGURE 6.42
World map of active volcanoes.

Creating Magma

Volcanoes erupt because mantle rock melts. This is the first stage in creating a volcano. Remember from "Concept Materials of Earth's Crust" that mantle may melt if temperature rises, pressure lowers, or water is added. Be sure to think about how and why melting occurs in the settings where there is volcanism mentioned in the next few lessons.

Stages

Of all the volcanoes in the world, very few are erupting at any given time. Scientists question whether a volcano that is not erupting will ever erupt again and then describe it as active, dormant, or extinct.

- **Active:** currently erupting or showing signs of erupting soon.
- **Dormant:** no current activity, but has erupted recently.
- **Extinct:** no activity for some time; will probably not erupt again.

Vocabulary

- **active volcano**: A volcano that is currently erupting or is just about to erupt.
- **dormant volcano**: A volcano that is not currently erupting, but that has erupted in the recent past.
- **extinct volcano**: A volcano that has not erupted in recorded history, and is unlikely to erupt again.

FIGURE 6.43

Volcanoes can be active, dormant, or extinct.

Summary

- Volcanoes are located along convergent and divergent plate boundaries.
- Magma can be created when temperature rises, pressure lowers, or water is added.
- Volcanoes may be active, dormant, or extinct depending on whether there is the possibility of magma in their magma chambers.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Volcanoes**

1. How are volcanoes formed?

2. Where do volcanoes occur?

3. What is the Ring of Fire? Where is it located?

4. Where is Mount St. Helen's located?

5. Where is Mount Pinatubo located?

Review

1. Where do most volcanoes occur? Why?

2. What is needed for magma to form?

3. If a volcano is dormant, can it become active? Can it become extinct?

6.21 Volcanoes at Plate Boundaries

- Describe volcanic activity at convergent and divergent plate boundaries and explain why it occurs.

Climb a volcano... are you mad?

Volcanoes are fun (and difficult) to climb. Climbing in the Cascades ranges in difficulty from a non-technical hike, like on South Sister, to a technical climb on Mount Baker in which an ice axe, crampons, and experience are needed.

Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If both are continental they will smash together and form a mountain range. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes.

In Concept Plate Tectonics we moved up western North America to visit the different types of plate boundaries there. Locations with converging in which at least one plate is oceanic at the boundary have volcanoes.

Melting

Melting at convergent plate boundaries has many causes. The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. As the sediments subduct, the water rises into the overlying mantle material and lowers its melting point. Melting in the mantle above the subducting plate leads to volcanoes within an island or continental arc.

Pacific Rim

Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in the previous lesson, Volcanoes I: What is a Volcano?.

The Cascades are a chain of volcanoes at a convergent boundary where an oceanic plate is subducting beneath a continental plate. Specifically the volcanoes are the result of subduction of the Juan de Fuca, Gorda, and Explorer Plates beneath North America. The volcanoes are located just above where the subducting plate is at the right depth in the mantle for there to be melting.

FIGURE 6.44

The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

The Cascades have been active for 27 million years, although the current peaks are no more than 2 million years old. The volcanoes are far enough north and are in a region where storms are common, so many are covered by glaciers.

The Cascades are shown on this interactive map with photos and descriptions of each of the volcanoes: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/6.Volcanoes4Rollover.swf.

FIGURE 6.45
Mt. Baker, Washington.

Divergent plate boundaries

At divergent plate boundaries hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock convects upward it rises higher in the mantle. The rock is under lower pressure; this lowers the melting temperature of the rock and so it melts. Lava erupts through long cracks in the ground, or **fissures.**

Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (**Figure** 6.46).

FIGURE 6.46
A volcanic eruption at Surtsey, a small island near Iceland.

Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure** 6.47 are in the East African Rift between the African and Arabian plates. Remember from Concept Plate Tectonics that Baja California is being broken apart from mainland Mexico as another example of continental rifting.

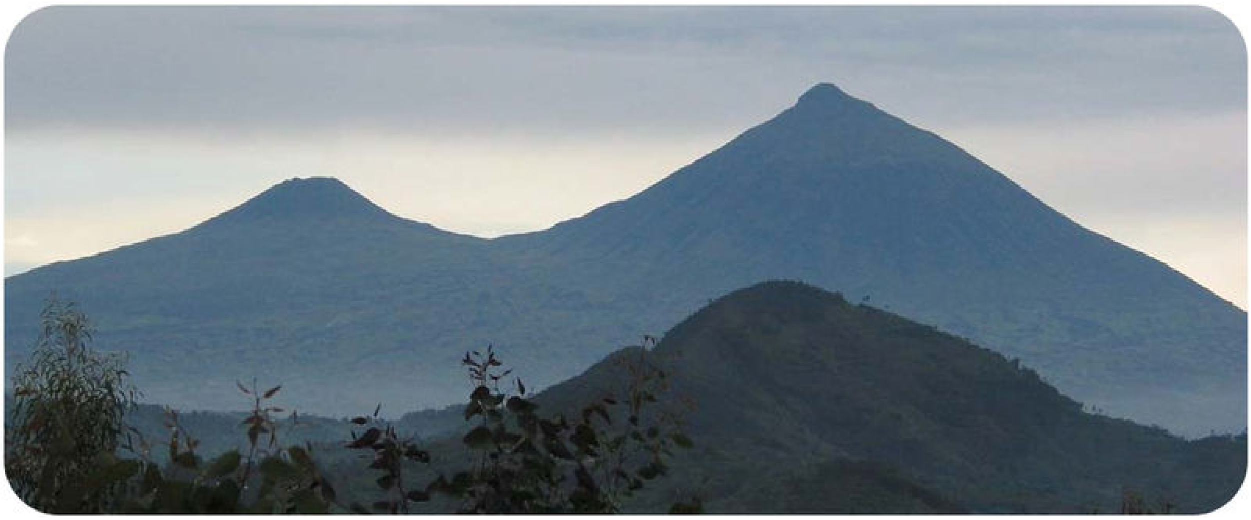

FIGURE 6.47
Mount Gahinga and Mount Muhabura in the East African Rift valley.

Vocabulary

- **fissure**: A crack in the ground that may be the site of a volcanic eruption.

Summary

- Melting is common at convergent plate boundaries.
- Convergent plate boundaries line the Pacific Ocean basin so that volcanic arcs line the region.
- Melting at divergent plate boundaries is due to pressure release.
- At mid-ocean ridges seafloor is pulled apart and new seafloor is created.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. Why does the melted rock rise?
2. What does spreading cause?
3. What happens at plate convergence?
4. How is carbon dioxide released from the rock?
5. How is carbon dioxide returned to the atmosphere?

Review

1. What causes melting at convergent plate boundaries?
2. Why are there so many volcanoes around the Pacific Ocean basin?
3. What causes melting at divergent plate boundaries?
4. How does a rifting within a continent lead to seafloor spreading?

6.22 Volcanoes at Hotspots

- Explain the relationship between hotspots and volcanic activity away from plate boundaries.

Hawaii is a hotspot, or is it a hot spot?

Both, actually. Hawaii is definitely a hot vacation spot, particularly for honeymooners. The Hawaiian Islands are formed from a hotspot beneath the Pacific Ocean. Volcanoes grow above the hotspot. Lava flows down the hillsides and some of it reaches the ocean, causing the islands to grow. Too hot now, but a great place in the future for beach lovers!

Intraplate Volcanoes

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes are found in the middle of a tectonic plate. These volcanoes rise at a hotspot above a **mantle plume**. Melting at a hotspot is due to pressure release as the plume rises through the mantle.

Earth is home to about 50 known hotspots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. But there are some large ones in the continents. Yellowstone is a good example of a mantle plume erupting within a continent.

Pacific Hotspots

The South Pacific has many hotspot volcanic chains. The hotspot is beneath the youngest volcano in the chain and older volcanoes are found to the northwest. A volcano forms above the hotspot, but as the Pacific Plate moves, that volcano moves off the hotspot. Without its source of volcanism, it no longer erupts. The crust gets cooler and the volcano erodes. The result is a chain of volcanoes and seamounts trending northwest from the hotspot.

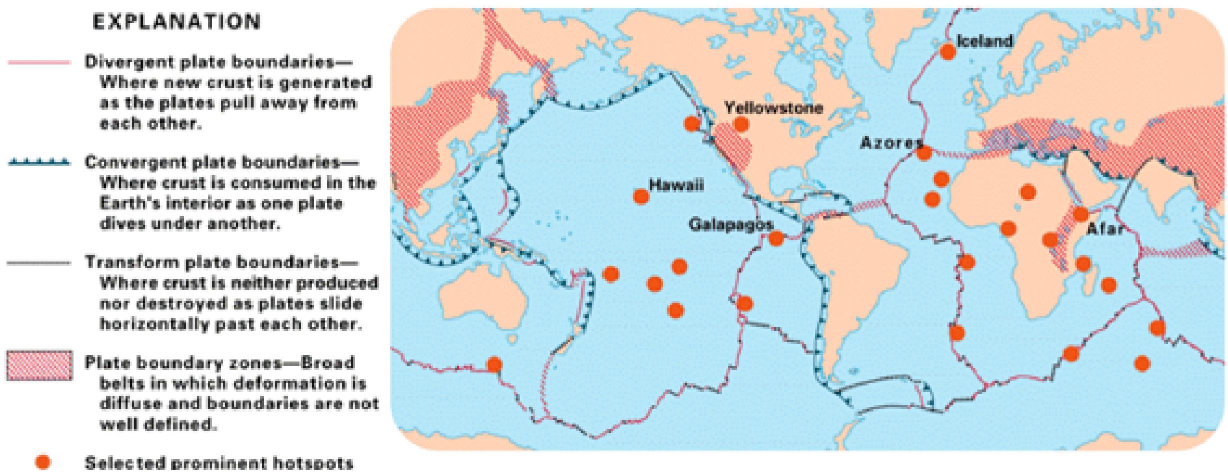

FIGURE 6.48

Prominent hotspots of the world.

The Society Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific Plate. The youngest island sits directly above the Society hotspot. (**Figure** 6.49).

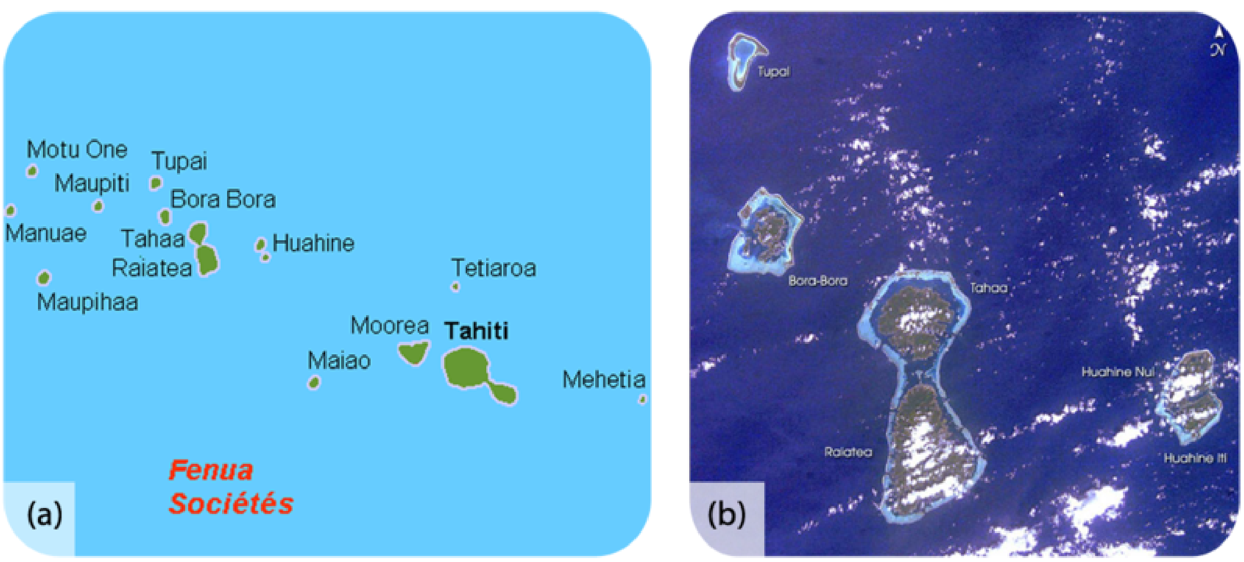

FIGURE 6.49

(a) The Society Islands formed above a hotspot that is now beneath Mehetia and two submarine volcanoes. (b) The satellite image shows how the islands become smaller and coral reefs became more developed as the volcanoes move off the hotspot and grow older.

The most famous example of a hotspot in the oceans is the Hawaiian Islands. Forming above the hotspot are massive shield volcanoes that together create the islands. The lavas are mafic and have low viscosity. These lavas produce beautiful ropy flows of pāhoehoe and clinkery flows of a'a, which will be described in more detail in Effusive Eruptions.

A hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed here(**3f**): http://www.youtube.com/watch?v=byJp5o49IF4#38;feature=related (2:06).

MEDIA

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Continental Hotspots

The hotspots that are known beneath continents are extremely large. The reason is that it takes a massive mantle plume to generate enough heat to penetrate through the relatively thick continental crust. The eruptions that come from these hotspots are infrequent but massive, often felsic and explosive. All that's left at Yellowstone at the moment is a giant caldera and a very hot spot beneath.

Hotspot Versus Island Arc Volcanoes

How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

Vocabulary

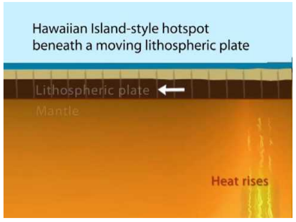
- **mantle plume**: A zone of hot material that rises toward the surface from deeper in the mantle and can generate hotspots.

Summary

- Volcanoes grow above hotspots, which are zones of melting above a mantle plume.
- Hotspot volcanoes are better able to penetrate oceanic crust, so there are more chains of hotspot volcanoes in the oceans.
- Shield volcanoes commonly form above hotspots in the oceans.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What is a hotspot?
2. What does a thermal plume allow for?
3. What causes convection?
4. What does the volcano build?
5. What carries the volcanoes away from a hotspot?

Review

1. What causes melting at a hotspot?
2. Why are there a relatively large number of hotspots in the Pacific Ocean basin?
3. Why do you think there are so many hotspots at mid-ocean ridges; e.g. four along the Mid-Atlantic Ridge and two at the East Pacific Rise?

6.23 Magma Composition at Volcanoes

- Describe types of magma composition and explain their effect on types of eruptions.

What's more viscous, water or honey?

Honey, of course! The composition of magma determines its viscosity, which affects how a lava flows and what kind of volcano forms from the lava.

Magma Composition

There are as many types of volcanic eruptions as there are eruptions. Actually more since an eruption can change character as it progresses. Each volcanic **eruption** is unique, differing in size, style, and composition of erupted material.

One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

Different minerals within a rock melt at different temperatures. The amount of partial melting and the composition of the original rock determine the composition of the magma.

The words that describe composition of igneous rocks also describe magma composition.

- Mafic magmas are low in silica and contain more dark, magnesium- and iron-rich mafic minerals, such as olivine and pyroxene.
- Felsic magmas are higher in silica and contain lighter colored minerals such as quartz and orthoclase feldspar. The higher the amount of silica in the magma, the higher is its **viscosity**. Viscosity is a liquid's resistance to flow.

Viscosity determines what the magma will do. Mafic magma is not viscous and will flow easily to the surface. Felsic magma is viscous and does not flow easily. Most felsic magma will stay deeper in the crust and will cool to form igneous intrusive rocks such as granite and granodiorite. If felsic magma rises into a magma chamber, it may be too viscous to move, so it gets stuck. Dissolved gases become trapped by thick magma. The magma churns in the chamber and the pressure builds.

Magma collects in **magma chambers** in the crust at 160 kilometers (100 miles) beneath the surface.

Vocabulary

- **eruption**: The release of lava, tephra, and gases from a volcano.
- **magma chamber**: A region below a volcano where magma and gases collect.
- **viscosity**: The thickness of a liquid; its resistance to flow.

Summary

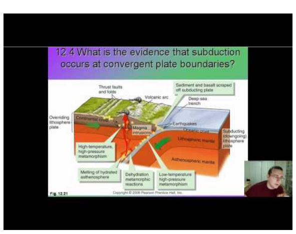
- Magmas differ in composition, which affects viscosity. Magma composition has a large effect on how a volcano erupts.
- Felsic lavas are more viscous and erupt explosively or do not erupt.
- Mafic lavas are less viscous and erupt effusively.

Practice

Use this resource to answer the questions that follow.

Magma Factors

http://www.youtube.com/watch?v=R0GT-C6BddA



MEDIA

Click image to the left for more content.

1. What are the two categories of magma?
2. What is mafic lava rich in?
3. Where is mafic lava eruptions more common?
4. What is felsic lava rich in?

5. Where is felsic lava found?
6. What are the characteristics of felsic lava?
7. List the characteristics of mafic lava.

Review

1. Why do felsic lavas erupt explosively? Why do mafic lavas erupt effusively?
2. How is magma composition related to viscosity?
3. How does the type of volcano formed relate to the viscosity of the magma that erupts from it?

6.24 Explosive Eruptions

- Describe the causes and effects of explosive volcanic eruptions.

Why do we still talk about Pompeii, 79 AD?

Nearly 2,000 years later, the explosive eruption of Mt. Vesuvius remains one of the most talked about eruptions in history. It began with a column of ash that blanketed the area, which was followed by fast-moving, dense, and scorching-hot pyroclastic flows. People suffocated or burnt, and structures in two thriving Roman cities were destroyed. Remains of some of the dead can be seen at Pompeii, where people were entombed in scorching ash. The eruption type was named plinian, after Pliny the Younger, who watched from offshore.

Explosive Eruptions

A large **explosive eruption** creates even more devastation than the force of the atom bomb dropped on Nagasaki at the end of World War II, in which more than 40,000 people died. A large explosive volcanic eruption is 10,000 times as powerful. Explosive eruptions are found at the convergent plate boundaries that line parts of western North America, resulting in the Cascades in the Pacific Northwest and the Aleutians in Alaska.

Causes of the Explosion

Explosive eruptions are caused by gas-rich, felsic magmas that churn within the magma chamber. When the pressure becomes too great the magma breaks through the rock above the chamber and explodes, just like when a cork is released from a bottle of champagne. Magma, rock, and ash burst upward in an enormous explosion (**Figure** 6.50).

FIGURE 6.50
Ash and gases create a mushroom cloud above Mt. Redoubt in Alaska, 1989. The cloud reached 45,000 feet and caught a Boeing 747 in its plume.

Pyroclastic Material

The erupted rock fragments are called **tephra**. Ash and gas also explode from the volcano. Scorching hot tephra, ash, and gas may speed down the volcano's slopes at 700 km/h (450 mph) as a **pyroclastic flow**. Pyroclastic means fire rock (**Figure** 6.51).

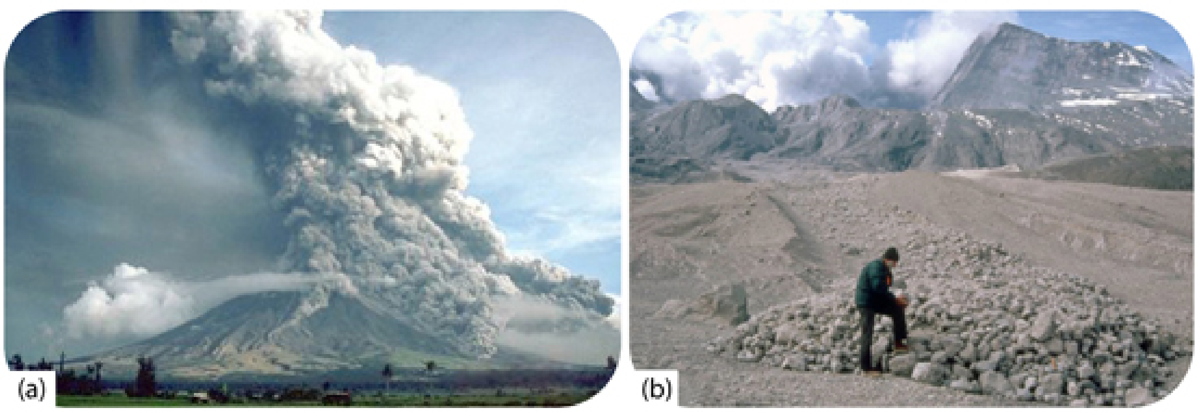


FIGURE 6.51
(a) An explosive eruption from the Mayon Volcano in the Philippines in 1984. Ash flies upward into the sky and pyroclastic flows pour down the mountainside. (b) The end of a pyroclastic flow at Mount St. Helens.

Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000^{o}C (1,800^{o}F).

A pyroclastic flow at Montserrat volcano is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/PyroclasticFlow.MOV.

FIGURE 6.52
Blowdown of trees near Mount St. Helens shows the direction of the blast and pyroclastic flow.

Cascades Volcanoes

Prior to the Mount St. Helens eruption in 1980, the Lassen Peak eruption on May 22, 1915, was the most recent Cascades eruption. A column of ash and gas shot 30,000 feet into the air. This triggered a high-speed pyroclastic flow, which melted snow and created a volcanic mudflow known as a **lahar**. Lassen Peak currently has geothermal activity and could erupt explosively again. Mt. Shasta, the other active volcano in California, erupts every 600 to 800 years. An eruption would most likely create a large pyroclastic flow, and probably a lahar. Of course, Mt. Shasta could explode and collapse like Mt. Mazama in Oregon (**Figure** 6.53).

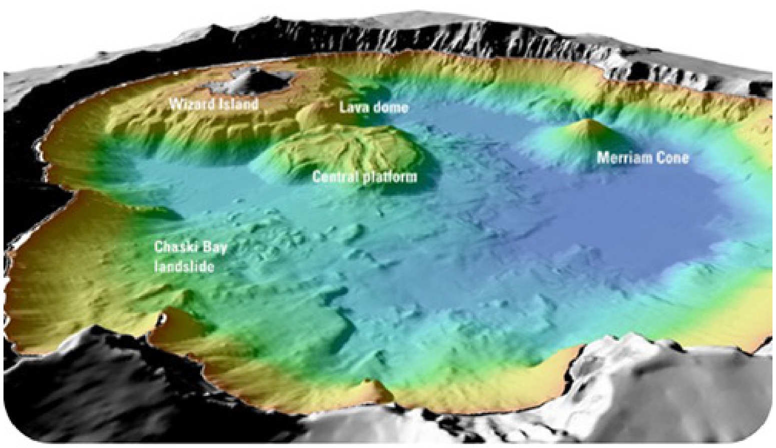


FIGURE 6.53
Crater Lake fills the caldera of the collapsed Mt. Mazama, which erupted with 42 times more power than Mount St. Helens in 1980. The bathymetry of the lake shows volcanic features such as cinder cones.

Volcanic Gases

Volcanic gases can form poisonous and invisible clouds in the atmosphere. These gases may contribute to environmental problems such as acid rain and ozone destruction. Particles of dust and ash may stay in the atmosphere for years, disrupting weather patterns and blocking sunlight (**Figure** 6.54).

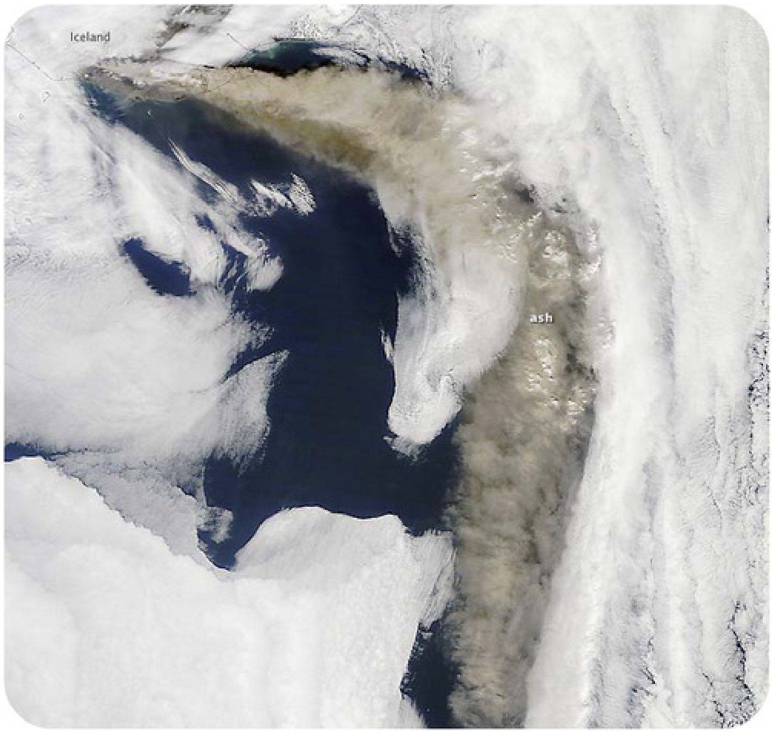


FIGURE 6.54

The ash plume from Eyjafjallajökull volcano in Iceland disrupted air travel across Europe for six days in April 2010.

Vocabulary

- **explosive eruption**: A potentially devastating eruption of rock, lava, ash, and gas exploding from a volcano.
- **lahar**: A volcanic mudflow containing ash, rock, and water from melting snow or rainfall that races down river valleys during an eruption.
- **pyroclastic flow**: Hot ash, gas, and rock that race down a volcano's slopes during an eruption.
- **tephra**: Fragments of material produced in a volcanic eruption.

Summary

- Felsic magmas erupt explosively, creating pyroclastic eruptions.
- Pyroclastic eruption types include tephra, ash, and lahars.
- Mt. Mazama blew its top off and then collapsed, creating Crater Lake in Oregon.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What was the force of Mt. Saint Helens' eruption?

2. How many people died in this eruption?

3. How much ash was sent into the air?
4. What type of eruption was it?
5. What is the deadliest part of the eruption?

Review

1. Why do convergent plate boundaries have explosive eruptions?
2. Why do felsic magmas erupt explosively?
3. How do volcanic gases affect the atmosphere?

6.25 Effusive Eruptions

- Describe the causes and effects of effusive volcanic eruptions.

Is Stromboli just a rolled-up pizza?

For most people a stromboli is a rolled sandwich of dough, cheeses, and meats. For volcanologists, Stromboli is a volcano for which a type of eruption was named. Strombolian eruptions spew lava into the air but do not explode as massively as in the plinian eruptions in the previous lesson. Still, the power of a volcano is easily seen in this eruption on Mt. Stromboli in Italy.

Effusive Eruptions

Mafic magma creates gentler **effusive eruptions**. Although the pressure builds enough for the magma to erupt, it does not erupt with the same explosive force as felsic magma. Magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent (**Figure** 6.55). Effusive eruptions are common in Hawaii, where lavas are mafic.

FIGURE 6.55
In effusive eruptions, lava flows readily, producing rivers of molten rock.

- The Kilauea volcanic eruption in 2008 is seen in this short video: http://www.youtube.com/watch?v=BtH79yxBIJI.
- A Quicktime movie with thermal camera of a lava stream within the vent of a Hawaiian volcano is seen here: http://hvo.wr.usgs.gov/kilauea/update/archive/2009/Nov/OverflightFLIR_13Jan2010.mov.

Types of Lava

Low-viscosity lava flows down mountainsides. Differences in composition and where the lavas erupt result in three types of lava flow coming from effusive eruptions. A'a lava forms a thick and brittle crust that is torn into rough and jagged pieces. A'a lava can spread over large areas as the lava continues to flow underneath the crust's surface. Pāhoehoe lava forms lava tubes where fluid lava flows through the outer cooled rock crust. Pāhoehoe lava is less viscous than a'a lava, so its surface looks is smooth and ropy. Mafic lava that erupts underwater creates pillow lava. The lava cools very quickly, forming roughly spherical rocks. Pillow lava is common at mid-ocean ridges (**Figure** 6.56).

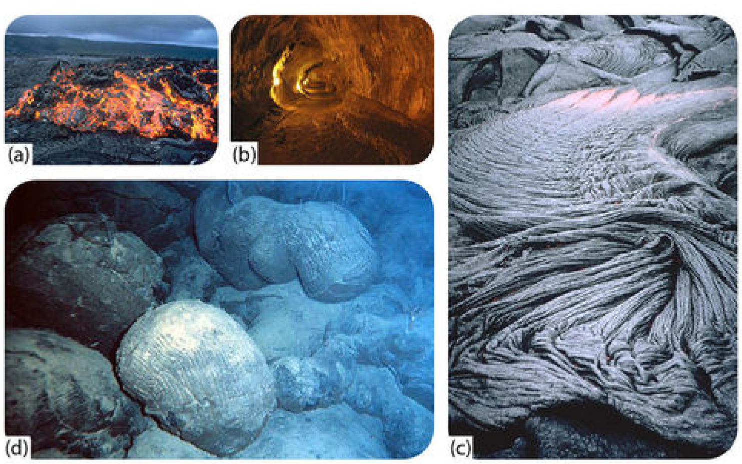


FIGURE 6.56
(a) A'a lava spread over large areas. (b) Pāhoehoe lava tubes where at the Thurston Lava Tube in Hawai[U+02BB]i Volcanoes National Park. (c) Pāhoehoe lava is less viscous than a'a lava so its surface looks is smooth and ropy. (d) Pillow lava.

- Undersea eruption videos are seen here http://news.discovery.com/videos/earth-undersea-eruption-now-in-stereo.html and here http://news.discovery.com/videos/earth-underwater-volcano-caught-on-video.html.

Effusive Eruptions Damage

People can usually be evacuated before an effusive eruption, so they are much less deadly. Although effusive eruptions rarely kill anyone, they can be destructive. Even when people know that a lava flow is approaching, there is not much anyone can do to stop it from destroying a building or road (**Figure** 6.57).

FIGURE 6.57
A road is overrun by an eruption at Kilauea volcano in Hawaii.

Vocabulary

- **effusive eruption**: A relatively gentle, non-explosive volcanic eruption.

Summary

- Mafic magma creates effusive eruptions. The pressure builds but the lava does not explode so violently from the vent.
- Effusive eruptions cause damage but usually people can be evacuated, so there are few or no fatalities.
- Mafic magma cools into different types of flows like a'a, pāhoehoe, and pillow lava.

Practice

Use these resources to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is observed instantly at this volcano?

2. What creates this type of lava at the surface?
3. What does this type of lava produce?

Multimedia

MEDIA
Click image to the left for more content.

4. How long has Kilauea been erupting?
5. What are the lava flows building?
6. What is this land called?
7. Why do scientists map the tephra?
8. What are skylights? What do scientists learn from them?

Review

1. Why do mafic lavas flow rather than explode?
2. Compare and contrast a'a and pāhoehoe lavas.
3. How do pillow lavas form?

6.26 Predicting Volcanic Eruptions

- Explain how scientists attempt to predict volcanic eruptions.

Can she see your future?

No one can predict exactly when a volcanic eruption will take place. Scientists do a bit better forecasting volcanic eruptions than earthquakes. Still, volcanologists have a high fatality rate because forecasting eruptions is so difficult.

Predicting Volcanic Eruptions

Many pieces of evidence can mean that a volcano is about to erupt, but the time and magnitude of the eruption are difficult to pin down. This evidence includes the history of previous volcanic activity, earthquakes, slope deformation, and gas emissions.

History of Volcanic Activity

A volcano's history — how long since its last eruption and the time span between its previous eruptions — is a good first step to predicting eruptions. Active and dormant volcanoes are heavily monitored, especially in populated areas.

Earthquakes

Moving magma shakes the ground, so the number and size of earthquakes increases before an eruption. A volcano that is about to erupt may produce a sequence of earthquakes. Scientists use seismographs that record the length and strength of each earthquake to try to determine if an eruption is imminent.

Slope Deformation

Magma and gas can push the volcano's slope upward. Most ground deformation is subtle and can only be detected by tiltmeters, which are instruments that measure the angle of the slope of a volcano. But ground swelling may sometimes create huge changes in the shape of a volcano. Mount St. Helens grew a bulge on its north side before its 1980 eruption. Ground swelling may also increase rock falls and landslides.

Gas Emissions

Gases may be able to escape a volcano before magma reaches the surface. Scientists measure gas emissions in vents on or around the volcano. Gases, such as sulfur dioxide (SO_2), carbon dioxide (CO_2), hydrochloric acid (HCl), and even water vapor can be measured at the site (**Figure** 6.58) or, in some cases, from a distance using satellites. The amounts of gases and their ratios are calculated to help predict eruptions.

FIGURE 6.58
Scientists monitoring gas emissions at Mount St. Helens.

Remote Monitoring

Some gases can be monitored using satellite technology (**Figure** 6.59). Satellites also monitor temperature readings and deformation. As technology improves, scientists are better able to detect changes in a volcano accurately and safely.

FIGURE 6.59
An Earth-Observation Satellite before launch.

Evacuate?

Since volcanologists are usually uncertain about an eruption, officials may not know whether to require an evacuation. If people are evacuated and the eruption doesn't happen, the people will be displeased and less likely to evacuate the next time there is a threat of an eruption. The costs of disrupting business are great. However, scientists continue to work to improve the accuracy of their predictions.

Summary

- Volcanologists use several lines of evidence to try to forecast volcanic eruptions.
- Magma moving beneath a volcano will cause earthquakes and slope deformation. Gases may be released from the magma out of the volcano vent.
- Deciding whether to call for an evacuation is very tricky.

Practice

Use this resource to answer the questions that follow.

Mount Pinatubo: Predicting a Volcanic Eruption http://www.teachersdomain.org/asset/ess05_vid_pinatubo/

1. What does the measurement of sulfur dioxide tell scientists?
2. How many seismic stations for established around the mountain?
3. What did the seismic stations measure?
4. What evidence was there for a potential eruption?
5. What finally triggered the evacuation from the island?
6. When did the first eruption occur? How soon after the evacuation?
7. When did the massive eruption occur?

Review

1. What are the detectable signs that magma is moving beneath a volcano?
2. What are the consequences of incorrectly predicting a volcanic eruption?
3. How would a successful prediction of a volcanic eruption resemble a successful prediction of an earthquake?

6.27 Types of Volcanoes

- Describe the magma compositions and characteristics of different types of volcanoes.

What does an active volcano look like?

Climbing up Mount St. Helens and looking into the crater at the steaming dome is an incredible experience. The slope is steep and the landscape is like something from another planet. Nothing's alive up there, except maybe a bird. When you're standing on the top you can see off to others of the Cascades volcanoes: Mt. Adams, Rainier, Hood, Jefferson, and sometimes more.

Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features, such as height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground (**Figure** 6.61). As you might expect, the shape of a volcano is related to the composition of its magma.

Composite Volcanoes

Composite volcanoes are constructed of felsic to intermediate rock. The viscosity of the lava means that eruptions at these volcanoes are often explosive.

Eruptions at Composite Volcanoes

Viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. In some eruptions the pressure builds up so much that the material explodes as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other (**Figure** 6.62). The result is the classic cone shape of composite volcanoes.

FIGURE 6.60
Mt. Fuji in Japan is one of the world's most easily recognized composite volcanoes.

FIGURE 6.61
Mount St. Helens was a beautiful, classic, cone-shaped volcano. In May 1980 the volcano blew its top off in an explosive eruption, losing 1,300 feet off its summit.

Shield Volcanoes

Shield volcanoes get their name from their shape. Although shield volcanoes are not steep, they may be very large. Shield volcanoes are common at spreading centers or intraplate hot spots (**Figure** 6.63). Hawaii has some spectacular shield volcanoes including Mauna Kea, which is the largest mountain on Earth from base to top. The mountain stands 33,500 ft high, about 4,000 feet greater than the tallest mountain above sea level, Mt. Everest.

Eruptions at Shield Volcanoes

The lava that creates shield volcanoes is fluid and flows easily. The spreading lava creates the shield shape. Shield volcanoes are built by many layers over time and the layers are usually of very similar composition. The low viscosity also means that shield eruptions are non-explosive.

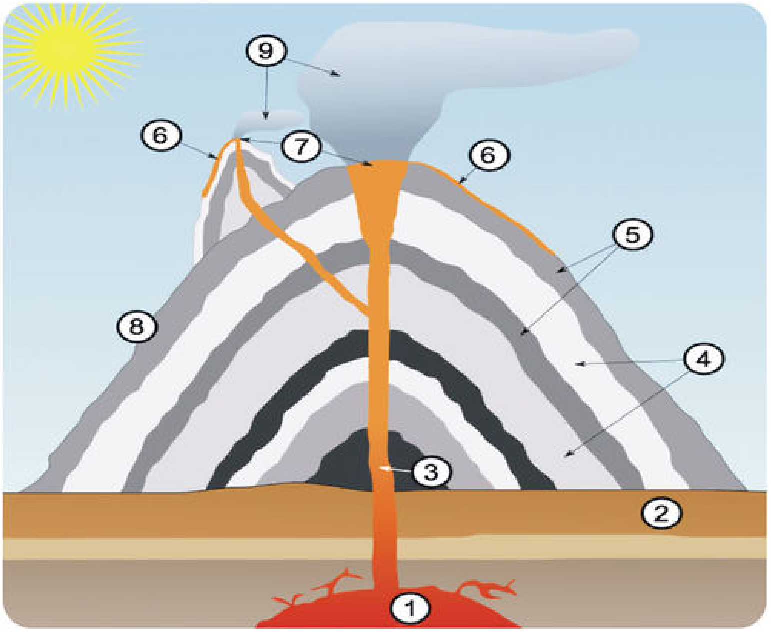


FIGURE 6.62

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.

FIGURE 6.63

Mauna Kea on the Big Island of Hawaii is a classic shield volcano.

This "Volcanoes 101" video from National Geographic discusses where volcanoes are found and what their properties come from (**3e**): http://www.youtube.com/watch?feature=player_profilepage#38;v=uZp1dNybgfc (3:05).

MEDIA

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Cinder Cones

Cinder cones are the most common type of volcano. A cinder cone has a cone shape, but is much smaller than a composite volcano. Cinder cones rarely reach 300 meters in height, but they have steep sides. Cinder cones grow rapidly, usually from a single eruption cycle. These volcanoes usually flank shield or composite volcanoes. Many cinder cones are found in Hawaii.

FIGURE 6.64
A lava fountain erupts from Pu'u O'o, a cinder cone on Kilauea.

Eruptions at Cinder Cones

Cinder cones are composed of small fragments of rock, such as pumice, piled on top of one another. The rock shoots up in the air and doesn't fall far from the vent. The exact composition of a cinder cone depends on the composition of the lava ejected from the volcano. Cinder cones usually have a crater at the summit. Most cinder cones are active only for a single eruption.

Vocabulary

- **cinder cone**: A small volcano composed of small rock fragments piled on top of one another.
- **composite volcano**: A large, steep-sided composed of alternating layers of ash and lava flows.
- **shield volcano**: A shield-shaped volcano composed of fluid lavas.

Summary

- Magma composition determines both eruption type and volcano type.

- Composite cones are built of felsic to intermediate lava and shield volcanoes of mafic lava.
- Cinder cones are made of small fragments of a variety of compositions usually from a single eruption.

Practice

Use these resources to answer the questions that follow.

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Composite Volcanoes**

1. What is another name for composite volcanoes?

2. Explain the composite volcano's typical structure.

3. List two examples of composite volcanoes. What is the location of each?

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Cinder Cones**

4. How is a cinder cone formed?

5. What is cinder cone's typical maximum height?

6. Where is Lava Butte located?

7. When did Izalco last erupt?

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Shield Volcanoes**

8. Describe a shield volcano's structure.

9. What is the height of Mauna Loa?

10. Where is Mount Washington located? How old is it?

Review

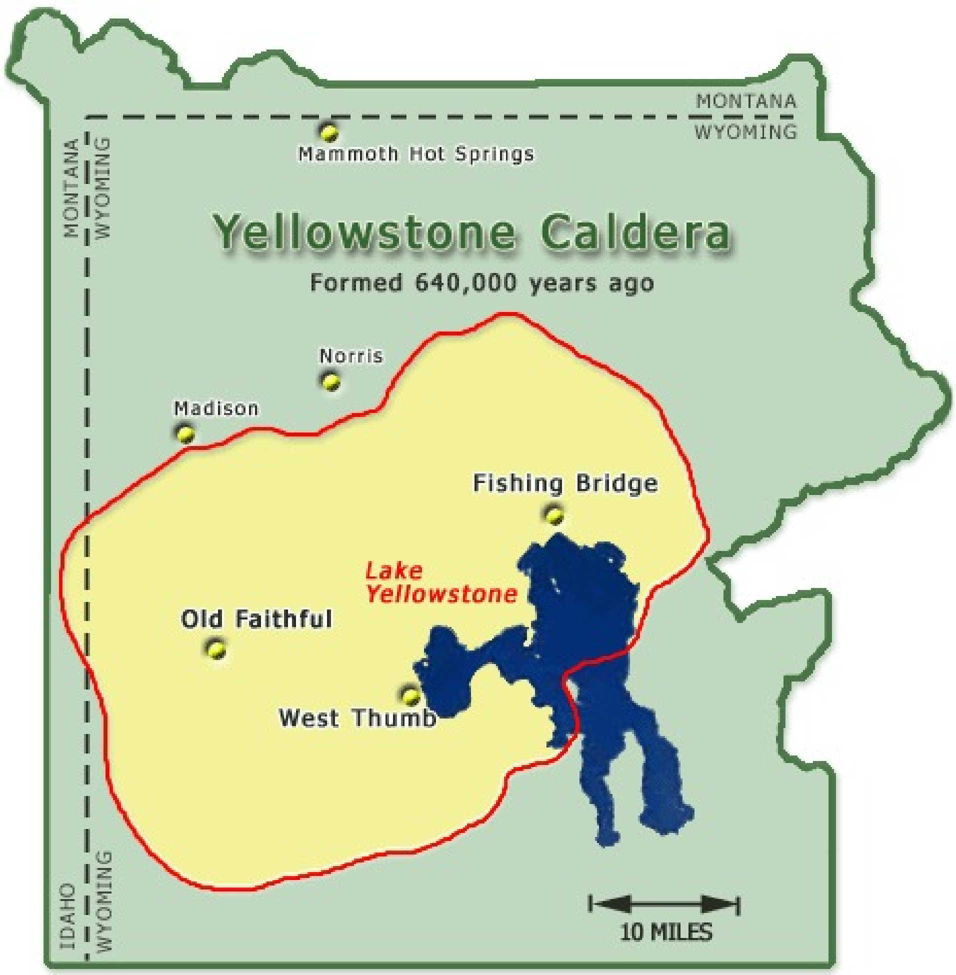
1. Why do mafic lavas produce shield-shaped volcanoes and felsic lavas produce cone-shaped volcanoes?

2. From what does a composite volcano get its name?

3. Describe how a cinder cone forms.

6.28 Supervolcanoes

- Describe the characteristics of supervolcanoes and their eruptions.



What would cause such a giant caldera?

You can stand on the rim and view the enormous Yellowstone Caldera, but it's hard to visualize a volcano or a set of eruptions that enormous. Supervolcanoes are a fairly new idea in volcanology. Although their eruptions are unbelievably massive, they are exceedingly rare. The power of Yellowstone, even 640,000 years after the most recent eruption, is seen in its fantastic geysers.

Supervolcanoes

Supervolcano eruptions are extremely rare in Earth's history. It's a good thing because they are unimaginably large. A supervolcano must erupt more than 1,000 cubic km (240 cubic miles) of material, compared with 1.2 km^3 for Mount St. Helens or 25 km^3 for Mount Pinatubo, a large eruption in the Philippines in 1991. Not surprisingly, supervolcanoes are the most dangerous type of volcano.

Supervolcano Eruptions

The exact cause of supervolcano eruptions is still debated. However, scientists think that a very large magma chamber erupts entirely in one catastrophic explosion. This creates a huge hole or **caldera** into which the surface collapses (**Figure** 6.65).

FIGURE 6.65
The caldera at Santorini in Greece is so large that it can only be seen by satellite.

Yellowstone Caldera

The largest supervolcano in North America is beneath Yellowstone National Park in Wyoming. Yellowstone sits above a hotspot that has erupted catastrophically three times: 2.1 million, 1.3 million, and 640,000 years ago. Yellowstone has produced many smaller (but still enormous) eruptions more recently (**Figure** 6.66). Fortunately, current activity at Yellowstone is limited to the region's famous geysers.

The Old Faithful web cam shows periodic eruptions of Yellowstone's famous geyser in real time: http://www.nps.gov/archive/yell/oldfaithfulcam.htm.

Supervolcano Eruptions and Life on Earth

A supervolcano could change life on Earth as we know it. Ash could block sunlight so much that photosynthesis would be reduced and global temperatures would plummet. Volcanic eruptions could have contributed to some of the mass extinctions in our planet's history. No one knows when the next super eruption will be.

Interesting volcano videos are seen on National Geographic Videos, Environment Video, Natural Disasters, Earthquakes: http://video.nationalgeographic.com/video/player/environment/. One interesting one is "Mammoth Mountain," which explores Hot Creek and the volcanic area it is a part of in California.

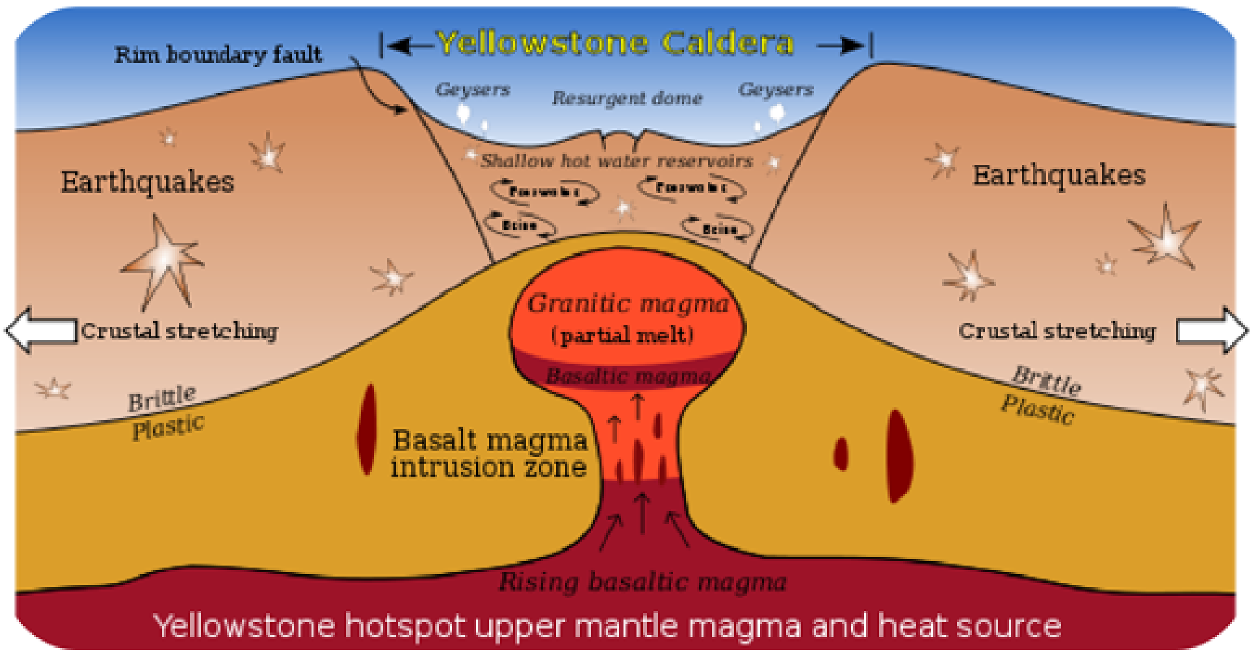


FIGURE 6.66
The Yellowstone hotspot has produced enormous felsic eruptions. The Yellowstone caldera collapsed in the most recent super eruption.

Vocabulary

- **caldera**: Circular-shaped hole into which a volcano collapses during an eruption.
- **supervolcano**: A massive volcano that can produce unbelievably enormous, but rare, eruptions.

Summary

- Supervolcano eruptions are rare but massive and deadly.
- Yellowstone Caldera is a supervolcano that has erupted catastropically three times.
- Supervolcano eruptions can change the course of life on Earth.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is the question at Yellowstone?
2. Why is gravity weaker at Yellowstone?
3. What will be the first indications of an eruption?
4. What is danger zone of a Yellowstone eruption?
5. How far may a pyroclastic flow reach?
6. What problems will the ash cause?
7. What is the deadliest part of the eruption?
8. What would the possible long term effects of an eruption?

Review

1. What is the composition of supervolcano eruptions? Why are these eruptions so massive?
2. What is the source of volcanism for the supervolcano at Yellowstone?
3. How does a supervolcano eruption potentially change the course of life on Earth?

6.29 Volcanic Landforms

- Identify and describe landforms created by volcanic activity.

Why is the Republic of Indonesia made of 17,508 islands?

Around the Pacific Rim is Indonesia, a nation built from the dotted volcanoes of an island arc. Indonesia is distinctive for its rich volcanic soil, tropical climate, tremendous biodiversity, and volcanoes. These volcanoes are in Java, Indonesia.

Landforms from Lava

Volcanoes and Vents

The most obvious landforms created by lava are volcanoes, most commonly as cinder cones, composite volcanoes, and shield volcanoes. Eruptions also take place through other types of vents, commonly from fissures (**Figure** 6.67). The eruptions that created the entire ocean floor are essentially fissure eruptions.

Lava Domes

Viscous lava flows slowly. If there is not enough magma or enough pressure to create an explosive eruption, the magma may form a **lava dome**. Because it is so thick, the lava does not flow far from the vent. (**Figure** 6.68).

Lava flows often make mounds right in the middle of craters at the top of volcanoes, as seen in the **Figure** 6.69.

FIGURE 6.67
A fissure eruption on Mauna Loa in Hawaii travels toward Mauna Kea on the Big Island.

FIGURE 6.68
Lava domes are large, round landforms created by thick lava that does not travel far from the vent.

Lava Plateaus

A **lava plateau** forms when large amounts of fluid lava flow over an extensive area (**Figure** 6.70). When the lava solidifies, it creates a large, flat surface of igneous rock.

Land

Lava creates new land as it solidifies on the coast or emerges from beneath the water (**Figure** 6.71).

FIGURE 6.69

Lava domes may form in the crater of composite volcanoes as at Mount St. Helens

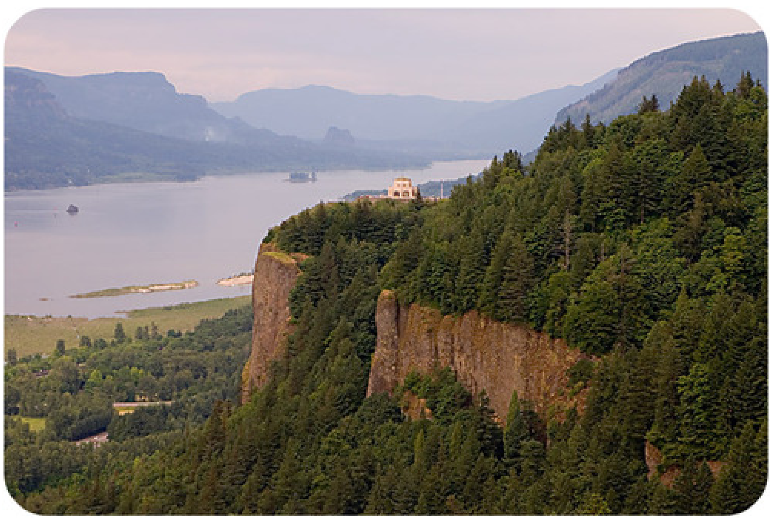


FIGURE 6.70

Layer upon layer of basalt have created the Columbia Plateau, which covers more than 161,000 square kilometers (63,000 square miles) in Washington, Oregon, and Idaho.

FIGURE 6.71

Lava flowing into the sea creates new land in Hawaii.

Over time the eruptions can create whole islands. The Hawaiian Islands are formed from shield volcano eruptions that have grown over the last 5 million years (**Figure** 6.72).

FIGURE 6.72
The island of Hawaii was created by hotspot volcanism. You can see some of the volcanoes (both active and extinct) in this mosaic of false-color composite satellite images.

Landforms from Magma

Magma intrusions can create landforms. Shiprock in New Mexico is the neck of an old volcano that has eroded away (**Figure** 6.73). The volcanic neck is the remnant of the conduit the magma traveled up to feed an eruption.

FIGURE 6.73
The aptly named Shiprock in New Mexico.

Vocabulary

- **lava dome**: A dome-shaped plug of viscous lava that cools near the vent of a volcano.
- **lava plateau**: A flat area formed by the eruption of large amounts of fluid lava.

Summary

- Landforms created by lava include volcanoes, domes, and plateaus.
- New land can be created by volcanic eruptions.
- Landforms created by magma include volcanic necks and domes.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What type of lava is produced by volcanoes?
2. How did the columns in the video form?
3. How was Fingal's cave formed?
4. Describe how the basalt lava flows?
5. How does basalt behave when it has a lot of gas trapped within it?

Review

1. What is Shiprock and how did it form?
2. How do lava plateaus form?
3. What types of landforms are created by very viscous magma?

6.30 Hot Springs and Geysers

- Define hot springs and geysers, and explain how they work.

Hot spring, anyone?

Even some animals enjoy relaxing in nature's hot tubs. Care to join them?

Hot Springs and Geysers

Water sometimes comes into contact with hot rock. The water may emerge at the surface as either a hot spring or a geyser.

Hot Springs

Water heated below ground that rises through a crack to the surface creates a **hot spring**. The water in hot springs may reach temperatures in the hundreds of degrees Celsius beneath the surface, although most hot springs are much cooler.

Geysers

Geysers are also created by water that is heated beneath the Earth's surface, but geysers do not bubble to the surface — they erupt.

When water is both superheated by magma and flows through a narrow passageway underground, the environment is ideal for a geyser. The passageway traps the heated water underground, so that heat and pressure can build.

FIGURE 6.74
Even in winter, the water in this hot spring in Yellowstone doesn't freeze.

Eventually, the pressure grows so great that the superheated water bursts out onto the surface to create a geyser. **Figure** 6.75.

Conditions are right for the formation of geysers in only a few places on Earth. Of the roughly 1,000 geysers worldwide, about half are found in the United States.

FIGURE 6.75
Castle Geyser is one of the many geysers at Yellowstone National Park. Castle erupts regularly, but not as frequently or predictably as Old Faithful.

Vocabulary

- **geyser**: A fountain of hot water and steam that erupts onto the surface.
- **hot spring**: A stream of hot water that flows out of the ground continuously.

Summary

- When magma heats groundwater it may come to the surface as a hot spring or a geyser.

- Geysers erupt because the water is trapped and becomes superheated until finally the pressure builds enough for it to break the seal.
- Yellowstone is famous for its geysers. Hot Creek in California is also above a supervolcano.

Practice

Use these resources to answer the questions that follow.

http://www.nps.gov/yell/naturescience/geysers_work.htm

1. What is required for a geyser to occur?
2. What provides the heat?
3. What supplies the water?

http://www.unmuseum.org/flash/geyflash.htm

4. How is a hot spring created?
5. Explain how a fumarole occurs?
6. How is a mud pot created?

Review

1. What creates a hot spring?
2. Why do geysers erupt rather than just bubble to the surface like a hot spring?
3. Are hot springs and geysers always found where there is active volcanism? What is the source of the heat?

Summary

Most earthquakes and volcanoes are located along plate boundaries. Plate tectonic processes can explain why we see these types of geological activity where we do. Stresses build up in some locations and may cause folding or faulting. Earthquakes strike along all three types of plate boundaries. The most damaging earthquakes are shallow and people in earthquake-prone regions must be aware of the potential damage from earthquakes. Seismologists have scales for measuring earthquake intensity and magnitude and work with designers to create earthquake-safe structures and guidelines for being safe in earthquakes. Earthquakes are often associated with volcanoes. Volcanoes erupt at all types of plate boundaries except transform. Volcanic eruptions can be quiet or explosive and the volcanoes they form range from large shields, to classic peaks, to small cones. Volcanic activity creates unique landforms. Some geological activity, both earthquakes and volcanic eruptions, are located away from plate boundaries.

6.31 References

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CHAPTER 7 Surface Processes and Landforms

Chapter Outline

Introduction

How long will these footprints be on the Moon?

In a billion years, or even 5 billion years, these footprints will still be on the Moon. In that time Earth will undergo enormous changes due to plate tectonics but also to the processes of weathering and erosion that modify the landscape. Of course, if commercial flights to the Moon ever become a reality, the trash from new visitors could cover or erase the tracks left by the Apollo astronauts.

7.1 Weathering and Erosion

- Define weathering and erosion.

What is the history of this rock face?

Walnut Canyon, just outside Flagstaff, Arizona, is a high desert landscape displaying cliff dwellings built 700 years ago by a long gone people. On the opposite side from the trail around the mesa is this incredible rock. In this rock you can see that the rock has slumped, and also see signs of mechanical weathering (fractures) and chemical weathering (dissolution). If you get a chance, go see the rock (and the cliff dwellings) for yourself.

Weathering

Weathering is the process that changes solid rock into sediments. Sediments were described in the chapter "Materials of Earth's Crust." With weathering, rock is disintegrated. It breaks into pieces. Once these sediments are separated from the rocks, **erosion** is the process that moves the sediments.

While plate tectonics forces work to build huge mountains and other landscapes, the forces of weathering gradually wear those rocks and landscapes away. Together with erosion, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas.

Weathering Takes Time

No human being can watch for millions of years as mountains are built, nor can anyone watch as those same mountains gradually are worn away. But imagine a new sidewalk or road. The new road is smooth and even. Over hundreds of years, it will completely disappear, but what happens over one year? What changes would you see? (**Figure** 7.1). What forces of weathering wear down that road, or rocks or mountains over time?

- Animations of different types of weathering processes can be found here: http://www.geography.ndo.co.uk/animationsweathering.htm#.

FIGURE 7.1
A once smooth road surface has cracks and fractures, plus a large pothole.

Vocabulary

- **erosion**: The transport of weathered materials and sediments by water, wind, ice, or gravity.
- **weathering**: The chemical or physical breakdown of rocks, soils or minerals at Earth's surface.

Summary

- Weathering breaks down Earth materials into smaller pieces.
- Erosion transports those pieces to other locations.
- Weathering and erosion modify Earth's surface landscapes over time.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is weathering?
2. What does weathering form?
3. What is mechanical weathering?
4. How do plants cause weathering?
5. How does ice cause weathering?
6. What is chemical weathering?
7. What can form through chemical weathering?

Review

1. What is weathering?
2. How is weathering different from erosion?
3. Why does weathering take so much time?

7.2 Mechanical Weathering

- Define mechanical weathering.
- Describe the various processes of mechanical weathering.

Who broke those rocks?

In extreme environments, where there is little moisture and soil development, it's possible to see rocks that have broken by mechanical weathering. This talus in Colorado's Indian Peaks broke from the jointed rock that is exposed.

Mechanical Weathering

Mechanical weathering (also called physical weathering) breaks rock into smaller pieces. These smaller pieces are just like the bigger rock, but smaller. That means the rock has changed physically without changing its composition. The smaller pieces have the same minerals, in just the same proportions as the original rock.

Ice Wedging

There are many ways that rocks can be broken apart into smaller pieces. **Ice wedging** is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point (**Figure** 7.2). Ice wedging works quickly, breaking apart rocks in areas with temperatures that cycle above and below freezing in the day and night, and also that cycle above and below freezing with the seasons.

Ice wedging breaks apart so much rock that large piles of broken rock are seen at the base of a hillside, as rock fragments separate and tumble down. Ice wedging is common in Earth's polar regions and mid latitudes, and also at higher elevations, such as in the mountains.

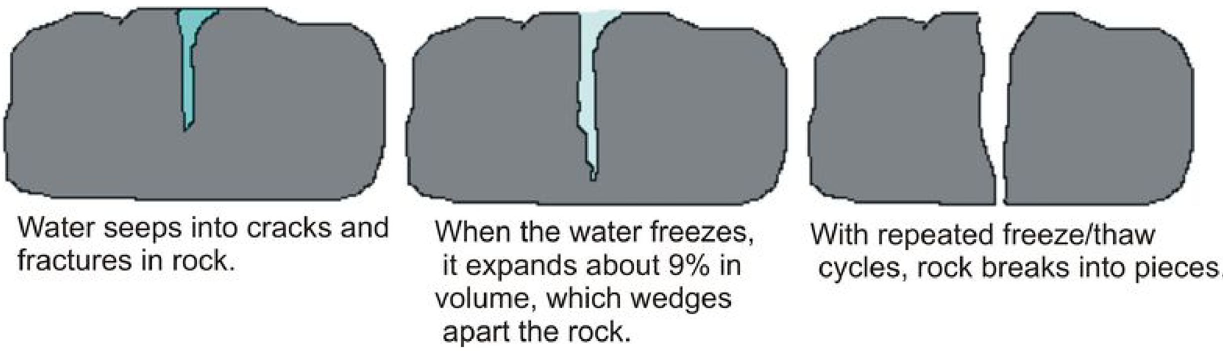


FIGURE 7.2
Ice wedging.

Abrasion

Abrasion is another form of mechanical weathering. In abrasion, one rock bumps against another rock.

- Gravity causes abrasion as a rock tumbles down a mountainside or cliff.
- Moving water causes abrasion as particles in the water collide and bump against one another.
- Strong winds carrying pieces of sand can sandblast surfaces.
- Ice in glaciers carries many bits and pieces of rock. Rocks embedded at the bottom of the glacier scrape against the rocks below.

Abrasion makes rocks with sharp or jagged edges smooth and round. If you have ever collected beach glass or cobbles from a stream, you have witnessed the work of abrasion (**Figure** 7.3).

Organisms

Now that you know what mechanical weathering is, can you think of other ways it could happen? Plants and animals can do the work of mechanical weathering (**Figure** 7.4). This could happen slowly as a plant's roots grow into a crack or fracture in rock and gradually grow larger, wedging open the crack. Burrowing animals can also break apart rock as they dig for food or to make living spaces for themselves.

Humans

Human activities are responsible for enormous amounts of mechanical weathering, by digging or blasting into rock to build homes, roads, and subways, or to quarry stone.

Vocabulary

- **abrasion**: A form of mechanical weathering that occurs whenever one rock hits another.
- **ice wedging**: Water enters a crack, expands as it freezes, and wedges the rock apart.

FIGURE 7.3

Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

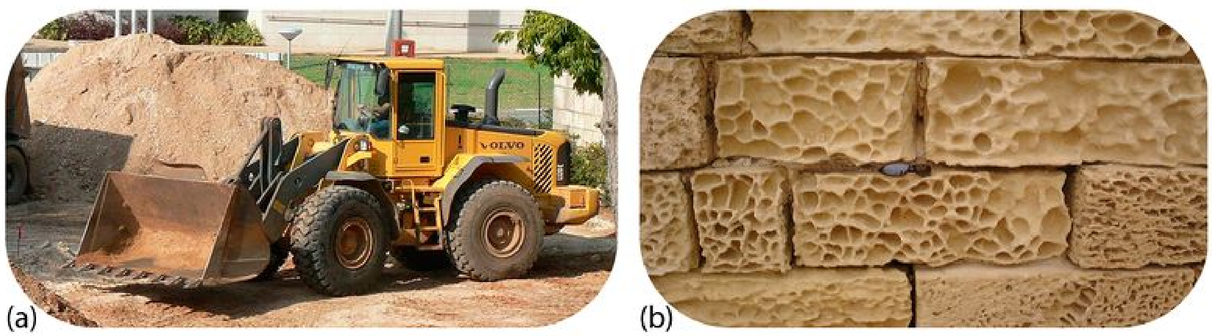


FIGURE 7.4

(a)Humans are tremendous agents of mechanical weathering. (b) Salt weathering of building stone on the island of Gozo, Malta.

- **mechanical weathering**: Weathering that breaks rocks into smaller pieces without altering their chemical composition.

Summary

- Mechanical weathering breaks down existing rocks and minerals without changing them chemically.
- Ice wedging, abrasion, and some actions of living organisms and humans are some of the agents of mechanical weathering.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is weathering?
2. What are the agents of weathering?
3. What is mechanical weathering?
4. Explain frost wedging.
5. Explain root wedging.
6. What is abrasion?
7. Explain the two types of abrasion.
8. What is exfoliation? What is it unique to?
9. What is differential weathering? What can be created with differential weathering?
10. What role does climate play in physical weathering?

Review

1. Describe the process of ice wedging.
2. Describe the process of abrasion.
3. How do plants and animals cause mechanical weathering?

7.3 Chemical Weathering

- Define chemical weathering.
- Describe the various processes of chemical weathering.

How do rocks turn red?

In the desert Southwest, red rocks are common. Tourists flock to Sedona, Arizona to see the beautiful red rocks, which are set off very nicely by the snow in this photo. What makes the rocks red? The same process that makes rust red!

Chemical Weathering

Chemical weathering is the other important type of weathering. Chemical weathering may change the size of pieces of rock materials, but definitely changes the composition. So one type of mineral changes into a different mineral. Chemical weathering works through chemical reactions that cause changes in the minerals.

No Longer Stable

Most minerals form at high pressure or high temperatures deep in the crust, or sometimes in the mantle. When these rocks are uplifed onto Earth's surface, they are at very low temperatures and pressures. This is a very different environment from the one in which they formed and the minerals are no longer stable. In chemical weathering, minerals that were stable inside the crust must change to minerals that are stable at Earth's surface.

Clay

Remember that the most common minerals in Earth's crust are the silicate minerals. Many silicate minerals form in igneous or metamorphic rocks. The minerals that form at the highest temperatures and pressures are the least stable at the surface. Clay is stable at the surface and chemical weathering converts many minerals to clay (**Figure** 7.5).

There are many types of chemical weathering because there are many agents of chemical weathering.

FIGURE 7.5
Deforestation in Brazil reveals the underlying clay-rich soil.

Chemical Weathering by Water

A water molecule has a very simple chemical formula, H_2O, two hydrogen atoms bonded to one oxygen atom. But water is pretty remarkable in terms of all the things it can do. Remember that water is a polar molecule. The positive side of the molecule attracts negative ions and the negative side attracts positive ions. So water molecules separate the ions from their compounds and surround them. Water can completely dissolve some minerals, such as salt.

FIGURE 7.6
Weathered rock in Walnut Canyon near Flagstaff, Arizona.

- Check out this animation of how water dissolves salt: http://www.northland.cc.mn.us/biology/Biology1111/animations/dissolve.html.

Hydrolysis is the name of the chemical reaction between a chemical compound and water. When this reaction takes place, water dissolves ions from the mineral and carries them away. These elements have been **leached**. Through hydrolysis, a mineral such as potassium feldspar is leached of potassium and changed into a clay mineral. Clay minerals are more stable at the Earth's surface.

Chemical Weathering by Carbonic Acid

Carbon dioxide (CO_2) combines with water as raindrops fall through the atmosphere. This makes a weak acid, called carbonic acid. Carbonic acid is a very common in nature, where it works to dissolve rock. Pollutants, such as sulfur and nitrogen from fossil fuel burning, create sulfuric and nitric acid. Sulfuric and nitric acids are the two main components of **acid rain**, which accelerates chemical weathering (**Figure** 7.7). Acid rain is discussed in Concept Human Impacts on Earth's Systems.

FIGURE 7.7
This chimera at Notre Dame Cathedral in Paris exhibits damage from acid rain.

Chemical Weathering by Oxygen

Oxidation is a chemical reaction that takes place when oxygen reacts with another element. Oxygen is very strongly chemically reactive. The most familiar type of oxidation is when iron reacts with oxygen to create rust (**Figure** 7.8). Minerals that are rich in iron break down as the iron oxidizes and forms new compounds. Iron oxide produces the red color in soils.

Plants and Animals

Now that you know what chemical weathering is, can you think of some other ways chemical weathering might occur? Chemical weathering can also be contributed to by plants and animals. As plant roots take in soluble ions as nutrients, certain elements are exchanged. Plant roots and bacterial decay use carbon dioxide in the process of respiration.

Mechanical and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases **Figure** 7.9. With more surfaces exposed, there are more surfaces on which chemical weathering can occur.

FIGURE 7.8
When iron-rich minerals oxidize, they produce the familiar red color found in rust.

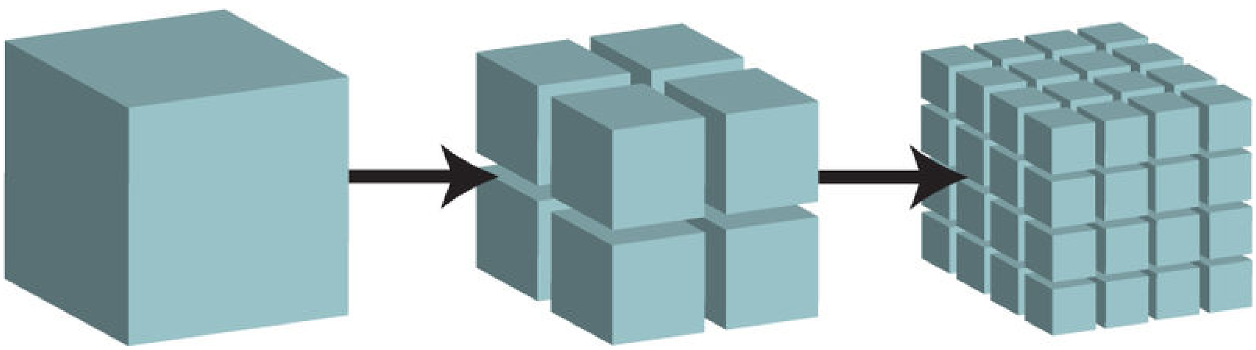


FIGURE 7.9
Mechanical weathering may increase the rate of chemical weathering.

Vocabulary

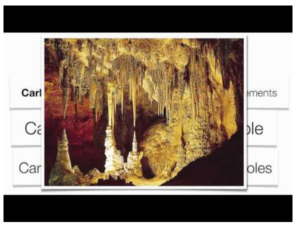
- **acid rain**: Rain that has a pH of less than 5.0.
- **chemical weathering**: Weathering that changes the chemical composition of minerals that form at high temperatures and pressures to minerals that are stable at the Earth's surface.
- **hydrolysis**: Hydrogen or hydroxide ions replace the cations in a mineral to change the mineral.
- **leaching**: The process of removing dissolved minerals as they are carried to lower layers in soil.
- **oxidation**: Oxygen reacts with another element to create a metal oxide.

Summary

- Chemical weathering changes the composition of a mineral to break it down.
- The agents of chemical weathering include water, carbon dioxide, and oxygen.
- Living organisms and humans can contribute to chemical weathering.

Practice

Use this resource to answer the questions that follow.



MEDIA

Click image to the left for more content.

1. What is chemical weathering?
2. What are the three ways chemical weathering occurs?
3. What is oxidation? What does it produced?
4. What is carbonation? What does it create?
5. What is hydration? What does it do?

Review

1. How does the structure of the water molecule lead to chemical weathering?
2. Describe how carbon dioxide and oxygen cause chemical weathering.
3. How does mechanical weathering increase the effectiveness of chemical weathering processes?

7.4 Influences on Weathering

- Identify and explain factors that influence the rate and intensity of weathering.

What circumstances allow for the most intense weathering?

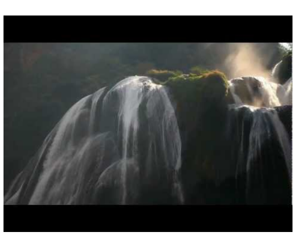
The rate and intensity of weathering depend on the climate of a region and the rocks materials that are being weathered. Material in Baraboo, Wisconsin weathers a lot more readily than similar material in Sedona, Arizona.

Rock and Mineral Type

Different rock types weather at different rates. Certain types of rock are very resistant to weathering. Igneous rocks, especially intrusive igneous rocks such as granite, weather slowly because it is hard for water to penetrate them. Other types of rock, such as limestone, are easily weathered because they dissolve in weak acids.

Rocks that resist weathering remain at the surface and form ridges or hills. Shiprock in New Mexico is the throat of a volcano that's left after the rest of the volcano eroded away. The rock that's left behind is magma that cooled relatively slowly and is harder than the rock that had surrounded it.

Different minerals also weather at different rates. Some minerals in a rock might completely dissolve in water, but the more resistant minerals remain. In this case, the rock's surface becomes pitted and rough. When a less resistant mineral dissolves, more resistant mineral grains are released from the rock. A beautiful example of this effect is the "Stone Forest" in China, see the video below:



MEDIA

Click image to the left for more content.

FIGURE 7.10

The Shiprock formation in northwest New Mexico is the central plug of resistant lava from which the surrounding rock weathered and eroded away.

Climate

A region's **climate** strongly influences weathering. Climate is determined by the temperature of a region plus the amount of precipitation it receives. Climate is weather averaged over a long period of time. Chemical weathering increases as:

- Temperature increases: Chemical reactions proceed more rapidly at higher temperatures. For each 10^{o}C increase in average temperature, the rate of chemical reactions doubles.
- Precipitation increases: More water allows more chemical reactions. Since water participates in both mechanical and chemical weathering, more water strongly increases weathering.

So how do different climates influence weathering? A cold, dry climate will produce the lowest rate of weathering. A warm, wet climate will produce the highest rate of weathering. The warmer a climate is, the more types of vegetation it will have and the greater the rate of biological weathering (**Figure** 7.11). This happens because plants and bacteria grow and multiply faster in warmer temperatures.

Resources from Weathering

Some resources are concentrated by weathering processes. In tropical climates, intense chemical weathering carries away all soluble minerals, leaving behind just the least soluble components. The aluminum oxide, bauxite, forms this way and is our main source of aluminum ore.

Vocabulary

- **climate**: The long-term average of weather.

Summary

- Different materials weather at different rates and intensities under the same conditions.

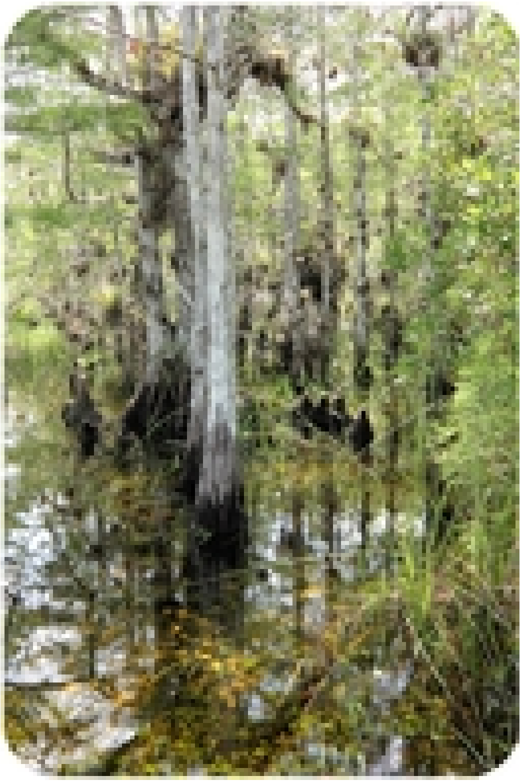


FIGURE 7.11
Wet, warm tropical areas have the most weathering.

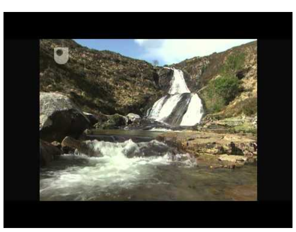
- Different climate conditions cause the same materials to weather different intensities.

Practice

Use this resource to answer the questions that follow.

Rock types on the Isle of Sky - Geological Landforms

http://www.youtube.com/watch?v=l-Y6588DnQg



MEDIA
Click image to the left for more content.

1. What type of rocks make up most of the Isle of Skye?
2. What other types of rocks are found on the island?
3. What two processes shape the landscape of the island?
4. What are the primary sources of weathering on Skye?
5. How is scree produced?
6. How does weathering effect granite?
7. What is responsible for the topography of the island?

8. Which rocks are more resistant to weathering?

Review

1. What types of rocks weather most readily? What types weather least readily?
2. What climate types cause more intense weathering? What climate types cause less intense weathering?
3. How does bauxite form?

7.5 Soil Characteristics

- Describe the characteristics of soil.

"Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals."
— Aldo Leopold, *A Sand County Almanac*, 1949

Even though soil is only a very thin layer on Earth's surface over the solid rocks below, it is the where the atmosphere, hydrosphere, biosphere, and lithosphere meet. We should appreciate soil more.

Characteristics of Soil

Soil is a complex mixture of different materials.

- About half of most soils are **inorganic** materials, such as the products of weathered rock, including pebbles, sand, silt, and clay particles.
- About half of all soils are **organic** materials, formed from the partial breakdown and decomposition of plants and animals. The organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients, such as nitrogen, needed for strong plant growth.
- In between the solid pieces, there are tiny spaces filled with air and water.

Within the soil layer, important reactions between solid rock, liquid water, air, and living things take place.

In some soils, the organic portion could be missing, as in desert sand. Or a soil could be completely organic, such as the materials that make up peat in a bog or swamp (**Figure** 7.12).

Soil Texture

The inorganic portion of soil is made of many different size particles, and these different size particles are present in different proportions. The combination of these two factors determines some of the properties of the soil.

FIGURE 7.12
Peat is so rich in organic material, it can be burned for energy.

- A **permeable** soil allows water to flow through it easily because the spaces between the inorganic particles are large and well connected. Sandy or silty soils are considered "light" soils because they are permeable, water-draining types of soils.
- Soils that have lots of very small spaces are water-holding soils. For example, when clay is present in a soil, the soil is heavier, holds together more tightly, and holds water.
- When a soil contains a mixture of grain sizes, the soil is called a **loam** (**Figure** 7.13).

FIGURE 7.13
A loam field.

Classification

When soil scientists want to precisely determine soil type, they measure the percentage of sand, silt, and clay. They plot this information on a triangular diagram, with each size particle at one corner (**Figure** 7.14). The soil type can then be determined from the location on the diagram. At the top, a soil would be clay; at the left corner, it would be sand; at the right corner, it would be silt. Soils in the lower middle with less than 50% clay are loams.

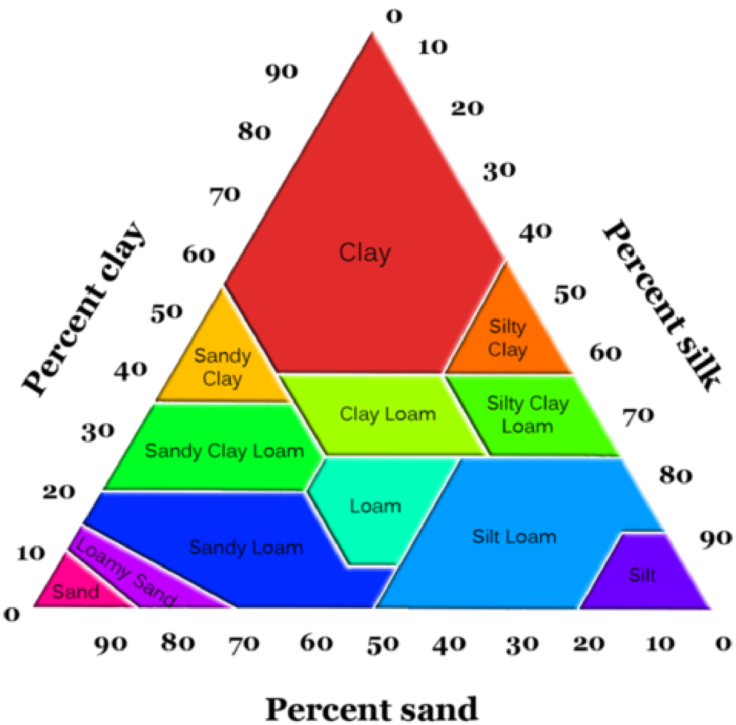


FIGURE 7.14
Soil types by particle size.

Soil, the Ecosystem

Soil is an ecosystem unto itself. In the spaces of soil, there are thousands or even millions of living organisms. Those organisms could include earthworms, ants, bacteria, or fungi (**Figure** 7.15).

Vocabulary

- **inorganic**: Not organic; not involving life or living organisms. For example, the rock and mineral portion of the soil.
- **loam**: Soil texture that forms from a roughly equal combination of sand, silt and clay.
- **organic**: Something from living organisms.
- **permeable**: A material with interconnecting holes so that water can move through it easily.
- **soil**: The top layer of Earth's surface containing weathered rocks and minerals and organic material.

Summary

- Soil reflects the interactions between the lithosphere, atmosphere, hydrosphere and biosphere.
- Permeable soils allow water to flow through.
- The proportions of silt, clay, and sand allow scientists to classify soil type.

Practice

Use this resource to answer the questions that follow.

FIGURE 7.15
Earthworms and insects are important residents of soils.

MEDIA
Click image to the left for more content.

1. Why is soil important?
2. How many different types of soils are there?
3. Explain the composition of average soil.
4. What is humus?
5. What does the amount of humus determine?
6. What is texture?
7. How can texture effect plant growth?
8. What type of soil do farmers prefer?
9. How is soil being lost each year?
10. List the different types of erosion.

Review

1. What is the inorganic material that makes up a soil?

2. What is the organic material that makes up a soil?
3. If a soil has equal amounts of silt, clay, and sand, what type of soil is it?

7.6 Soil Formation

- Identify the factors that influence soil formation and explain how they work.

What do different types of soil feel like?

Did you ever plant a garden? Even if you live in an area with poor soil you can buy some dirt and put in some seeds. The type of soil that forms in an area depends on many factors. Some regions produce soil that are not good for crops, but may be good for something else, like cactus!

Soil Formation

How well soil forms and what type of soil forms depends on several different factors, which are described below.

- An animation of how weathering makes soil is found here: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/mineral_weathering.swf.

Climate

Scientists know that climate is the most important factor determining soil type because, given enough time, different rock types in a given climate will produce a similar soil (**Figure** 7.16). Even the same rock type in different climates will not produce the same type of soil. This is true because most rocks on Earth are made of the same eight elements and when the rock breaks down to become soil, those elements dominate.

The same factors that lead to increased weathering also lead to greater soil formation.

- More rain equals more chemical reactions to weather minerals and rocks. Those reactions are most efficient in the top layers of the soil, where the water is fresh and has not yet reacted with other materials.

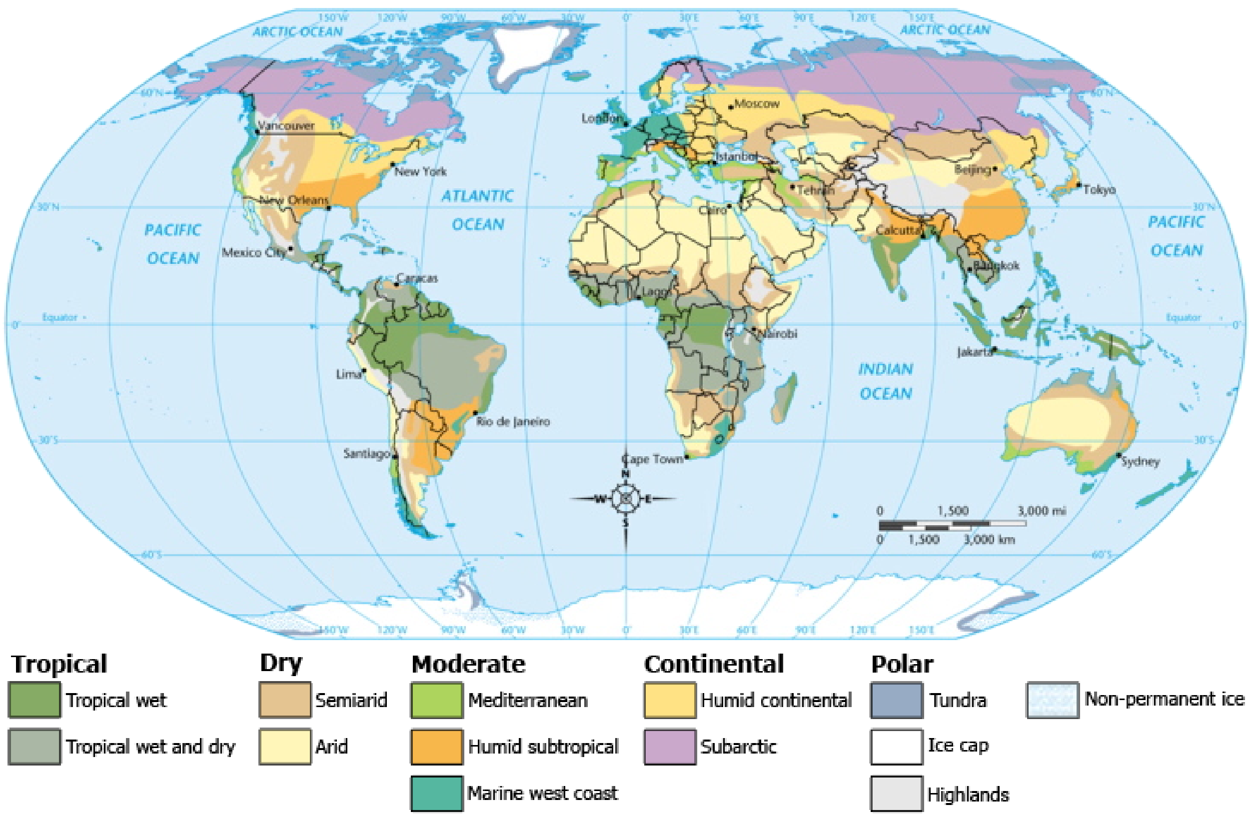


FIGURE 7.16
Climate is the most important factor in determining the type of soil that will form in a particular area.

- Increased rainfall increases the amount of rock that is dissolved as well as the amount of material that is carried away by moving water. As materials are carried away, new surfaces are exposed, which also increases the rate of weathering.
- Increased temperature increases the rate of chemical reactions, which also increases soil formation.
- In warmer regions, plants and bacteria grow faster, which helps to weather material and produce soils. In tropical regions, where temperature and precipitation are consistently high, thick soils form. Arid regions have thin soils.

Soil type also influences the type of vegetation that can grow in the region. We can identify climate types by the types of plants that grow there.

Rock Type

The original rock is the source of the inorganic portion of the soil. The minerals that are present in the rock determine the composition of the material that is available to make soil. Soils may form in place or from material that has been moved.

- **Residual soils** form in place. The underlying rock breaks down to form the layers of soil that reside above it. Only about one-third of the soils in the United States are residual.

- **Transported soils** have been transported in from somewhere else. Sediments can be transported into an area by glaciers, wind, water, or gravity. Soils form from the loose particles that have been transported to a new location and deposited.

Slope

The steeper the slope, the less likely material will be able to stay in place to form soil. Material on a steep slope is likely to go downhill. Materials will accumulate and soil will form where land areas are flat or gently undulating.

Time

Soils thicken as the amount of time available for weathering increases. The longer the amount of time that soil remains in a particular area, the greater the degree of alteration.

Biological Activity

The partial decay of plant material and animal remains produces the organic material and nutrients in soil. In soil, decomposing organisms breakdown the complex organic molecules of plant matter and animal remains to form simpler inorganic molecules that are soluble in water. Decomposing organisms also create organic acids that increase the rate of weathering and soil formation. Bacteria in the soil change atmospheric nitrogen into nitrates.

The decayed remains of plant and animal life are called **humus**, which is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that then hold the soil together, creating its structure. Humus increases the soil's porosity and water-holding capacity and helps to buffer rapid changes in soil acidity. Humus also helps the soil to hold its nutrients, increasing its fertility. Fertile soils are rich in nitrogen, contain a high percentage of organic materials, and are usually black or dark brown in color. Soils that are nitrogen poor and low in organic material might be gray or yellow or even red in color. Fertile soils are more easily cultivated.

- An animation of how different types of weathering affect different minerals in soil: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/elemental_change.swf.

Vocabulary

- **humus**: The partially decayed remains of plants and animals; forms the organic portion of soil.
- **residual soil**: Soil that forms from the bedrock upon which it lies.
- **transported soil**: Soil that forms from weathered components transported to a different area.

Summary

- The factors that affect soil formation are climate, rock type, slope, time, and biological activity. Differences in these factors will produce different types of soil.
- Soil type determines what can grow in a region.
- Humus, the decayed remains of living organisms, is essential for soils to be fertile.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What two features do parent material have on soil formation?
2. What are the physical properties that contribute to soil formation?
3. How does relief effect soil formation?
4. What is seen on slopes?
5. How does climate determine soil formation?
6. How does time effect soil formation?
7. How are humans changing soil formation?

Review

1. How does climate affect soil type? Why is climate the most important factor in developing the characteristics of a soil?
2. How does time affect soil formation in an arid environment versus in a warm, humid environment?
3. What is the role of partially decayed plant and animal remains in a soil?

7.7 Soil Horizons and Profiles

- Define soil horizon and soil profile.
- Describe the characteristics of the three major types of soil horizon, and explain the relationship of each to weathering processes.

What conditions would create so much clay?

Soils are so different. In the desert there's a very thin layer and then bedrock. The quarry in the photo is of clay. A thick, thick layer of clay is found in this area. The area must be quite moist for so much rock material to have weathered to clays.

Soil Horizons and Profiles

A residual soil forms over many years, as mechanical and chemical weathering slowly change solid rock into soil. The development of a residual soil may go something like this.

1. The bedrock fractures because of weathering from ice wedging or another physical process.
2. Water, oxygen, and carbon dioxide seep into the cracks to cause chemical weathering.
3. Plants, such as lichens or grasses, become established and produce biological weathering.
4. Weathered material collects until there is soil.
5. The soil develops **soil horizons**, as each layer becomes progressively altered. The greatest degree of weathering is in the top layer. Each successive, lower layer is altered just a little bit less. This is because the first place where water and air come in contact with the soil is at the top.

A cut in the side of a hillside shows each of the different layers of soil. All together, these are called a **soil profile** (**Figure** 7.17).

The simplest soils have three horizons.

FIGURE 7.17
Soil is an important resource. Each soil horizon is distinctly visible in this photograph.

Topsoil

Called the **A-horizon**, the **topsoil** is usually the darkest layer of the soil because it has the highest proportion of organic material. The topsoil is the region of most intense biological activity: insects, worms, and other animals burrow through it and plants stretch their roots down into it. Plant roots help to hold this layer of soil in place.

In the topsoil, minerals may dissolve in the fresh water that moves through it to be carried to lower layers of the soil. Very small particles, such as clay, may also get carried to lower layers as water seeps down into the ground.

Subsoil

The **B-horizon** or **subsoil** is where soluble minerals and clays accumulate. This layer is lighter brown and holds more water than the topsoil because of the presence of iron and clay minerals. There is less organic material. **Figure** 7.18.

C horizon

The **C-horizon** is a layer of partially altered bedrock. There is some evidence of weathering in this layer, but pieces of the original rock are seen and can be identified.

Not all climate regions develop soils, and not all regions develop the same horizons. Some areas develop as many as five or six distinct layers, while others develop only very thin soils or perhaps no soils at all.

- An animation of soil profile development can be viewed here: http://courses.soil.ncsu.edu/resources/soil_classification_genesis/soil_formation/soil_transform.swf.

Vocabulary

- **C-horizon**: The lowest layer of soil; partially altered bedrock.
- **soil horizon**: An individual layer of a complete soil profile; examples include A, B & C horizons.

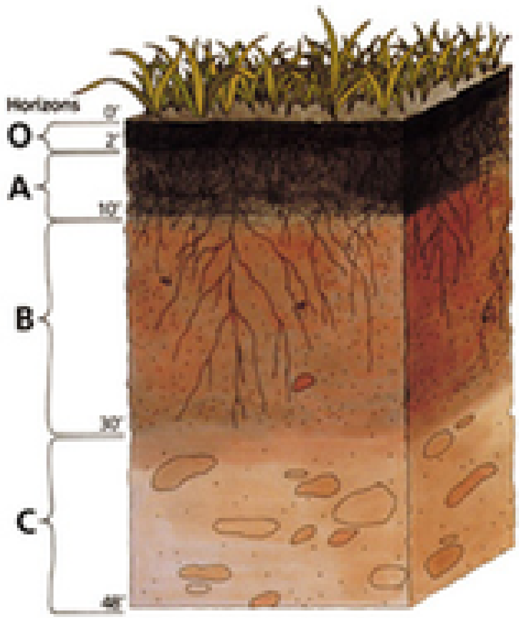


FIGURE 7.18

A soil profile is the complete set of soil layers. Each layer is called a horizon.

- **soil profile**: The entire set of soil layers or horizons for a particular soil.
- **subsoil (B-horizon)**: The subsoil; the zone where iron oxides and clay minerals accumulate.
- **topsoil (A-horizon)**: The A horizon; the most fertile layer with humus, plant roots and living organisms.

Summary

- Soil horizons are layers within a soil showing different amounts of alteration.
- Soil profiles show the layers of soil, which include topsoil, subsoil and the C horizon.
- Topsoil has the highest proportion of organic material and is very important for agriculture.

Practice

Use this resource to answer the questions that follow.

http://uccpbank.k12hsn.org/courses/APEnvironmentalScience/course%20files/multimedia/lesson51/animations/4c_soil_profile.html

1. What is a horizon?
2. How many horizons does typical soil contain?
3. What does the O-horizon contain?
4. What is duff?
5. What is the A-horizon? What does it contain?
6. What are the characteristics of the B-horizon?
7. What is the C-horizon? How does it differ from the other horizons?

Review

1. Describe topsoil. Why is loss of topsoil a very large problem when it happens?
2. Describe the weathering processes that go into producing soil.
3. What is the C horizon?

7.8 Types of Soils

- Describe the characteristics of types of soil and where each is found.

What makes soil good?

Some types of soils are good for growing crops and some are not. When good soils are found in good climates where water is available, a variety of crops will grow. If one of these things is missing, the possibilities are much more limited.

Types of Soils

Although soil scientists recognize thousands of types of soil – each with its own specific characteristics and name - let's consider just three soil types. This will help you to understand some of the basic ideas about how climate produces a certain type of soil, but there are many exceptions to what we will learn right now (**Figure** 7.19).

FIGURE 7.19
Just some of the thousands of soil types.

Pedalfer

Deciduous trees, the trees that lose their leaves each winter, need at least 65 cm of rain per year. These forests produce soils called **pedalfers**, which are common in many areas of the temperate, eastern part of the United States (**Figure** 7.20). The word pedalfer comes from some of the elements that are commonly found in the soil. The "Al" in ped**al**fer is the chemical symbol of the element aluminum, and the "Fe" in pedal**fe**r is the chemical symbol for iron. Pedalfers are usually a very fertile, dark brown or black soil. Not surprisingly, they are rich in aluminum clays and iron oxides. Because a great deal of rainfall is common in this climate, most of the soluble minerals dissolve and are carried away, leaving the less soluble clays and iron oxides behind.

Pedocal

Pedocal soils form in drier, temperate areas where grasslands and brush are the usual types of vegetation (**Figure** 7.21). The climates that form pedocals have less than 65 cm rainfall per year. Compared to pedalfers there is less chemical weathering and less water to dissolve away soluble minerals, so more soluble minerals are present and fewer clay minerals are produced. It is a drier region with less vegetation, so the soils have lower amounts of organic material and are less fertile.

A pedocal is named for the calcite enriched layer that forms. Water begins to move down through the soil layers, but before it gets very far, it begins to evaporate. Soluble minerals, like calcium carbonate, concentrate in a layer that marks the lowest place that water was able to reach. This layer is called caliche.

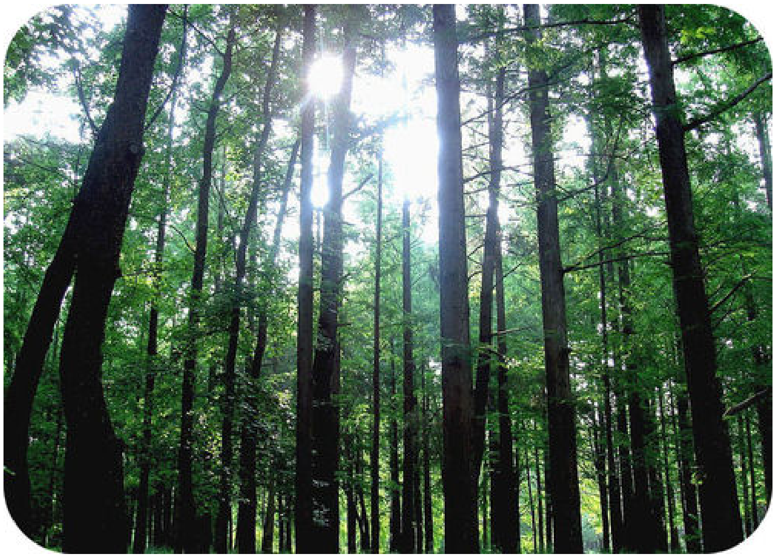


FIGURE 7.20
A pedalfer is the dark, fertile type of soil that will form in a forested region.

FIGURE 7.21

Laterite

In tropical rainforests where it rains literally every day, **laterite** soils form (**Figure** 7.22). In these hot, wet, tropical regions, intense chemical weathering strips the soils of their nutrients. There is practically no humus. All soluble minerals are removed from the soil and all plant nutrients are carried away. All that is left behind are the least soluble materials, like aluminum and iron oxides. These soils are often red in color from the iron oxides. Laterite soils bake as hard as a brick if they are exposed to the sun.

Many climate types have not been mentioned here. Each produces a distinctive soil type that forms in the particular circumstances found there. Where there is less weathering, soils are thinner but soluble minerals may be present.

FIGURE 7.22

Where there is intense weathering, soils may be thick but nutrient-poor. Soil development takes a very long time, it may take hundreds or even thousands of years for a good fertile topsoil to form. Soil scientists estimate that in the very best soil-forming conditions, soil forms at a rate of about 1mm/year. In poor conditions, soil formation may take thousands of years!

Vocabulary

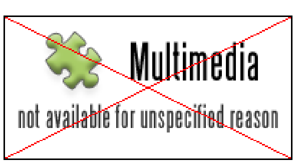
- **laterite**: Nutrient poor, red, tropical soil that forms in rainforest areas.
- **pedalfer**: Fertile, dark soil that forms in mid latitude, forested regions.
- **pedocal**: Less fertile soil that forms in drier, grassland regions.

Summary

- Pedalfer is the soil common in deciduous forests and is rich in aluminum and iron. Pedalfers are dark brown and fertile.
- Pedocal is the soil common in grasslands where the climate is drier and is rich in calcium.
- Laterite forms in tropical rain forests. Chemical weathering strips the soils of their nutrients, so when the forest is removed the soil is not very fertile.

Practice

Use these resources to answer the questions that follow.



MEDIA

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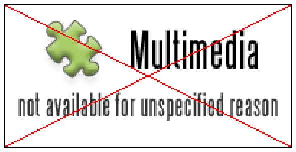
1. What are the three most common types of soil?
2. Where are pedalfers found?
3. Where are pedocals found?

4. Where is laterite found?



MEDIA

Click image to the left for more content.

5. What is laterite?
6. Where is it found?
7. What zones are in laterite?

Review

1. What is pedocal and under what conditions does it form?
2. What is pedalfer and under what conditions does it form?
3. What is laterite and under what conditions does it form?

7.9 Landforms from Stream Erosion and Deposition

- Describe how streams erode and deposit sediments.

What on Earth are 'goosenecks'?

In Southeastern Utah, stream meanders have been immortalized by erosion into the Goosenecks of the San Juan River. This satellite image shows the amazing path the river has cut, but it's also breathtaking to stand at the edge and look into one of the meanders. Goosenecks State Park is in the southeastern corner of Utah.

Erosion by Streams

Flowing streams pick up and transport weathered materials by eroding sediments from their banks. Streams also carry ions and ionic compounds that dissolve easily in the water.

Sediment Transport

Sediments are carried as:

- **Dissolved load**: Dissolved load is composed of ions in solution. These ions are usually carried in the water all the way to the ocean.
- **Suspended load**: Sediments carried as solids as the stream flows are suspended load. The size of particles that can be carried is determined by the stream's velocity (**Figure** 7.23). Faster streams can carry larger particles. Streams that carry larger particles have greater **competence**. Streams with a steep **gradient** (slope) have a faster velocity and greater competence.

FIGURE 7.23
The Amazon River appears brown when carrying a large sediment load.

- **Bed load**: Particles that are too large to be carried as suspended load are bumped and pushed along the stream bed as bed load. Bed load sediments do not move continuously. This intermittent movement is called **saltation**. Streams with high velocities and steep gradients do a great deal of down cutting into the stream bed, which is primarily accomplished by movement of particles that make up the bed load.

- An animation of saltation is found here: http://www.weru.ksu.edu/new_weru/multimedia/movies/dust003.mpg.
- A video of bedload transport is found here: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/bdld.mov.

Stream Deposition

As a stream gets closer to its **base level**, where it meets a large body of water, its gradient lowers and it deposits more material than it erodes. On flatter ground, streams deposit material on the inside of meanders. Placer mineral deposits are often deposited there.

A stream's **floodplain** is much broader and shallower than the stream's channel. When a stream flows onto its floodplain, its velocity slows and it deposits much of its load. These sediments are rich in nutrients and make excellent farmland (**Figure** 7.24).

A stream at flood stage carries lots of sediments. When its gradient decreases, the stream overflows its banks and broadens its channel. The decrease in gradient causes the stream to deposit its sediments, the largest first. These large sediments build a higher area around the edges of the stream channel, creating **natural levees**.

When a river enters standing water, its velocity slows to a stop. The stream moves back and forth across the region and drops its sediments in a wide triangular-shaped deposit called a **delta** (**Figure** 7.25).

If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops (**Figure** 7.26). Alluvial fans generally form in arid regions.

Vocabulary

- **alluvial fan**: Curved, fan-shaped, coarse-sediment deposit that forms when a stream meets flat ground.

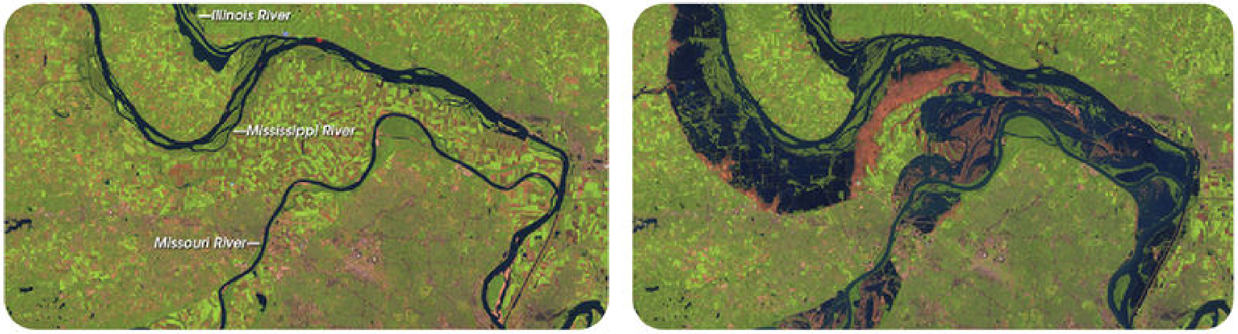


FIGURE 7.24
The Mississippi floodplain is heavily farmed. Flooding can wipe out farms and towns, but the stream also deposits nutrient-rich sediments that enrich the floodplain.

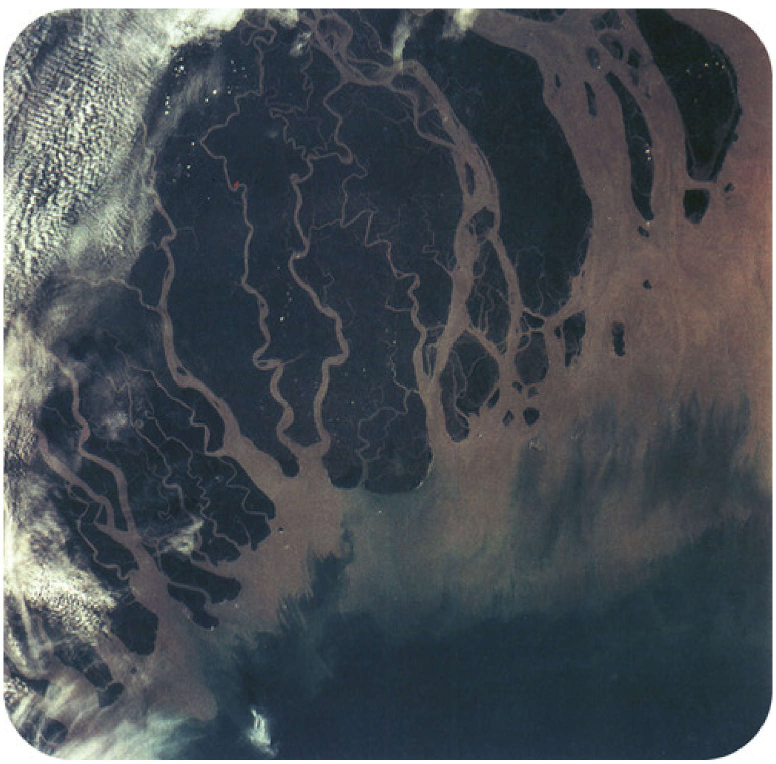


FIGURE 7.25
The Ganges River forms an enormous delta in Bangladesh.

- **base level**: Where a stream meets a large body of standing water, usually the ocean.
- **bed load**: Sediments moved by rolling or bumping along the stream bed.
- **competence**: A measure of the largest particle a stream can carry.
- **delta**: A triangular-shaped deposit of sediments that forms where a river meets standing water.
- **dissolved load**: The elements carried in solution by a stream.
- **floodplain**: The flat area around a stream where water flows when the stream is in flood.
- **gradient**: The slope of a stream.

FIGURE 7.26
A series of alluvial fans spread out from mountains along the Badwater Basin in Death Valley, California.

- **meander**: A bend or curve in a stream channel.
- **saltation**: The intermittent movement of bed load particles.
- **suspended load**: Solid particles that are carried in the main stream flow.

Summary

- Streams carry dissolved ions and sediments. The sizes of the sediments a stream can carry, its competence, depend on the stream's velocity.
- Particles that are too large to be suspended move along the stream bed by saltation.
- Rivers deposit sediments on levees, floodplains, and in deltas and alluvial fans.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is laminar flow?
2. What is turbulent flow?
3. What is jet flow?
4. Where does jet flow occur?
5. What is water velocity?
6. What factors can influence the stream velocity?

Review

1. If the amount of water in a stream in flood starts to go down, what will happen to the stream's competence? What will be deposited and where?

2. Under what conditions do streams cut down into their beds? Under what conditions do they erode their banks?

3. Deserts are extremely dry, yet alluvial fans are said to be deposited by stream flow. Describe how this occurs.

7.10 Landforms from Groundwater Erosion and Deposition

- Describe how groundwater erodes and deposits sediments.

How would you find an undiscovered cave?

Caves may be beneath your feet, especially if your feet are on limestone. In 1974 two amateur cavers found warm, moist air coming out of a crack in the ground in southern Arizona. They managed to find a way in and discovered the amazing Kartchner Caverns, 2.5 miles of pristine caves. You can see these spectacular caverns on a guided tour.

Groundwater Erosion

Rainwater absorbs carbon dioxide (CO_2) as it falls. The CO_2 combines with water to form carbonic acid. The slightly acidic water sinks into the ground and moves through pore spaces in soil and cracks and fractures in rock. The flow of water underground is **groundwater**. Groundwater is described further in "Concept Water on Earth."

FIGURE 7.27
When water sinks into the ground, it becomes groundwater.

Groundwater is a strong erosional force, as it works to dissolve away solid rock (**Figure** 7.27). Carbonic acid is especially good at dissolving the rock limestone.

Cave Formation

Working slowly over many years, groundwater travels along small cracks. The water dissolves and carries away the solid rock, gradually enlarging the cracks. Eventually, a cave may form (**Figure** 7.28).

FIGURE 7.28
Water flows through Russell Cave National Monument in Alabama.

You can explore a fantastic cave, Kartchner Caverns, in Arizona, by watching this video: http://video.nationalgeographic.com/video/player/science/earth-sci/exploring-kartchner-sci.html.

Sinkholes

If the roof of a cave collapses, a **sinkhole** could form. Some sinkholes are large enough to swallow up a home or several homes in a neighborhood (**Figure** 7.29).

Groundwater Deposition

Groundwater carries dissolved minerals in solution. The minerals may then be deposited, for example, as **stalagmites** or **stalactites** (**Figure** 7.30). Stalactites form as calcium carbonate drips from the ceiling of a cave, forming beautiful icicle-like formations. The word stalactite has a c, and it forms from the ceiling. Stalagmites form as calcium carbonate drips from the ceiling to the floor of a cave and then grow upwards. The g in stalagmite means it forms on the ground.

If a stalactite and stalagmite join together, they form a **column**. One of the wonders of visiting a cave is to witness the beauty of these amazing and strangely captivating structures. Some of the largest, and most beautiful, natural crystals can be found in the Naica mine, in Mexico. These gypsum crystals were formed over thousands of years as groundwater, rich in calcium and sulfur flowed through an underground cave. Check it out:

FIGURE 7.29
A relatively small sinkhole in the United Kingdom.

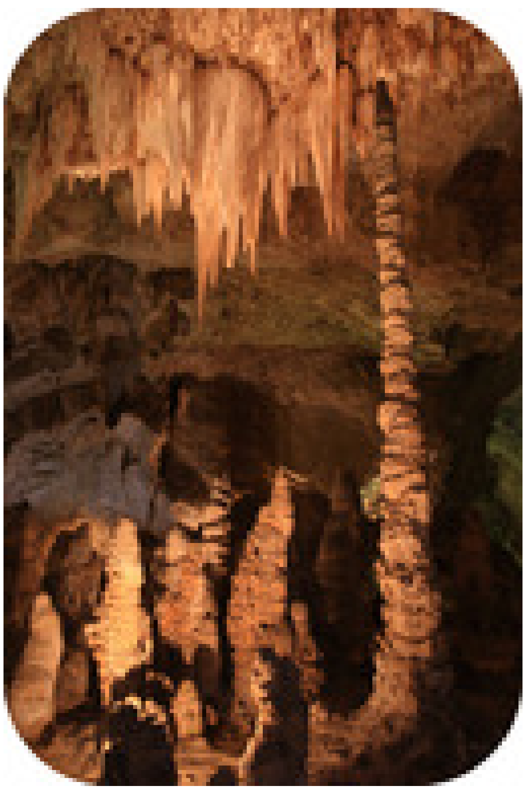


FIGURE 7.30
Stalactites hang from the ceiling and stalagmites rise from the floor of Carlsbad Caverns in New Mexico. The large stalagmite on the right is almost tall enough to reach the ceiling (or a stalactite) and form a column.

MEDIA
Click image to the left for more content.

Vocabulary

- **column**: A cave deposit formed by the merging of a stalactite and a stalagmite.
- **groundwater**: Fresh water that moves through pore spaces and fractures in soil and rock beneath the land surface.
- **sinkhole**: Circular hole in the ground that forms as the roof of a cave collapses.
- **stalactite**: Icicle-like formation of calcium carbonate from water dripping from the ceiling of a cave.
- **stalagmite**: Deposit of calcium carbonate that grows upward in caves as water drips onto the floor.

Summary

- Groundwater dissolves minerals, carries the ions in solution, and then deposits them.
- Groundwater erodes rock beneath the ground surface, especially carbonate rock.
- Groundwater deposits material in caves to create stalactites, stalagmites, and columns.

Practice

Use this resource to answer the questions that follow.

Kartchner Caverns State Park, Arizona

http://www.youtube.com/watch?v=uF75q4vzbAY

MEDIA

Click image to the left for more content.

1. What is under Arizona?
2. When were they discovered?
3. When did this area become a state park?
4. How long did it take the caverns to form?
5. What makes caves interesting?

Review

1. How does groundwater erode rock material?
2. Describe how groundwater deposits stalactites and stalagmites.
3. Why is groundwater acidic?

7.11 Landforms from Wave Erosion and Deposition

- Describe how waves erode and deposit sediments.

How is surfing like erosion?

Have you ever surfed or even body surfed? Have you felt a wave crash onto your body and then try to drag you offshore? Surfers use the power of waves for a wild ride. But that power can also be used to create landforms along a shoreline.

Wave Erosion

Wave energy does the work of erosion at the shore. Waves approach the shore at some angle so the inshore part of the wave reaches shallow water sooner than the part that is further out. The shallow part of the wave "feels" the bottom first. This slows down the inshore part of the wave and makes the wave "bend." This bending is called **refraction**.

- In this animation, notice how the wave refracts as it comes into the beach. http://www.grossmont.edu/garyjacobson/Oceanography%20112/Wave%20Model.htm

Wave refraction either concentrates wave energy or disperses it. In quiet water areas, such as bays, wave energy is dispersed, so sand is deposited. Areas that stick out into the water are eroded by the strong wave energy that concentrates its power on the **wave-cut cliff** (**Figure** 7.31).

FIGURE 7.31
These colorful cliffs on Martha's Vineyard are eroded by wave action. Note that the topsoil and vegetation at the top of the cliff are undercut by the falling sand and clay beneath.

Other features of wave erosion are pictured and named in **Figure** 7.32. A **wave-cut platform** is the level area formed by wave erosion as the waves undercut a cliff. An **arch** is produced when waves erode through a cliff. When a sea arch collapses, the isolated towers of rocks that remain are known as **sea stacks**.

FIGURE 7.32
(a) The high ground is a large wave-cut platform formed from years of wave erosion. (b) A cliff eroded from two sides produces an arch. (c) The top of an arch erodes away, leaving behind a tall sea stack.

Wave Deposition

Rivers carry sediments from the land to the sea. If wave action is high, a delta will not form. Waves will spread the sediments along the coastline to create a **beach**. Waves also erode sediments from cliffs and shorelines and transport them onto beaches. Beaches can be made of mineral grains like quartz, rock fragments, and also pieces of shell or coral (**Figure** 7.33).

FIGURE 7.33
Quartz, rock fragments, and shell make up the sand along a beach.

Waves continually move sand along the shore. Waves also move sand from the beaches on shore to bars of sand offshore as the seasons change. In the summer, waves have lower energy so they bring sand up onto the beach. In the winter, higher energy waves bring the sand back offshore.

Some of the features formed by wave-deposited sand are in **Figure** 7.34. These features include barrier islands and spits. A **spit** is sand connected to land and extending into the water. A spit may hook to form a tombolo.

Shores that are relatively flat and gently sloping may be lined with long, narrow **barrier islands** (**Figure** 7.35). Most barrier islands are a few kilometers wide and tens of kilometers long.

In its natural state, a barrier island acts as the first line of defense against storms such as hurricanes. When barrier islands are urbanized (**Figure** 7.35), hurricanes damage houses and businesses rather than vegetated sandy areas in which sand can move. A large hurricane brings massive problems to the urbanized area.

Protecting Shorelines

Intact shore areas protect inland areas from storms that come off the ocean. Where the natural landscape is altered or the amount of development makes damage from a storm too costly to consider, people use several types of structures to attempt to slow down wave erosion. A few are pictured below (**Figure** 7.36). A **groin** is a long, narrow pile of rocks built perpendicular to the shoreline to keep sand at that beach. A **breakwater** is a structure built in the water parallel to the shore in order to protect the shore from strong incoming waves. A **seawall** is also parallel to the shore, but it is built onshore.

People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive.

Protection does not always work. The northeastern coast of Japan was protected by anti-tsunami seawalls. Yet waves

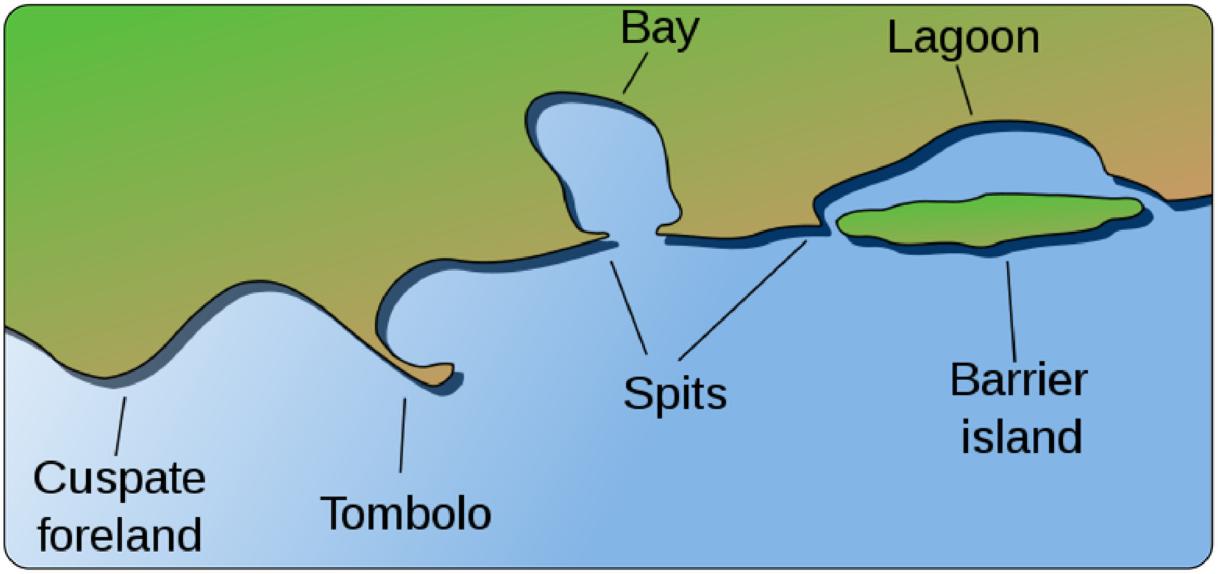


FIGURE 7.34
Examples of features formed by wave-deposited sand.

FIGURE 7.35
Much of North Carolina's coast is protected by barrier islands that enclose Pamlico Sound. The thin white strips on the outer edges of the islands are beach sand.

from the 2011 tsunami that resulted from the Tohoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

Vocabulary

- **arch**: An erosional landform that is produced when waves erode through a cliff.

FIGURE 7.36

(a) Groins trap sand on the up-current side so then people down current build groins to trap sand too. (b) Breakwaters are visible in this satellite image parallel to the shoreline. (c) Seawalls are similar to breakwaters except built onshore. Extremely large storm waves may destroy the sea wall, leaving the area unprotected.

- **barrier island**: Long, narrow island composed of sand; nature's first line of defense against storms.
- **beach**: The sediments on a shore.
- **breakwater**: Structure built in the water parallel to the shore to protect from strong incoming waves.
- **groin**: Long, narrow piles of stone or timbers built perpendicular to the shore to trap sand.
- **refraction**: A change in the direction of a wave caused by a change in speed. Waves refract when they travel from one type of medium to another.
- **sea stack**: Isolated tower of rock that forms when a sea arch collapses.
- **seawall**: Structure built parallel to the shore on the beach to protect against strong waves.
- **spit**: Long, narrow bar of sand that forms as waves transport sand along shore.
- **wave-cut cliff**: A sea cliff cut by strong wave energy.
- **wave-cut platform**: Level area formed by wave erosion as waves undercut cliffs.

Summary

- Ocean waves have a tremendous amount of energy and so they may do a great deal of erosion. Some landforms created by erosion are platforms, arches, and sea stacks.
- Transported sand will eventually be deposited on beaches, spits, or barrier islands.
- People love the shore, so they develop these regions and then must build groins, breakwaters, and seawalls to protect them.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What are the two methods to stop coastal erosion?
2. What is a sea wall?
3. What is a jetty?
4. What is a groynes?
5. What are breakwaters?
6. Why don't people like most of the methods to prevent coastal erosion?
7. What is beach nourishment?
8. What problems does beach nourishment cause?

Review

1. Describe how a set of waves erodes a rocky headland.
2. What processes cause spits and barrier islands to form?
3. How do barrier islands and mangroves protect beaches? What happens when these natural barriers are destroyed?

7.12 Landforms from Wind Erosion and Deposition

- Describe how wind erodes and deposits sediments.

What are the effects of sandblasting?

If you've ever been in a sand storm, you've felt the power of the wind blasting at your skin. Over time, this natural sand blasting can be a tremendous erosional force on rocks or buildings. Hopefully, you won't stay out long enough to experience permanent damage.

Transport of Particles by Wind

Wind transports small particles, such as silt and clay, over great distances, even halfway across a continent or an entire ocean basin. Particles may be suspended for days. Wind more easily picks up particles on ground that has been disturbed, such as a construction site or a sand dune. Just like flowing water, wind transports particles as both bed load and suspended load. For wind, bed load is made of sand-sized particles, many of which move by saltation (**Figure** 7.37). The suspended load is very small particles of silt and clay.

Wind Erosion

Wind is a stronger erosional force in arid regions than it is in humid regions because winds are stronger. In humid areas, water and vegetation bind the soil so it is harder to pick up. In arid regions, small particles are selectively picked up and transported.

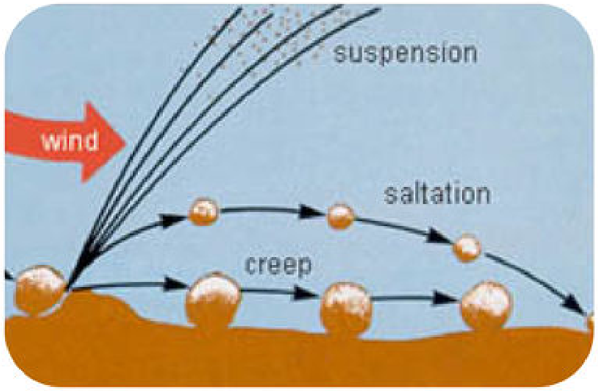


FIGURE 7.37
(a) Wind transport is by suspension, saltation, and creep (bed load). (b) In a sandstorm, sand is usually within a meter of the ground. A dust storm's smaller particles can travel higher. A dust storm as it approaches Al Asad, Iraq.

Deflation

As small particles are removed, the ground surface gets lower and rockier, causing **deflation**. What is left is **desert pavement** (**Figure** 7.38), a surface covered by gravel-sized particles that are not easily moved by wind.

FIGURE 7.38
This desert pavement formed in the Mojave Desert as a result of deflation.

Abrasion

Particles moved by wind do the work of abrasion. As a grain strikes another grain or surface it erodes that surface. Abrasion by wind may polish natural or human-made surfaces, such as buildings. Stones that have become polished and faceted due to abrasion by sand particles are called **ventifacts** (**Figure** 7.39).

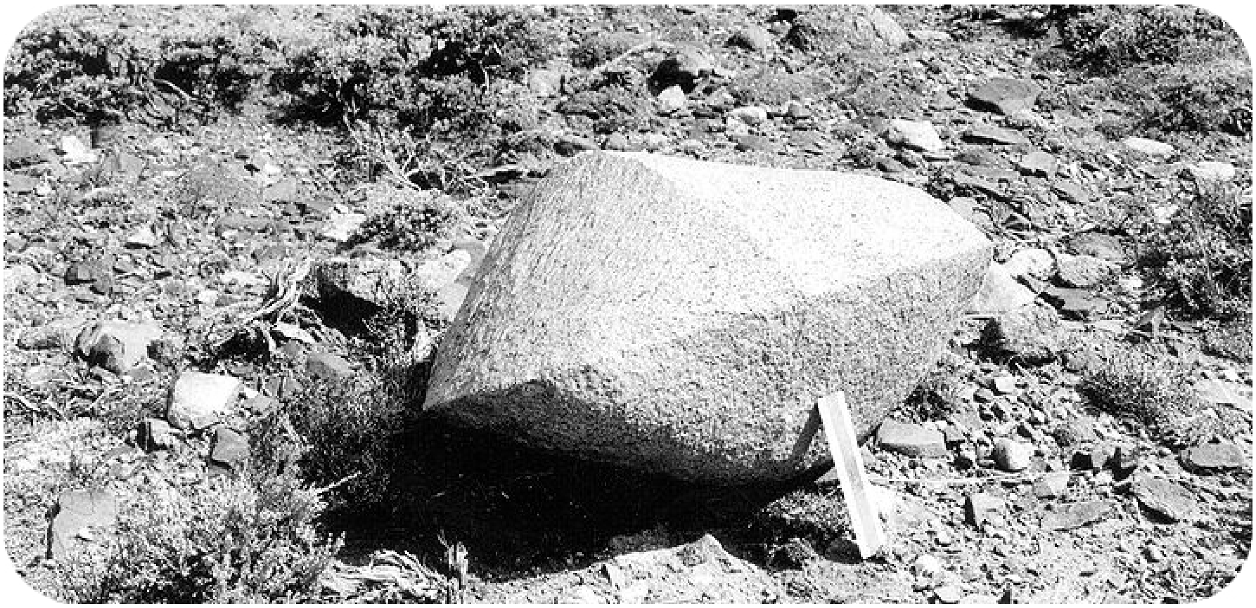


FIGURE 7.39
As wind blows from different direction, polished flat surfaces create a ventifact.

Desert Varnish

Exposed rocks in desert areas often develop a dark brown or black coating called **desert varnish**. Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron and manganese oxides (**Figure** 7.40).

Wind Deposition

The main features deposited by wind are sand dunes. Loess are wind deposits of finer sediments.

Sand Dunes

Deserts and seashores sometimes have **sand dunes** (**Figure** 7.41). Beach dunes are usually made of quartz because quartz is what's left in humid areas as other minerals weather into clays. Sand dunes may be composed of calcium carbonate in tropical areas. But in deserts, sand dunes are composed of a variety of minerals because there is little weathering.

Dune sands are usually very uniform in size and shape. Larger particles are too heavy for the wind to transport by

FIGURE 7.40
Ancient people carved these petroglyphs into desert varnish near Canyonlands National Park in Utah.

suspension and smaller particles can't be picked up. Particles are rounded, since rounded grains roll more easily than angular grains.

FIGURE 7.41
This sand dune in Death Valley, California shows secondary sand ripples along its slip face.

For sand dunes to form there must be an abundant supply of sand and steady winds. A strong wind slows down, often over some type of obstacle, such as a rock or some vegetation, and drops its sand. As the wind moves up and over the obstacle, it increases in speed. It carries the sand grains up the gently sloping, upwind side of the dune by saltation. As the wind passes over the dune, its speed decreases. Sand cascades down the crest, forming the **slip face** of the dune. The slip face is steep because it is at the angle of repose for dry sand, about 34^o (**Figure** 7.42).

Wind deposits dune sands layer by layer. If the wind changes directions, cross beds form. Cross beds are named for the way each layer is formed at an angle to the ground (**Figure** 7.43).

The type of sand dune that forms depends on the amount of sand available, the character and direction of the wind, and the type of ground the sand is moving over. Dunes may be crescent-shaped, star-shaped, parabolic, linear, or barchan.

- An animation of the formation of the dunes at Great Sand Dunes National Park is seen on this website: http

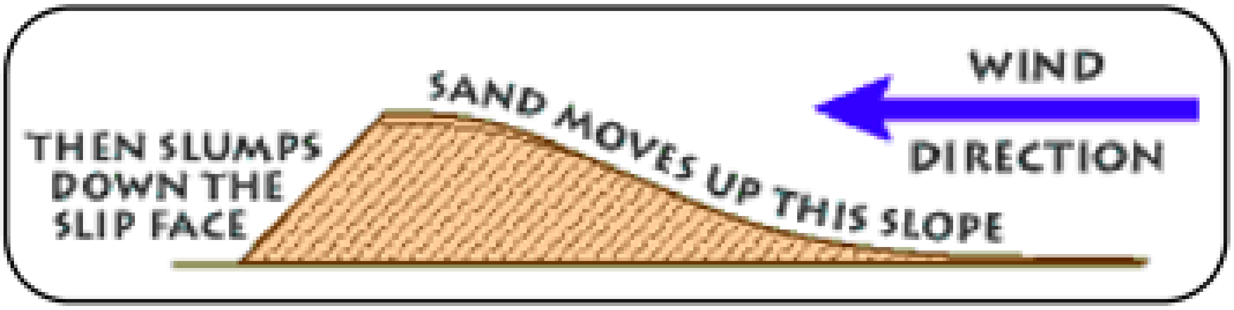


FIGURE 7.42
Sand dunes slope gently in the upwind direction. Downwind, a steeper slip face forms.

FIGURE 7.43
This sandstone in Zion National Park, Utah, shows crossbedding.

://www.nps.gov/grsa/naturescience/sanddunes.htm.

Loess

Windblown silt and clay deposited layer on layer over a large area form **loess** (**Figure** 7.44). Loess deposits form downwind of glacial outwash or desert, where fine particles are available. Loess deposits make very fertile soils in many regions of the world.

Seafloor Mud

Fine-grained mud in the deep ocean is formed from silts and clays brought from the land by wind. The particles are deposited on the sea surface, then slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

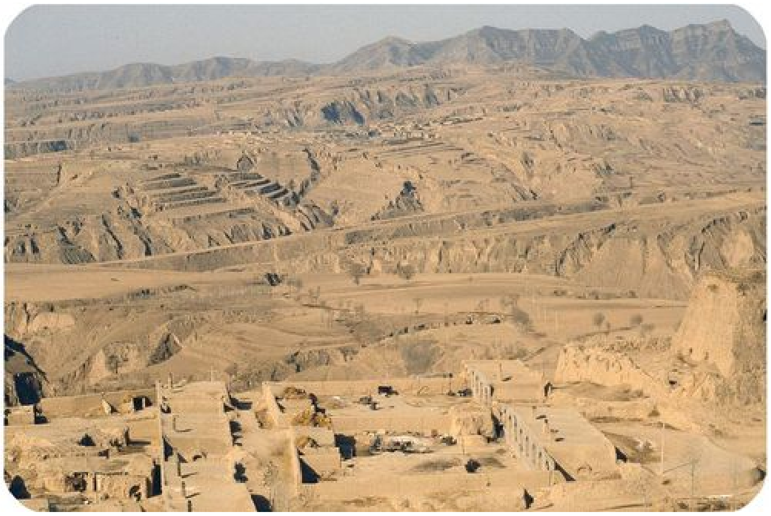


FIGURE 7.44
Loess deposits form nearly vertical cliffs, without grains sliding down the face. In some places in China, they are so thick and stable that entire structures can be carved out of them.

Vocabulary

- **deflation**: Wind removes finer grains of silt and clay, causing the ground surface to subside.
- **desert pavement**: Rocky, pebbled surface created as finer silts and clays are removed by wind.
- **desert varnish**: Dark mineral coating that forms on exposed rock surfaces as windborne clays are deposited.
- **loess**: Extremely fine-grained, wind-borne deposit of silts and clays; forms nearly vertical cliffs.
- **sand dunes**: Sand deposit formed in regions of abundant sand and frequent winds.
- **slip face**: Steeper, downwind side of a dune where sand grains fall down from the crest.
- **ventifacts**: Polished, faceted stones formed by abrasion by sand particles.

Summary

- In deserts, wind picks up small particles and leaves behind larger rocks to form desert pavement.
- Moving sand may sand blast rocks and other features to create ventifacts.
- The sand is transported until it is deposited in a sand dune.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What causes erosion?
2. Why is soil erosion a problem?
3. How does wind erosion occur?
4. What are the 3 types of wind erosion?

5. What type of wind erosion moves 50% of the soil?
6. What is creep?
7. What is saltation?
8. What is suspension?
9. When is suspension easily seen?
10. What has accelerated erosion?

Review

1. How does desert varnish form?
2. Describe how sand dunes form and move.
3. Why is loess a non-renewable resource?

7.13 Landforms from Glacial Erosion and Deposition

- Describe how glaciers erode rock and deposit sediments.

How is a geologist like a detective?

A geologist uses evidence left by events to reconstruct a geological history. Where should we go to study the tracks glaciers have left behind but Glacier National Park in Montana? The glaciers in the park have melted back a great deal in the past century, continuing a trend that began at the end of the ice ages. The features left behind by the glaciers are visible for everyone to see.

Glacial Erosion

Glaciers erode the underlying rock by abrasion and **plucking**. Glacial meltwater seeps into cracks of the underlying rock. When the water freezes, it pushes pieces of rock outward. The rock is then plucked out and carried away by the flowing ice of the moving glacier (**Figure** 7.45). With the weight of the ice over them, these rocks can scratch deeply into the underlying bedrock, making long, parallel grooves in the bedrock, called **glacial striations**.

Mountain glaciers leave behind unique erosional features. When a glacier cuts through a V-shaped river valley, the glacier plucks rocks from the sides and bottom. This widens the valley and steepens the walls, making a U-shaped valley (**Figure** 7.46).

Smaller tributary glaciers, like tributary streams, flow into the main glacier in their own shallower U-shaped valleys. A **hanging valley** forms where the main glacier cuts off a tributary glacier and creates a cliff. Streams plunge over the cliff to create waterfalls (**Figure** 7.47).

Up high on a mountain, where a glacier originates, rocks are pulled away from valley walls. Some of the resulting erosional features are shown in **Figure** 7.48 and **Figure** 7.49.

FIGURE 7.45
Glacial striations point the direction a glacier has gone.

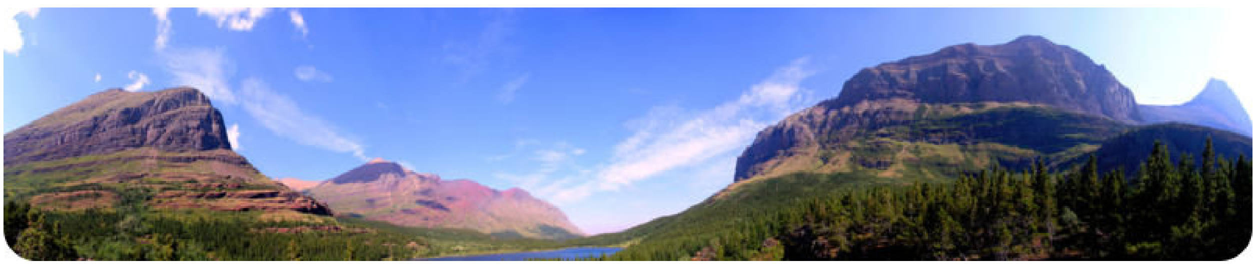


FIGURE 7.46
A U-shaped valley in Glacier National Park.

Depositional Features of Glaciers

As glaciers flow, mechanical weathering loosens rock on the valley walls, which falls as debris on the glacier. Glaciers can carry rock of any size, from giant boulders to silt (**Figure** 7.50). These rocks can be carried for many kilometers for many years.

Erratics

Rocks carried by a glacier are eventually dropped. These **glacial erratics** are noticeable because they are a different rock type from the surrounding bedrock.

Glacial Till

Melting glaciers deposit all the big and small bits of rocky material they are carrying in a pile. These unsorted deposits of rock are called **glacial till**. Glacial till is found in different types of deposits. Linear rock deposits are called **moraines**. Geologists study moraines to figure out how far glaciers extended and how long it took them to melt away.

FIGURE 7.47

Yosemite Valley is known for waterfalls that plunge from hanging valleys.

FIGURE 7.48

(a) A bowl-shaped cirque in Glacier National Park was carved by glaciers. (b) A high altitude lake, called a tarn, forms from meltwater trapped in the cirque. (c) Several cirques from glaciers flowing in different directions from a mountain peak, leave behind a sharp sided horn, like the Matterhorn in Switzerland. (d) When glaciers move down opposite sides of a mountain, a sharp edged ridge, called an arête, forms between them.

Moraines are named by their location relative to the glacier:

- Lateral moraines form at the edges of the glacier as material drops onto the glacier from erosion of the valley walls.
- Medial moraines form where the lateral moraines of two tributary glaciers join together in the middle of a larger glacier (**Figure** 7.51).

- Ground moraines forms from sediments that were beneath the glacier and left behind after the glacier melts.

FIGURE 7.49

FIGURE 7.50

A large boulder dropped by a glacier is a glacial erratic.

Ground moraine sediments contribute to the fertile transported soils in many regions.

- Terminal moraines are long ridges of till left at the furthest point the glacier reached.
- End moraines are deposited where the glacier stopped for a long enough period to create a rocky ridge as it retreated. Long Island in New York is formed by two end moraines.

- Try to pick out some of the glacial features seen in this Glacier National Park video: http://www.visitmt.com/national_parks/glacier/video_series/part_3.htm.

Varves

Several types of stratified deposits form in glacial regions but are not formed directly by the ice. **Varves** form where lakes are covered by ice in the winter. Dark, fine-grained clays sink to the bottom in winter, but melting ice in spring brings running water that deposits lighter colored sands. Each alternating dark/light layer represents one year of deposits.

FIGURE 7.51
The long, dark lines on a glacier in Switzerland are medial and lateral moraines.

FIGURE 7.52
(a) An esker is a winding ridge of sand and gravel deposited under a glacier by a stream of meltwater. (b) A drumlin is an asymmetrical hill made of sediments that points in the direction the ice moved. Usually drumlins are found in groups called drumlin fields.

Vocabulary

- **glacial erratic**: Large boulder with a different rock type or origin from the surrounding bedrock.
- **glacial striations**: Long, parallel scratches carved into underlying bedrock by moving glaciers.
- **glacial till**: Any unsorted sediment deposited by glacial ice.
- **hanging valley**: A cliff where a large glacier cut off the U-shaped valley of a tributary glacier.

- **moraine**: Linear deposit of unsorted, rocky material on, under, or left behind by glacial ice.
- **plucking**: Removal of blocks of underlying bedrock as meltwater seeps into cracks and freezes.
- **varve**: Paired deposit of light-colored, coarser sediments and darker, fine-grained sediments deposited in a glacial lake that represent an annual cycle.

Summary

- Glaciers have more force than any of the other erosional agents because of their incredible mass. As a result, they can erode the landscape. Glacial features in alpine areas are beautiful.
- Glaciers dump material, leaving clues for scientists as to where the glacier went. Glacial moraines outline a glacier's extent.
- Varves form in lakes covered by ice. Varves are useful to scientists for understanding climate.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. When did glaciers last cover the Earth?
2. What do glaciers do?
3. How did glaciers change the landscape?
4. What was formed from glaciers?
5. How was Half Dome created?
6. What creates a glacier?
7. How fast does a glacier move?
8. How much of the land is still covered in the ice?
9. What is a terminal moraine?
10. What is happening to the Columbia glacier?

Review

1. How can glacial striations be used to indicate the direction a glacier moved? What is the process that creates striations?
2. How do glaciers modify mountain terrain? What are some of the features they create?
3. What information can scientists get from varves and how do they get it?

7.14 Landforms from Erosion and Deposition by Gravity

- Describe how gravity erodes and deposits sediments.

Would you live here?

La Conchita, California is in a beautiful location, nestled between a Southern California beach and a hillside. That hillside, though, is prone to landslides, and the town has lost several homes, a banana plantation, and 10 residents to landslides in 1995 and 2005. Despite these problems people stay in the community. Would you?

Landforms and Gravity

Gravity shapes the Earth's surface by moving weathered material from a higher place to a lower one. This occurs in a variety of ways and at a variety of rates, including sudden, dramatic events as well as slow, steady movements that happen over long periods of time. The force of gravity is constant and it is changing the Earth's surface right now.

Downslope Movement by Gravity

Erosion by gravity is called **mass wasting**. Mass wasting can be slow and virtually imperceptible, or rapid, massive, and deadly.

Weathered material may fall away from a cliff because there is nothing to keep it in place. Rocks that fall to the base of a cliff make a **talus slope**. Sometimes as one rock falls, it hits another rock, which hits another rock, and begins a landslide.

Landslides

Landslides are the most dramatic, sudden, and dangerous examples of Earth materials moved by gravity. Landslides are sudden falls of rock; by contrast, avalanches are sudden falls of snow.

When large amounts of rock suddenly break loose from a cliff or mountainside, they move quickly and with tremendous force (**Figure** 7.53). Air trapped under the falling rocks acts as a cushion that keeps the rock from slowing down. Landslides can move as fast as 200 to 300 km/hour.

FIGURE 7.53
This landslide in California in 2008 blocked Highway 140.

Landslides are exceptionally destructive. Homes may be destroyed as hillsides collapse. Landslides can even bury entire villages. Landslides may create lakes when the rocky material dams a stream. If a landslide flows into a lake or bay, they can trigger a tsunami.

Landslides often occur on steep slopes in dry or semi-arid climates. The California coastline, with its steep cliffs and years of drought punctuated by seasons of abundant rainfall, is prone to landslides.

- Rapid downslope movement of material is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/dflows.mov.

Mudflows and Lahars

Added water creates natural hazards produced by gravity (**Figure** 7.54). On hillsides with soils rich in clay, little rain, and not much vegetation to hold the soil in place, a time of high precipitation will create a **mudflow**. Mudflows follow river channels, washing out bridges, trees, and homes that are in their path.

- A debris flow is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/Moscardo.mov.

A lahar is mudflow that flows down a composite volcano (**Figure** 7.55). Ash mixes with snow and ice melted by the eruption to produce hot, fast-moving flows. The lahar caused by the eruption of Nevado del Ruiz in Columbia in 1985 killed more than 23,000 people.

Slump and Creep

Less dramatic types of downslope movement move Earth materials slowly down a hillside. **Slump** moves materials as a large block along a curved surface (**Figure** 7.56). Slumps often happen when a slope is undercut, with no support for the overlying materials, or when too much weight is added to an unstable slope.

FIGURE 7.54
Mudflows are common in southern California.

FIGURE 7.55
A lahar is a mudflow that forms from volcanic ash and debris.

Creep is the extremely gradual movement of soil downhill. Curves in tree trunks indicate creep because the base of the tree is moving downslope while the top is trying to grow straight up (**Figure** 7.57). Tilted telephone or power company poles are also signs of creep.

Contributing Factors

There are several factors that increase the chance that a landslide will occur. Some of these we can prevent and some we cannot.

FIGURE 7.56
Slump material moves as a whole unit, leaving behind a crescent shaped scar.

FIGURE 7.57
The trunks of these trees near Mineral King, California, were bent by snow creeping downhill when the trees were saplings.

Water

A little bit of water helps to hold grains of sand or soil together. For example, you can build a larger sand castle with slightly wet sand than with dry sand. However, too much water causes the sand to flow quickly away. Rapid snow melt or rainfall adds extra water to the soil, which increases the weight of the slope and makes sediment grains lose contact with each other, allowing flow.

Rock Type

Layers of weak rock, such as clay, also allow more landslides. Wet clay is very slippery, which provides an easy surface for materials to slide over.

Undercutting

If people dig into the base of a slope to create a road or a homesite, the slope may become unstable and move downhill. This is particularly dangerous when the underlying rock layers slope towards the area.

- Ocean waves undercut cliffs and cause landslides on beaches, as in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/Cliff_retreat.mov.

When construction workers cut into slopes for homes or roads, they must stabilize the slope to help prevent a landslide (**Figure** 7.58). Tree roots or even grasses can bind soil together. It is also a good idea to provide drainage so that the slope does not become saturated with water.

FIGURE 7.58
A rock wall stabilizes a slope that has been cut away to make a road.

Ground Shaking

An earthquake, volcanic eruption, or even just a truck going by can shake unstable ground loose and cause a slide. Skiers and hikers may disturb the snow they travel over and set off an avalanche.

A very good introduction to the topic, "Landslide 101," is a video seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/.

Prevention and Awareness

Landslides cause $1 billion to $2 billion damage in the United States each year and are responsible for traumatic and sudden loss of life and homes in many areas of the world.

Some at-risk communities have developed landslide warning systems. Around San Francisco Bay, the National Weather Service and the U.S. Geological Survey use rain gauges to monitor soil moisture. If soil becomes saturated, the weather service issues a warning. Earthquakes, which may occur on California's abundant faults, can also trigger landslides.

To be safe from landslides:

- Be aware of your surroundings and notice changes in the natural world.
- Look for cracks or bulges in hillsides, tilting of decks or patios, or leaning poles or fences when rainfall is heavy. Sticking windows and doors can indicate ground movement as soil pushes slowly against a house and knocks windows and doors out of alignment.
- Look for landslide scars because landslides are most likely to happen where they have occurred before.
- Plant vegetation and trees on the hillside around your home to help hold soil in place.
- Help to keep a slope stable by building retaining walls. Installing good drainage in a hillside may keep the soil from getting saturated.

Hillside properties in the San Francisco Bay Area and elsewhere may be prone to damage from landslides. Geologists are studying the warning signs and progress of local landslides to help reduce risks and give people adequate warnings of these looming threats.

See more at http://science.kqed.org/quest/video/landslide-detectives/.

MEDIA

Click image to the left for more content.

Vocabulary

- **creep**: Exceptionally slow movement of soil downhill.
- **landslide**: Rapid movement downslope of rock and debris under the influence of gravity.
- **mass wasting**: The downslope movement of material due to gravity.
- **mudflow**: Saturated soil that flows down river channels.
- **slump**: Downslope slipping of a mass of soil or rock, generally along a curved surface.
- **talus slope**: A pile of angular rock fragments formed at the base of a cliff or mountain.

Summary

- Landslides are sudden and massive falls of rock down a slope that may be very destructive or even deadly. Mudflows or lahars, which are volcanic mudflows, are mass movements that contain a lot of water. Slump and creep are slower types of mass wasting.
- Mass movements are more likely to occur on slopes that are wet, have weak rock, or are undercut. An earthquake or other ground shaking can trigger a landslide.
- To avoid being in a landslide, be aware of signs in a hillside, such as cracks or bulges and old landslide scars.
- To keep a slope stable, install good drainage or build retaining walls.

Practice

Use these resources to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/landslides/

1. Where do landslides occur?

2. How many people are killed by landslides each year?

3. What can cause landslides to become more frequent?

MEDIA

Click image to the left for more content.

4. What is creep?

5. How do trees compensate for creep?

Review

1. How would installing drainage pipes in a slope change that slope's chance of a landslide?

2. If you look at a hillside, how can you tell that it's vulnerable to landslides? How can you tell that it's vulnerable to creep?

3. What is the scenario that creates a mudflow that kills 23,000 people?

Summary

Earth materials weather by mechanical or chemical processes; mechanical processes change the size of a substance but not its composition and chemical processes change its composition. Different types of weathering can work together on the same material. Soil forms on top of rock, the type depending on the environmental conditions in the region. A soil profile exhibits horizons, the nature of which depend on the type of soil. Topsoil is extremely important since it is in good topsoil that crops can grow. Water, ice, wind, and gravity create or modify landforms on Earth's surface. These agents can erode or deposit features that indicate their presence. Coastlines are modified by waves and currents along shore; groundwater carves caves and deposits cave features; wind abrades features and deposits sands in dunes; glaciers carve mountains into characteristic features and deposits massive amounts of debris; and gravity causes mass wasting, such as landslides.

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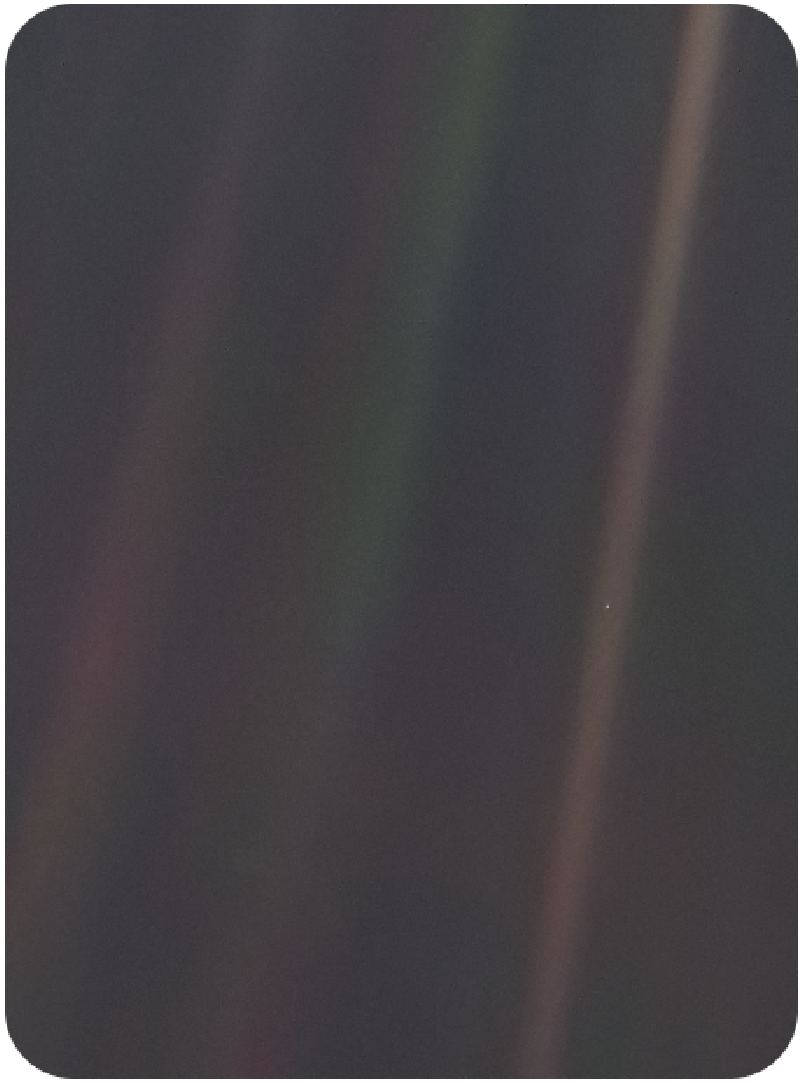
CHAPTER 8 Water on Earth

Chapter Outline

Introduction



Pale Blue Dot.

"From this distant vantage point, the Earth might not seem of any particular interest. But for us, it's different. Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every 'superstar,' every 'supreme leader,' every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam." —Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space*, p. 6

8.1 Distribution of Water on Earth

- Describe the distribution of Earth's water.
- Explain why fresh water is a scarce resource.

Water, water everywhere. But how much of it is useful?

Earth is the water planet. From space, Earth is a blue ball, unlike any of the other planets in our solar system. Life, also unique to Earth of the planets in our solar system, depends on this water. While there's a lot of salt water, a surprisingly small amount of it is fresh water.

Distribution of Water

Earth's oceans contain 97% of the planet's water. That leaves just 3% as fresh water, water with low concentrations of salts (**Figure** 8.1). Most fresh water is trapped as ice in the vast glaciers and ice sheets of Greenland.

How is the 3% of fresh water divided into different reservoirs? How much of that water is useful for living creatures? How much for people?

A storage location for water such as an ocean, glacier, pond, or even the atmosphere is known as a **reservoir**. A water molecule may pass through a reservoir very quickly or may remain for much longer. The amount of time a molecule stays in a reservoir is known as its **residence time**.

Vocabulary

- **reservoir**: A storage location for a substance, such as water. The atmosphere is a reservoir for carbon dioxide.
- **residence time**: The amount of time, on average, a substance remains in a reservoir.

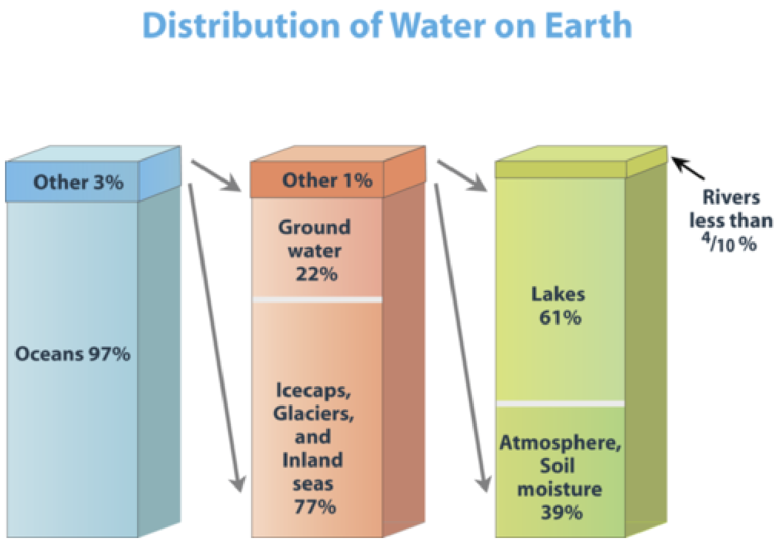


FIGURE 8.1
The distribution of Earth's water.

Summary

- Of Earth's water, 97% is in the oceans.
- Of the remaining 3%, much is trapped in ice and glaciers.
- A substance is stored in a reservoir and the amount of time it stays in that reservoir is its residence time.

Practice

Use this resource to answer the questions that follow.

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

1. What percentage of Earth's water is usable for humans?
2. How much of the Earth's water is ocean water?
3. How much freshwater is in glaciers?
4. How much freshwater is groundwater?
5. How much freshwater is in lakes?

Review

1. If Earth is the water planet, why is water sometimes a scarce resource?
2. What are the reservoirs for water?
3. In which reservoirs does water have the longest residence times? The shortest?

8.2 States of Water

- Define polar molecule.
- Describe the water molecule.
- Identify the three states of water.

H - two - O. Why is something so simple so important?

Water is the most important substance on Earth. Think about all the things you use water for? If your water access were restricted what would you miss about it?

The Water Molecule

Water is simply two atoms of hydrogen and one atom of oxygen bonded together. The hydrogen ions are on one side of the oxygen ion, making water a **polar molecule**. This means that one side, the side with the hydrogen ions, has a slightly positive electrical charge. The other side, the side without the hydrogen ions, has a slightly negative positive charge.

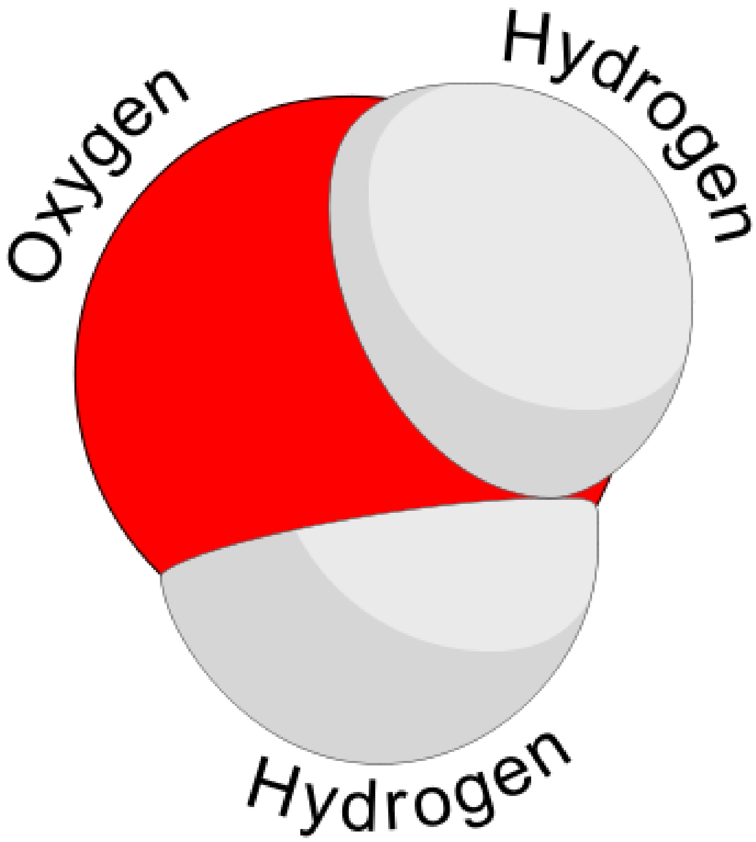


FIGURE 8.2
A water molecule. The hydrogen atoms have a slightly positive charge, and the oxygen atom has a slightly negative charge.

Despite its simplicity, water has remarkable properties. Water expands when it freezes, has high surface tension (because of the polar nature of the molecules, they tend to stick together), and others. Without water, life might not be able to exist on Earth and it certainly would not have the tremendous complexity and diversity that we see.

Three States of Matter

Water is the only substance on Earth that is present in all three states of matter – as a solid, liquid or gas. (And Earth is the only planet where water is present in all three states.) Because of the ranges in temperature in specific locations around the planet, all three phases may be present in a single location or in a region. The three phases are solid (ice or snow), liquid (water), and gas (**water vapor**). See ice, water, and clouds (**Figure** 8.3).

Vocabulary

- **polar molecule**: A molecule with an unevenly distributed electrical charge.

FIGURE 8.3
(a) Ice floating in the sea. Can you find all three phases of water in this image? (b) Liquid water. (c) Water vapor is invisible, but clouds that form when water vapor condenses are not.

- **water vapor**: Water in the form of a gas. Water vapor is invisible to humans; when we see clouds, we actually are seeing liquid water in the clouds.

Summary

- Water is a polar molecule with a more positive charge on one side and a more negative charge on the other side.
- Water is the only substance on Earth that is stable in all three states.
- Earth is the only planet in the Solar System that has water in all three states.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=KCL8zqjXbME

MEDIA
Click image to the left for more content.

1. What is water made of?
2. Explain how water becomes a solid.
3. What happens when a solid melts?
4. How do molecules move in a liquid?
5. What are the major differences between a solid, a liquid, and a gas?

Review

1. What is a polar molecule?

2. What are the three states that a substance can have?
3. Where in the solar system is water found in all three states?

8.3 Processes of the Water Cycle

- Describe the water cycle and describe the processes that carry water between reservoirs.
- Define the processes by which water changes state and explain the role each plays in the water cycle.

Where have these water molecules been?

Because of the unique properties of water, water molecules can cycle through almost anywhere on Earth. The water molecule found in your glass of water today could have erupted from a volcano early in Earth's history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high up in the atmosphere and maybe deep in the belly of a dinosaur. Where will that water molecule go next?

The Water Cycle

The movement of water around Earth's surface is the **hydrological (water) cycle** (**Figure** 8.4). Water inhabits reservoirs within the cycle, such as ponds, oceans, or the atmosphere. The molecules move between these reservoirs by certain processes, including condensation and precipitation. There are only so many water molecules and these molecules cycle around. If climate cools and glaciers and ice caps grow, there is less water for the oceans and sea level will fall. The reverse can also happen.

The following section looks at the reservoirs and the processes that move water between them.

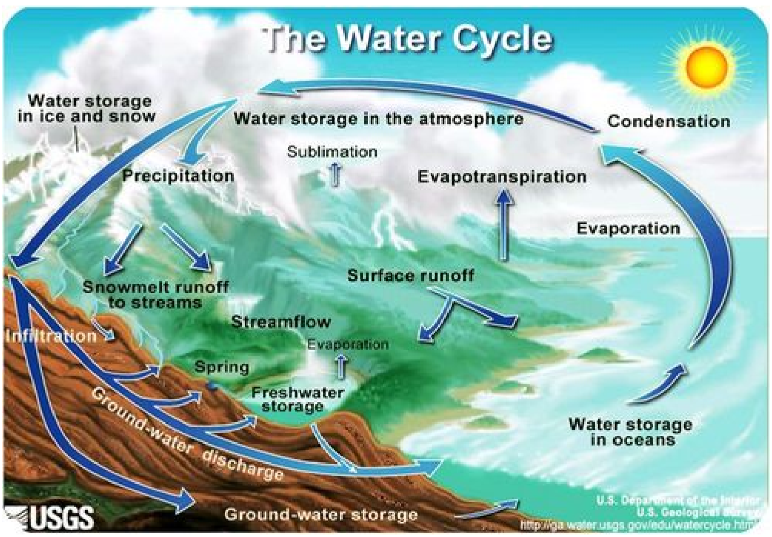


FIGURE 8.4
Because it is a cycle, the water cycle has no beginning and no end.

Solar Energy

The Sun, many millions of kilometers away, provides the energy that drives the water cycle. Our nearest star directly impacts the water cycle by supplying the energy needed for evaporation.

Oceans

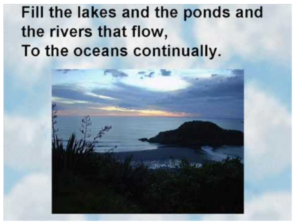
Most of Earth's water is stored in the oceans, where it can remain for hundreds or thousands of years.

Atmosphere

Water changes from a liquid to a gas by **evaporation** to become water vapor. The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a fresh water reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** to become tiny droplets of liquid. The droplets gather in clouds, which are blown about the globe by wind. As the water droplets in the clouds collide and grow, they fall from the sky as precipitation. **Precipitation** can be rain, sleet, hail, or snow. Sometimes precipitation falls back into the ocean and sometimes it falls onto the land surface.

For a little fun, watch this video. This water cycle song focuses on the role of the sun in moving H_2O from one reservoir to another. The movement of all sorts of matter between reservoirs depends on Earth's internal or external sources of energy **(7c)**: http://www.youtube.com/watch?v=Zx_1g5pGFLI#38;feature=related (2:38).



MEDIA

Click image to the left for more content.

This animation shows the annual cycle of monthly mean precipitation around the world: http://en.wikipedia.org/wiki/File:MeanMonthlyP.gif.

Streams and Lakes

When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by sublimation, the process in which a solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor undergoing **sublimation** from a glacier, you may have seen dry ice sublimate in air.

Snow and ice slowly melt over time to become liquid water, which provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere.

Soil

A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water (**Figure** 8.5). Water trapped in soil is important for plants to grow.

Groundwater

Water may seep through dirt and rock below the soil and then through pores infiltrating the ground to go into Earth's groundwater system. Groundwater enters aquifers that may store fresh water for centuries. Alternatively, the water may come to the surface through springs or find its way back to the oceans.

Biosphere

Plants and animals depend on water to live. They also play a role in the water cycle. Plants take up water from the soil and release large amounts of water vapor into the air through their leaves (**Figure** 8.6), a process known as **transpiration**.

An online guide to the hydrologic cycle from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hyd/home.rxml.

How the water cycle works and how rising global temperatures will affect the water cycle, especially in California, are the topics of this Quest video.

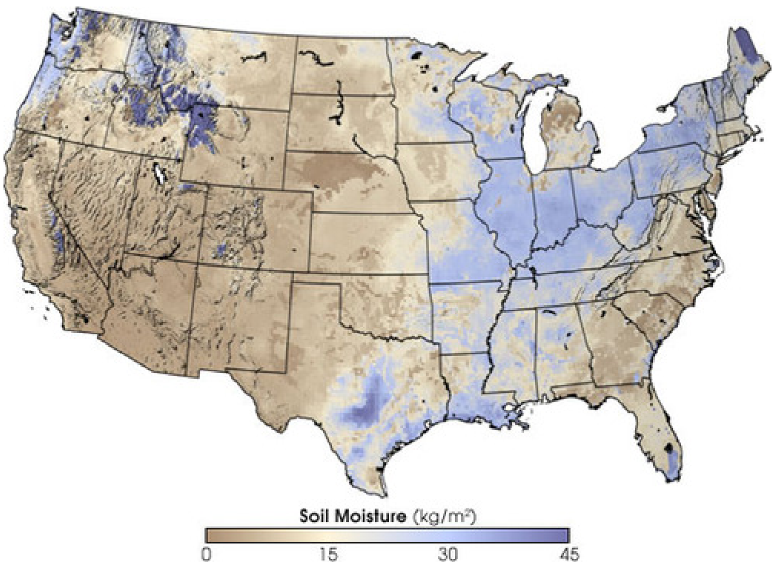


FIGURE 8.5
The moisture content of soil in the United States varies greatly.

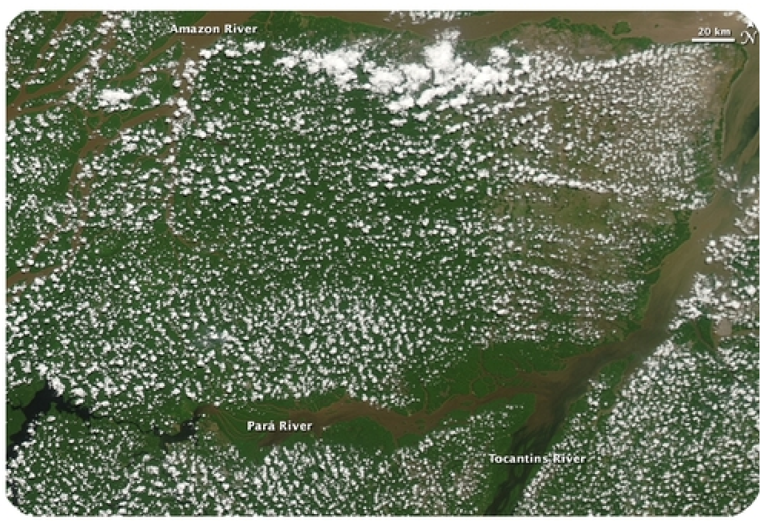


FIGURE 8.6
Clouds form above the Amazon Rainforest even in the dry season because of moisture from plant transpiration.

Watch it at http://www.kqed.org/quest/television/tracking-raindrops/.

MEDIA
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Human Uses

People also depend on water as a natural resource. Not content to get water directly from streams or ponds, humans create canals, aqueducts, dams, and wells to collect water and direct it to where they want it (**Figure** 8.7).

FIGURE 8.7
Pont du Gard in France is an ancient aqueduct and bridge that was part of of a well-developed system that supplied water around the Roman empire.

Vocabulary

- **condensation**: The change in a substance from a gas to a liquid, releases energy.
- **evaporation**: The change in a substance from a liquid to a gas by the addition of energy.
- **hydrological (water) cycle**: The movements of water in and between reservoirs (e.g. oceans, clouds, streams, ice, and ground water).
- **precipitation**: Water that falls from the sky as rain, snow, sleet, or hail.
- **sublimation**: The change of a substance from a solid to a gas without going through the liquid phase.
- **transpiration**: The release of water vapor into the air through the leaves of plants.

Summary

- The water cycle describes all of the reservoirs of water and the processes that carry it between them.
- Water changes state by evaporation, condensation, and sublimation.
- Plants release water through their leaves by transpiration.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Water Cycle**

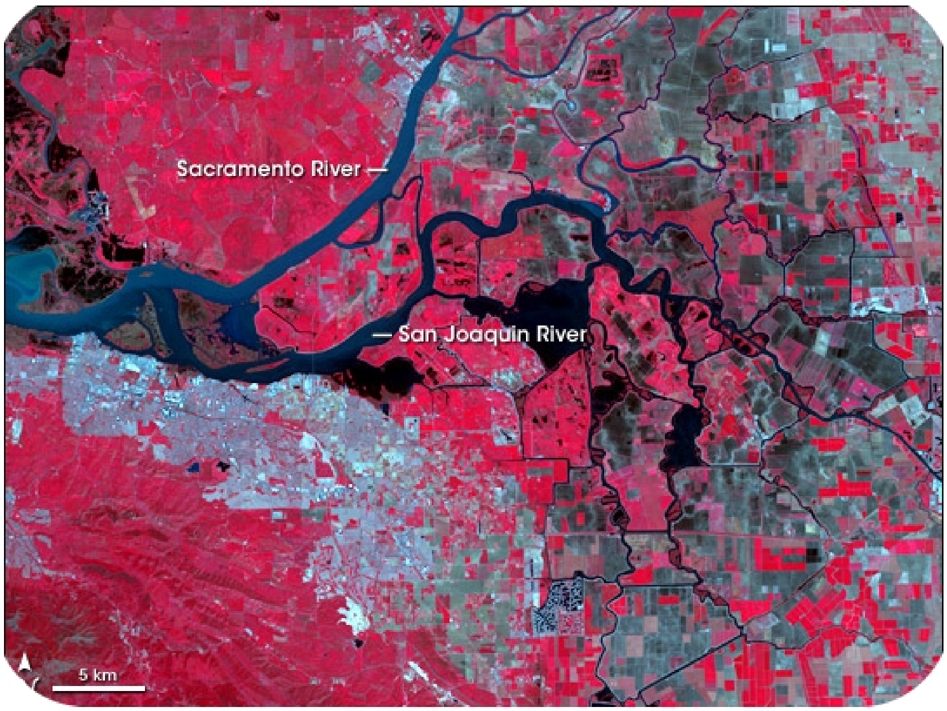
1. What is condensation?
2. List the types of precipitation.
3. What is infiltration?
4. What is surface runoff?
5. Explain what happens with groundwater.
6. Explain the difference between evaporation and transpiration.

Review

1. What is transpiration?
2. Describe when and how sublimation occurs.
3. What is the role of the major reservoirs in the water cycle?

8.4 Streams and Rivers

- Define stream and describe its parts and stages.



Do you see the Sacramento and San Joaquin Rivers?

The farmland in the Central Valley of California is among the most productive in the world. Besides good soil and a mild climate, the region has a lot of water. Streams drain off of the Sierra Nevada mountains to the east and join the mighty Sacramento and San Joaquin Rivers in the Central Valley. How many of the features that are discussed below can you find in this image?

Streams

Streams are bodies of water that have a current; they are in constant motion. Geologists recognize many categories of streams depending on their size, depth, speed, and location. Creeks, brooks, tributaries, bayous, and rivers are all streams. In streams, water always flows downhill, but the form that downhill movement takes varies with rock type, topography, and many other factors. Stream erosion and deposition are extremely important creators and destroyers of landforms.

Rivers are the largest streams. People have used rivers since the beginning of civilization as a source of water, food, transportation, defense, power, recreation, and waste disposal.

With its high mountains, valleys and Pacific coastline, the western United States exhibits nearly all of the features common to rivers and streams. The photos below are from the western states of Montana, California and Colorado.

Parts of a Stream

A stream originates at its source. A source is likely to be in the high mountains where snows collect in winter and melt in summer, or a source might be a spring. A stream may have more than one source.

Two streams come together at a **confluence**. The smaller of the two streams is a **tributary** of the larger stream (**Figure** 8.8).

FIGURE 8.8
The confluence between the Yellowstone River and one of its tributaries, the Gardiner River, in Montana.

The point at which a stream comes into a large body of water, like an ocean or a lake, is called the **mouth**. Where the stream meets the ocean or lake is an **estuary** (**Figure** 8.9).

FIGURE 8.9
The mouth of the Klamath River creates an estuary where it flows into the Pacific Ocean in California.

The mix of fresh and salt water where a river runs into the ocean creates a diversity of environments where many different types of organisms create unique ecosystems.

Stages of Streams

As a stream flows from higher elevations, like in the mountains, towards lower elevations, like the ocean, the work of the stream changes. At a stream's **headwaters**, often high in the mountains, gradients are steep (**Figure** 8.10). The stream moves fast and does lots of work eroding the stream bed.

FIGURE 8.10
Headwaters of the San Gabriel River in southern California.

As a stream moves into lower areas, the gradient is not as steep. Now the stream does more work eroding the edges of its banks. Many streams develop curves in their channels called **meanders** (**Figure** 8.11).

FIGURE 8.11
The East River meanders through Crested Butte, Colorado.

As the river moves onto flatter ground, the stream erodes the outer edges of its banks to carve a **floodplain**, which is a flat, level area surrounding the stream channel (**Figure** 8.12).

Base level is where a stream meets a large body of standing water, usually the ocean, but sometimes a lake or pond. Streams work to down cut in their stream beds until they reach base level. The higher the elevation, the farther the stream is from where it will reach base level and the more cutting it has to do. The ultimate base level is sea level.

Divides

A **divide** is a topographically high area that separates a landscape into different water basins (**Figure** 8.13). Rain that falls on the north side of a ridge flows into the northern drainage basin and rain that falls on the south side flows into the southern drainage basin. On a much grander scale, entire continents have divides, known as **continental divides**.

FIGURE 8.12
A green floodplain surrounds the Red Rock River as it flows through Montana.

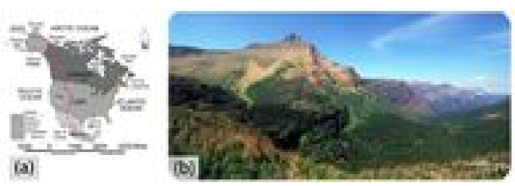


FIGURE 8.13
(a) The divides of North America. In the Rocky Mountains in Colorado, where does a raindrop falling on the western slope end up? How about on the eastern slope? (b) At Triple Divide Peak in Montana water may flow to the Pacific, the Atlantic, or Hudson Bay depending on where it falls. Can you locate where in the map of North America (above) this peak sits?

Vocabulary

- **base level**: Where a stream meets a large body of standing water, usually the ocean.
- **confluence**: Where two streams join together.
- **continental divide**: A divide that separates water that goes to different oceans.
- **divide**: A ridge that separates one water basin from another.
- **estuary**: Where a stream meets a lake or, more usually, an ocean. The mixture of fresh and salt water attracts a large number of species and so estuaries have high biodiversity.
- **floodplain**:The region near a stream bed where water from the stream overflows during floods.
- **headwaters**: The location where a stream forms, often high in the mountains.
- **meanders**: A bend or curve in a stream channel.
- **mouth**: Where a stream enters a larger body of water such as a lake or an ocean.
- **stream**: A body of moving water, contained within a bank (sides) and bed (bottom).
- **tributary**: The smaller of two streams that join together to make a larger stream.

Summary

- A moving body of water of any size is a stream.
- A tributary begins at its headwaters on one side of a divide, comes together with another tributary at a

confluence, and empties out at an estuary.
- Base level is where a large body of water is located; sea level is the ultimate base level.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=TxI9gTvNY0M

MEDIA
Click image to the left for more content.

1. Where is water speed and weight the greatest?
2. What is created by this fast moving water?
3. Explain what is occurring where the water moves slowly.

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

MEDIA
Click image to the left for more content.

4. What has destabilized the Minnesota River area?
5. What speeds up the water as it moves down the river?
6. What caused the ravines to form?
7. Where does most of the sediment end up?
8. List the sources of the sediment.

Review

1. Very little land is below sea level and all of it does not drain to the sea. Why not?
2. What happens to two drops of water that fall on opposite sides of a divide?
3. What happens to a river's floodplain if the river is dammed?

8.5 Ponds and Lakes

- Describe the characteristics and zones of ponds and lakes.

Why is Lake Tahoe so large and clear?

Block faulting in the eastern Sierra Nevada Mountains created a basin that filled with water. This created beautiful Lake Tahoe, which straddles the California-Nevada border. The lake has been exceedingly clear though its history, although now development around the lake has resulted in some loss of clarity.

Ponds

Ponds are small bodies of fresh water that usually have no outlet; ponds are often are fed by underground springs. Like lakes, ponds are bordered by hills or low rises so the water is blocked from flowing directly downhill.

Lakes

Lakes are larger bodies of water. Lakes are usually fresh water, although the Great Salt Lake in Utah is just one exception. Water usually drains out of a lake through a river or a stream and all lakes lose water to evaporation.

Lakes form in a variety of different ways: in depressions carved by glaciers, in calderas (**Figure** 8.14), and along tectonic faults, to name a few. Subglacial lakes are even found below a frozen ice cap.

As a result of geologic history and the arrangement of land masses, most lakes are in the Northern Hemisphere. In fact, more than 60% of all the world's lakes are in Canada — most of these lakes were formed by the glaciers that covered most of Canada in the last Ice Age (**Figure** 8.15).

Lakes are not permanent features of a landscape. Some come and go with the seasons, as water levels rise and fall. Over a longer time, lakes disappear when they fill with sediments, if the springs or streams that fill them diminish,

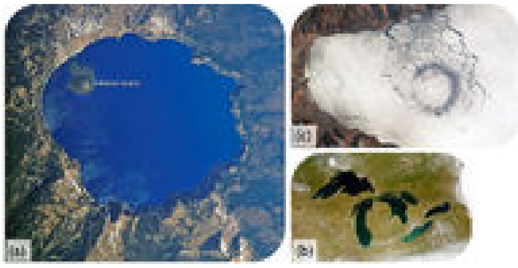


FIGURE 8.14

(a) Crater Lake in Oregon is in a volcanic caldera. Lakes can also form in volcanic craters and impact craters. (b) The Great Lakes fill depressions eroded as glaciers scraped rock out from the landscape. (c) Lake Baikail, ice coated in winter in this image, formed as water filled up a tectonic faults.

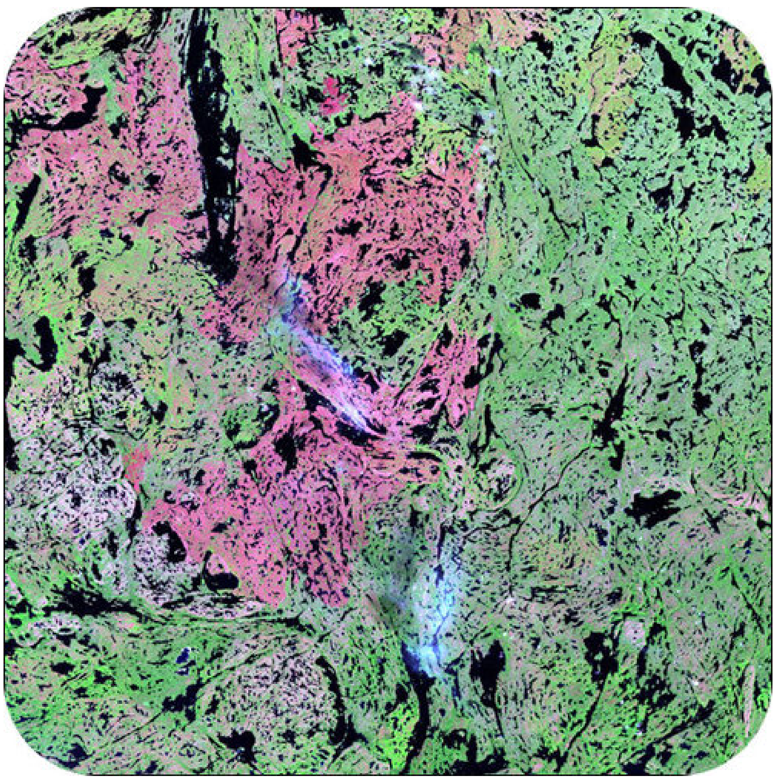


FIGURE 8.15

Lakes near Yellowknife were carved by glaciers during the last Ice Age.

or if their outlets grow because of erosion. When the climate of an area changes, lakes can either expand or shrink (**Figure** 8.16). Lakes may disappear if precipitation significantly diminishes.

Large lakes have tidal systems and currents, and can even affect weather patterns. The Great Lakes in the United States contain 22% of the world's fresh surface water (**Figure** 8.14). The largest them, Lake Superior, has a tide that rises and falls several centimeters each day. The Great Lakes are large enough to alter the weather system in Northeastern United States by the "lake effect," which is an increase in snow downwind of the relatively warm lakes. The Great Lakes are home to countless species of fish and wildlife.

Many lakes are not natural, but are human-made. People dam a stream in a suitable spot and then let the water back up behind it, creating a lake. These lakes are called "reservoirs."

FIGURE 8.16
The Badwater Basin in Death Valley contains water in wet years. The lake basin is a remnant from when the region was much wetter just after the Ice Ages.

Vocabulary

- **pond**: A small body of freshwater, with no stream draining it; fed by an underground spring.
- **lake**: A large body of freshwater drained by a stream; naturally occurring or human-made.

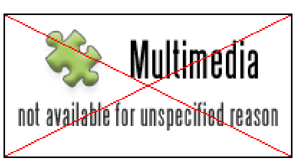
Summary

- Ponds are small water bodies often fed by springs.
- A lake may form in many locations, including a volcanic crater, where a glacier has carved out a depression, or a fault zone.
- Lakes have surface, open-water, and deep-water zones.

Practice

Use this resource to answer the questions that follow.

http://www.untamedscience.com/biology/world-biomes/lakes-and-ponds-biome



MEDIA
Click image to the left for more content.

1. List the zones of a lake.
2. What can you do in very large lakes, like Lake Michigan?
3. What happens in a temperate lake?
4. What causes the lake to cycle?
5. What will happen to a lake over time?

Review

1. What is the reason that Earth has many more lakes than is normal during Earth's history? What will happen as climate warms?

2. How is a large lake like an ocean? How is it different?

3. What is the difference between ponds and lakes? How are they similar?

8.6 Flooding

- Explain the causes and effects of floods.
- Describe types of flood protection.

Why are there so many floods?

Floods are a natural part of the water cycle, but that doesn't make them any less terrifying. Put most simply, a flood is an overflow of water in one place. How can you prepare for a flood? What do you do if you're caught in one?

Causes of Floods

Floods usually occur when precipitation falls more quickly than water can be absorbed into the ground or carried away by rivers or streams. Waters may build up gradually over a period of weeks, when a long period of rainfall or snowmelt fills the ground with water and raises stream levels.

Extremely heavy rains across the Midwestern U.S. in April 2011 led to flooding of the rivers in the Mississippi River basin in May 2011 (**Figures** 8.17 and 8.18).

Flash Floods

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period (**Figure** 8.19). A flash flood may do its damage miles from where the rain actually falls if the water travels far down a dry streambed.

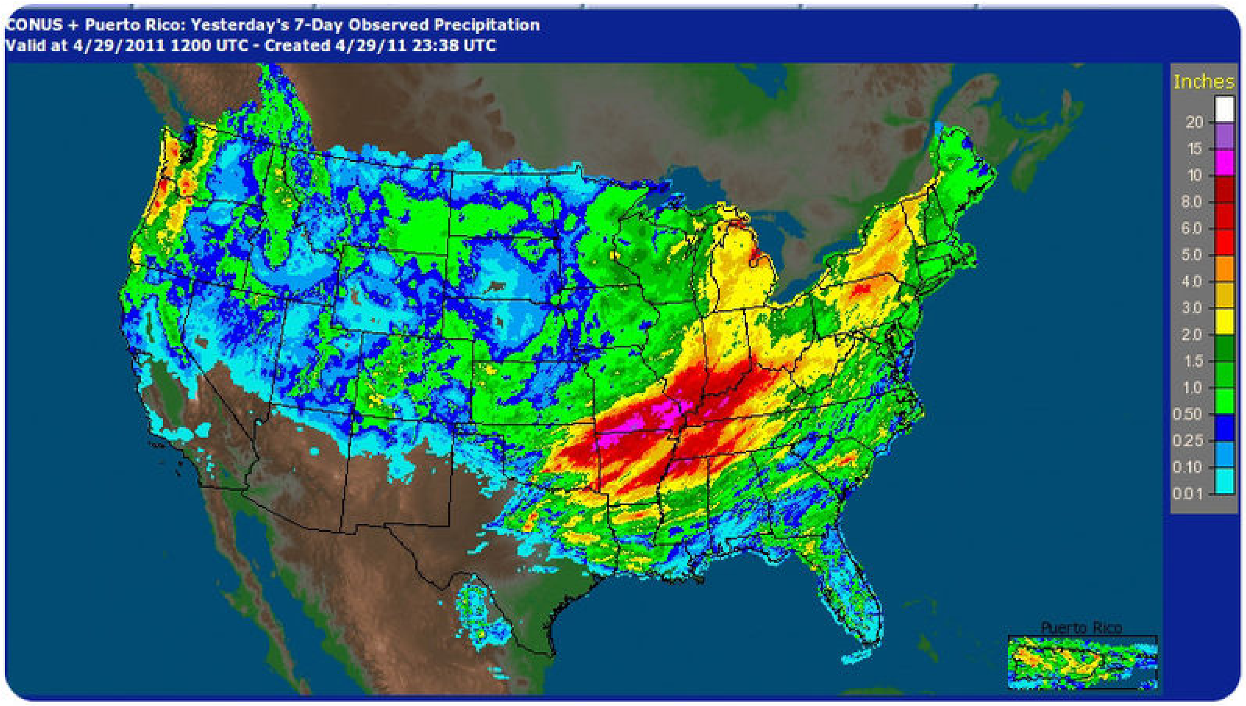


FIGURE 8.17

This map shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.

FIGURE 8.18

Record flow in the Ohio and Mississippi Rivers has to go somewhere. Normal spring river levels are shown in 2010. The flooded region in the image from May 3, 2011 is the New Madrid Floodway, where overflow water is meant to go. 2011 is the first time since 1927 that this floodway was used.

FIGURE 8.19

A 2004 flash flood in England devastated two villages when 3-1/2 inches of rain fell in 60 minutes.

Buffers to Flooding

Heavily vegetated lands are less likely to experience flooding. Plants slow down water as it runs over the land, giving it time to enter the ground. Even if the ground is too wet to absorb more water, plants still slow the water's passage and increase the time between rainfall and the water's arrival in a stream; this could keep all the water falling over a region from hitting the stream at once. Wetlands act as a buffer between land and high water levels and play a key role in minimizing the impacts of floods. Flooding is often more severe in areas that have been recently logged.

Flood Protection

People try to protect areas that might flood with dams, and dams are usually very effective. But high water levels sometimes cause a dam to break and then flooding can be catastrophic. People may also line a river bank with **levees**, high walls that keep the stream within its banks during floods. A levee in one location may just force the high water up or downstream and cause flooding there. The New Madrid Overflow in the image above was created with the recognition that the Mississippi River sometimes simply cannot be contained by levees and must be allowed to flood.

Effects of Floods

Not all the consequences of flooding are negative. Rivers deposit new nutrient-rich sediments when they flood, so floodplains have traditionally been good for farming. Flooding as a source of nutrients was important to Egyptians along the Nile River until the Aswan Dam was built in the 1960s. Although the dam protects crops and settlements from the annual floods, farmers must now use fertilizers to feed their cops.

Floods are also responsible for moving large amounts of sediments about within streams. These sediments provide habitats for animals, and the periodic movement of sediment is crucial to the lives of several types of organisms. Plants and fish along the Colorado River, for example, depend on seasonal flooding to rearrange sand bars.

"Floods 101" is a National Geographic video found in Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/.

FIGURE 8.20
Within the floodplain of the Nile, soils are fertile enough for productive agriculture. Beyond this, infertile desert soils prevent viable farming.

Vocabulary

- **flash flood**: A rapid flood in a low-lying area that may allow no preparation.
- **levee**: A raised structure designed to hold back the waters of a stream or river in the case of a flood.

Summary

- When the amount of water in a drainage exceeds the capacity of the drainage, there is a flood.
- Floods are made worse when vegetation is cleared, when the land is already soaked, or when hillsides have been logged.
- People build dams and levees to protect from flooding.
- Floods are a source of nutrients on a floodplain.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/floods/

1. Where are floods more likely to occur?
2. Why have farmers relied on floods?
3. What causes floods?
4. At what depth can a flood move a car? Why is this dangerous?
5. What cause the Mississippi Flood of 1993?
6. Why did Hurricane Katrina cause so much damage to New Orleans?
7. What could cause massive flooding today?

Review

1. How does a flash flood differ from another type of flood?

2. What was the role of flooding on the Nile River and what was the consequence of damming the river?
3. Why do floods still occur, even though people build dams and levees?

8.7 Glaciers

- Describe the formation, movement, and characteristics of glaciers.

Can solid ice really move?

Yes! Ice that moves downslope is called a "glacier." Glaciers move extremely slowly along the land surface. They may survive for thousands of years.

Where are the Glaciers?

Nearly all glacial ice, 99%, is contained in ice sheets in the polar regions, particularly Antarctica and Greenland.

Glaciers often form in the mountains because higher altitudes are colder and more likely to have snow that falls and collects. Every continent, except Australia, hosts at least some glaciers in the high mountains.

Types of Glaciers

The types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amounts of snow and ice accumulate.
- **Alpine (valley) glaciers** flow downhill from where the snow and ice accumulates through mountains along existing valleys.
- **Ice caps** are large glaciers that cover a larger area than just a valley, possibly an entire mountain range or region. Glaciers come off of ice caps into valleys.

The Greenland ice cap covers the entire landmass.

FIGURE 8.21
The Greenland ice cap covers the entire landmass.

Glacial Growth

Formation

Glaciers grow when more snow falls near the top of the glacier, in the **zone of accumulation**, than is melted from lower down in the glacier, in the **zone of ablation**. These two zones are separated by the equilibrium line.

Snow falls and over time converts to granular ice known as firn. Eventually, as more snow and ice collect, the firn becomes denser and converts to glacial ice.

Water is too warm for a glacier to form, so they form only on land. A glacier may run out from land into water, but it usually breaks up into icebergs that eventually melt into the water.

Movement

Whether an ice field moves or not depends on the amount of ice in the field, the steepness of the slope and the roughness of the ground surface. Ice moves where the pressure is so great that it undergoes plastic flow. Ice also slides at the bottom, often lubricated by water that has melted and travels between the ground and the ice.

The speed of a glacier ranges from extremely fast, where conditions are favorable, to nearly zero.

Because the ice is moving, glaciers have **crevasses**, where cracks form in the ice as a result of movement. The large crevasse at the top of an alpine glacier where ice that is moving is separated from ice that is stuck to the mountain above is called a **bergshrund**.

Shrinking

Glaciers are melting back in many locations around the world. When a glacier no longer moves, it is called an ice sheet. This usually happens when it is less than 0.1 km2 in area and 50 m thick.

FIGURE 8.22
Crevasses in a glacier are the result of movement.

Glacier National Park

Many of the glaciers in Glacier National Park have shrunk and are no longer active. Summer temperatures have risen rapidly in this part of the country and so the rate of melting has picked up. Whereas Glacier National Park had 150 glaciers in 1850, there are only about 25 today. Recent estimates are that the park will have no active glaciers as early as 2020.

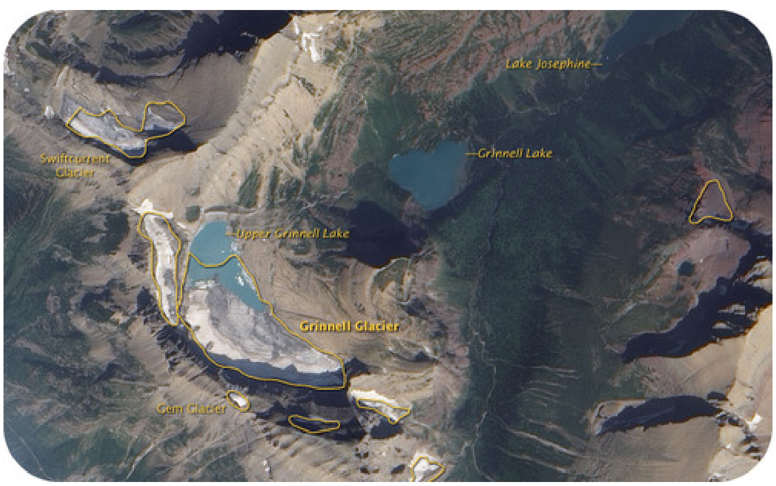


FIGURE 8.23
This satellite image shows Grinnell Glacier, Swiftcurrent Glacier, and Gem Glacier in 2003 with an outline of the extent of the glaciers as they were in 1950. Although it continues to be classified as a glacier, Gem Glacier is only 0.020 km2 (5 acres) in area, only one-fifth the size of the smallest active glaciers.

Glaciers as a Resource

In regions where summers are long and dry, melting glaciers in mountain regions provide an important source of water for organisms and often for nearby human populations.

Vocabulary

- **alpine (valley) glacier**: A glacier found in a valley in the mountains.

- **bergshrund**: A crevasse near the top of a glacier where moving ice below is separated from stagnant ice above.
- **continental glacier**: A sheet of ice covering a large area that is not confined to a valley.
- **crevasse**: A deep crack in a glacier that forms as a result of ice movement.
- **glacier**: Large sheets of flowing ice.
- **zone of ablation**: The lower part of a glacier where the amount of snow and ice that melts off is greater than the amount that accumulates.
- **zone of accumulation**: The upper part of a glacier where the amount of snow and ice that accumulates is greater than the amount that melts off.

Summary

- Glaciers are ice that moves because the amount of snow and ice that collects in the zone of accumulation exceeds the amount that melts off in the zone of ablation.
- Continental glaciers form in a central location with ice moving outward in all directions. Alpine glaciers form in high mountains and travel through valleys.
- Because glaciers move, they have characteristic features like crevasses and bergshrunds.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=mgnzSTY5zRg

MEDIA

Click image to the left for more content.

1. Where are glaciers found?
2. What is the largest glacier in Yosemite National Park?
3. What are the dangers on glaciers?
4. What are sun cups?
5. What is a crevasse? What creates it?
6. What is a glacier?
7. Describe the bergshrund.
8. What is the challenge with glaciers?

Review

1. Compare and contrast alpine glaciers, continental glaciers, and ice caps.
2. With a glacier that is melting back, what is happening in the zone of accumulation and the zone of ablation? What is happening to the equilibrium line?
3. How do glaciers serve as a water resource for people and organisms in the summertime?

8.8 Introduction to Groundwater

- Define aquifer and explain how aquifers form and recharge.

Is there always water flowing beneath the land surface?

Although this may seem surprising, water beneath the ground is commonplace, moving slowly and silently through an aquifer and then bubbling to the surface at a spring. Groundwater is an extremely important source of water in many parts of the world where development and agricvulture outmatch the amount of water available from rainfall and streams.

Aquifer

Groundwater resides in **aquifers**, porous rock and sediment with water in between. Water is attracted to the soil particles, and **capillary action**, which describes how water moves through porous media, moves water from wet soil to dry areas.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far away, perhaps in a mountainous area.

Recharge

The amount of water that is available to enter groundwater in a region, called **recharge**, is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water goes into the ground where there is a lot of rain, flat land, porous rock, exposed soil, and where water is not already filling the soil and rock.

Fossil Water

The residence time of water in a groundwater aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages.

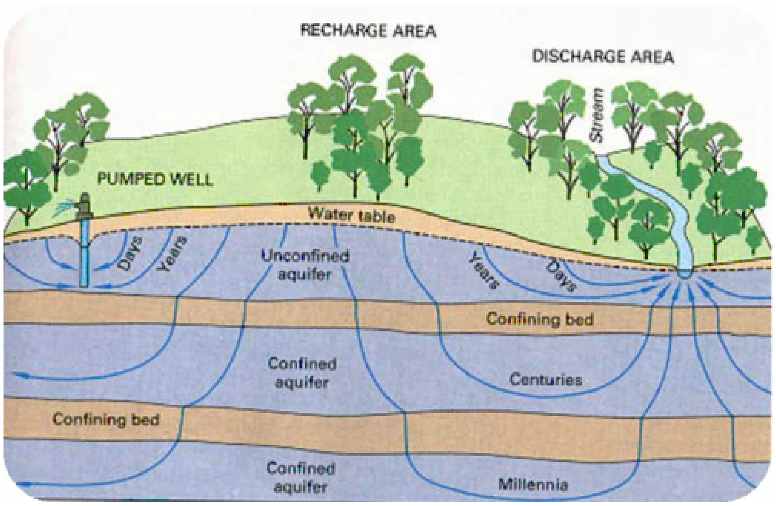


FIGURE 8.24

A diagram of groundwater flow through aquifers showing residence times. Deeper aquifers typically contain older "fossil water."

Vocabulary

- **aquifer**: A layer of rock, sand, or gravel that holds large amounts of ground water.
- **capillary action**: Water moves from wet to dry regions in soil.
- **recharge**: Water that moves down from the surface into the groundwater.

Summary

- Groundwater is in aquifers, a porous and permeable rock layer.
- Groundwater recharges in wet regions.
- Much groundwater is from the end of the ice ages, so it is called fossil water.

Practice

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/earthguide/diagrams/groundwater/index.html

1. What is groundwater?

2. How does groundwater begin?

3. What is the water table?

4. What is an aquifer?

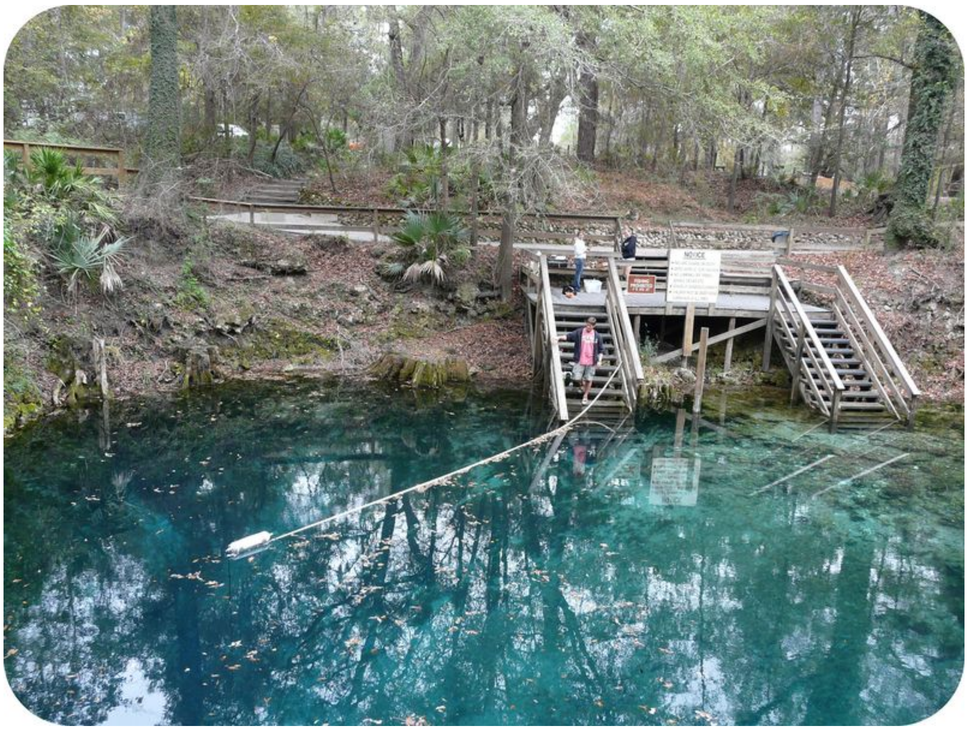
5. What is the cone of depression? How is it created?

Review

1. What effects the residence time of groundwater in a region?
2. Where does groundwater come from in a region that has very little rainfall?
3. If groundwater is used, how will there be more?

8.9 Groundwater Aquifers

- Describe the features of an aquifer.
- Define water table and explain how changes in the water table occur.
- Explain how springs are created.



Does groundwater move as an underground river?

People often think of groundwater as an underground river, but that is rarely true. In Florida, though, water has so thoroughly dissolved the limestone that streams travel underground and above ground. This photo shows where a large spring brings groundwater to the surface as if from nowhere.

Features of an Aquifer

To be a good aquifer, the rock in the aquifer must have good:

- **porosity**: small spaces between grains
- **permeability**: connections between pores

This animation shows porosity and permeability. The water droplets are found in the pores between the sediment grains, which is porosity. When the water can travel between ores, that's permeability. http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/POROS_3.MPG

To reach an aquifer, surface water infiltrates downward into the ground through tiny spaces or pores in the rock. The water travels down through the permeable rock until it reaches a layer that does not have pores; this rock is **impermeable** (**Figure** 8.25). This impermeable rock layer forms the base of the aquifer. The upper surface where the groundwater reaches is the **water table**.

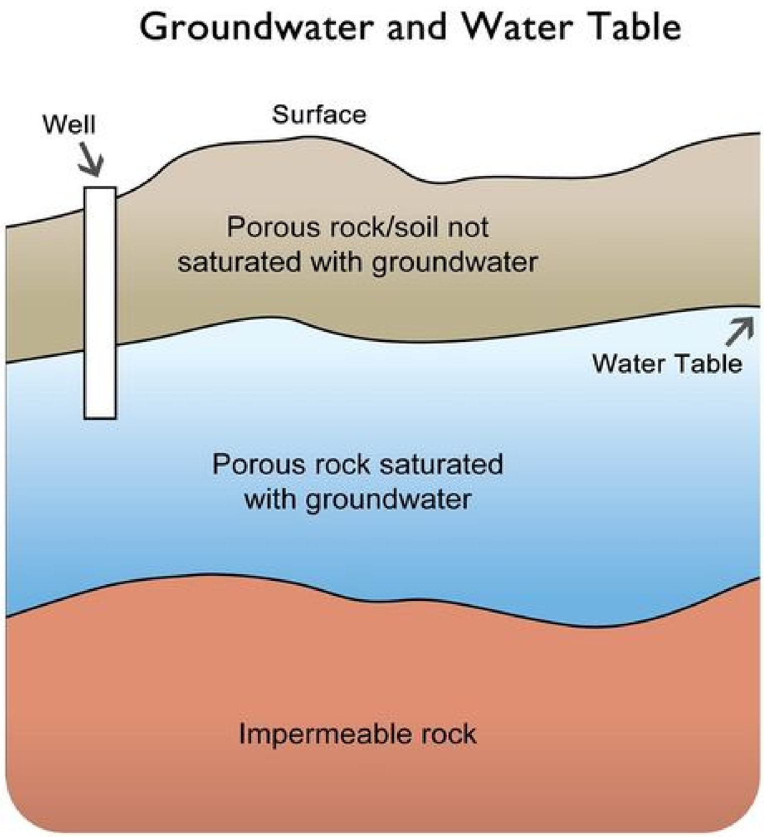


FIGURE 8.25
Groundwater is found beneath the solid surface. Notice that the water table roughly mirrors the slope of the land's surface. A well penetrates the water table.

The Water Table

For a groundwater aquifer to contain the same amount of water, the amount of recharge must equal the amount of discharge. What are the likely sources of recharge? What are the likely sources of discharge?

What happens to the water table when there is a lot of rainfall? What happens when there is a drought? Although groundwater levels do not rise and fall as rapidly as at the surface, over time the water table will rise during wet periods and fall during droughts.

In wet regions, streams are fed by groundwater; the surface of the stream is the top of the water table (**Figure** 8.26). In dry regions, water seeps down from the stream into the aquifer. These streams are often dry much of the year. Water leaves a groundwater reservoir in streams or springs. People take water from aquifers, too.

Springs

Groundwater meets the surface in a stream, as shown above, or a **spring** (**Figure** 8.27). A spring may be constant, or may only flow at certain times of year. Towns in many locations depend on water from springs. Springs can be an extremely important source of water in locations where surface water is scarce.

Wells

A **well** is created by digging or drilling to reach groundwater. It is important for anyone who intends to dig a well to know how deep beneath the surface the water table is. When the water table is close to the surface, wells are a convenient method for extracting water. When the water table is far below the surface, specialized equipment must

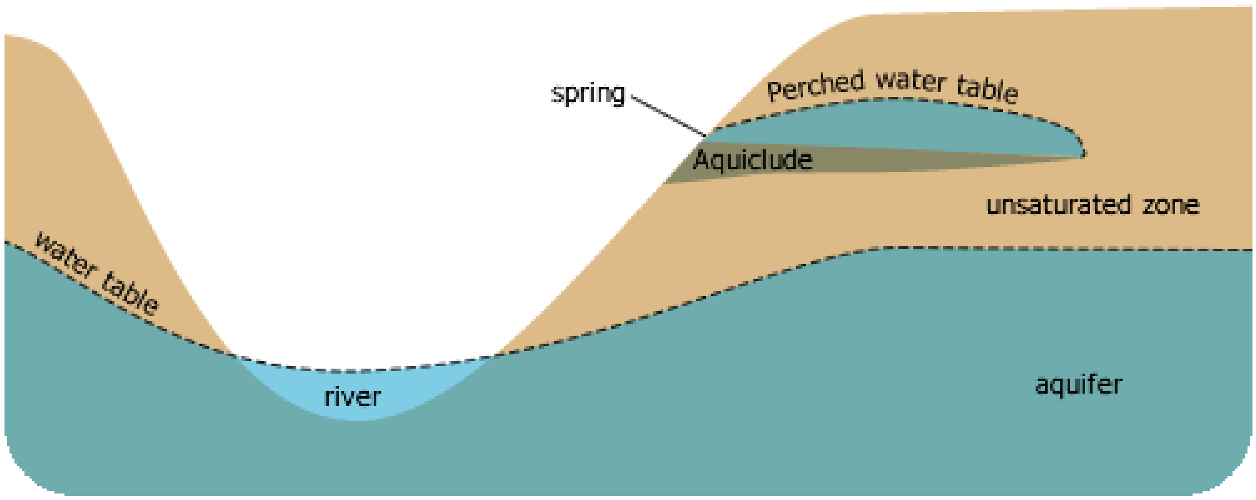


FIGURE 8.26
The top of the stream is the top of the water table. The stream feeds the aquifer.

FIGURE 8.27
A spring in Great Britain bubbles to the surface and feeds the River Gade.

be used to dig a well. Most wells use motorized pumps to bring water to the surface, but some still require people to use a bucket to draw water up (**Figure** 8.28).

Vocabulary

- **impermeable**: Something that water cannot penetrate.

FIGURE 8.28
An old-fashioned well that uses a bucket drawn up by hand.

- **permeable**: A material with interconnecting holes so that water can move through it easily.
- **porosity**: The small holes that exist between grains in a rock or sediment.
- **spring**: A point on the Earth's surface where ground water bubbles up.
- **water table**: The upper surface of ground water.
- **well**: A circular hole that goes into an aquifer to allow people to access groundwater.

Summary

- A rock layer must be porous and permeable to be a good aquifer. An impermeable layer makes up the bottom of an aquifer.
- The water table rises and falls with additions or subtractions to the groundwater system.
- Although people get groundwater from springs, which bring water to the surface, most groundwater is accessed using wells.

Practice

Use this resource to answer the questions that follow.

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

MEDIA
Click image to the left for more content.

1. How does water get to the recharge zone?
2. What is the artesian zone?
3. What does hydrologic pressure do?

4. Where are the wells located?
5. What is a confined aquifer?
6. What is the saline water zone?
7. What happens when pollution leaks from a single area?
8. Explain the two types of pollutants.
9. What can cause each type of pollution?
10. How can the pollution of aquifers be prevented?

Review

1. What happens to the water table in an extremely wet year? In an extremely dry one?
2. What characteristics are needed for rock in and around an aquifer?
3. What causes a spring?

8.10 Importance of the Oceans

- Describe the important roles of oceans as related to climate, the water cycle, and biodiversity.

Just what is down there?

Mostly the oceans are cold, dark and have extremely high pressure. Except at the very top, they are completely inhospitable to humans. Even this humpback whale can only dive to about 700 feet, so there's a lot about the ocean it doesn't know. Earth would not be the same planet without its oceans.

Oceans Moderate Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70^{o}C and others as hot as 55^{o}C, the range is only 125^{o}C. On Mercury temperatures go from -180^{o}C to 430^{o}C, a range of 610^{o}C.

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the equator and then move that solar energy to more polar regions. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller in lands nearer the oceans than away from the oceans. Summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down.

Water Cycle

The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from oceans and most precipitation falls on oceans.

Biologically Rich

The oceans are home to an enormous amount of life. That is, they have tremendous biodiversity (**Figure** 8.29). Tiny ocean plants create the base of a food web that supports all sorts of life forms. Marine life makes up the majority of all biomass on Earth. (**Biomass** is the total mass of living organisms in a given area.) These organisms supply us with food and even the oxygen created by marine plants.

FIGURE 8.29
Polar bears are well adapted to frigid Arctic waters.

Vocabulary

- **biomass**: The total mass of living organisms in a given region.

Summary

- Oceans moderate Earth's temperature by not changing temperature rapidly and by distributing heat around the planet.
- Oceans are an enormous reservoir for water in the water cycle.
- Oceans have tremendous biodiversity and the majority of all biomass on Earth.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/environment/habitats-environment/habitats-oceans-env/why-ocean-matters/

1. What are found in the oceans?
2. How much oxygen does the ocean produce?
3. How much of the water is covered by water?
4. How much of the ocean is protected?
5. What percentage of large predators are gone?
6. What percentage of coral reefs have disappeared?

Review

1. What organisms form the base of the ocean food web?
2. How do the oceans moderate Earth's temperature?
3. What role do oceans play in the water cycle?

8.11 Seawater Chemistry

- Describe the composition of seawater.
- Explain the relationship between the composition of seawater and its properties.

What is salt?

Besides making food taste better, salt is important for the human diet. Before refrigeration, salt was essential for curing and preserving food. Even in antiquity people built access roads they called "salt roads" so that they could obtain this essential mineral. What is salt? It's what you get when you evaporate seawater!

Composition of Ocean Water

Remember that H_2O is a polar molecule, so it can dissolve many substances (**Figure** 8.30). Salts, sugars, acids, bases, and organic molecules can all dissolve in water.

Salinity

Where does the salt in seawater come from? As water moves through rock and soil on land it picks up ions. This is the flip side of weathering. Salts comprise about 3.5% of the mass of ocean water, but the salt content, or **salinity**, is different in different locations.

What would the salinity be like in an estuary? Where seawater mixes with fresh water, salinity is lower than average.

What would the salinity be like where there is lots of evaporation? Where there is lots of evaporation but little circulation of water, salinity can be much higher. The Dead Sea has 30% salinity — nearly nine times the average salinity of ocean water (**Figure** 8.31). Why do you think this water body is called the Dead Sea?

In some areas, dense saltwater and less dense freshwater mix, and they form an immiscible layer, just like oil and water. One such place is a "cenote", or underground cave, very common in certain parts of Central America. Check

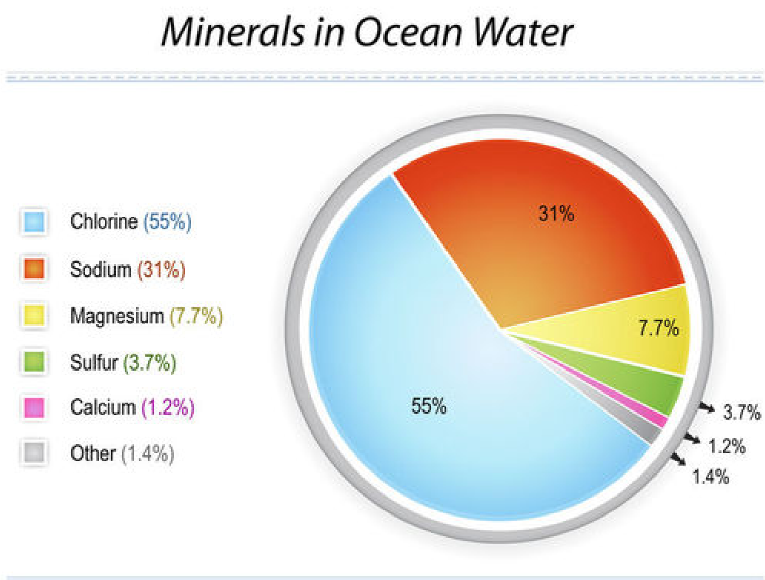
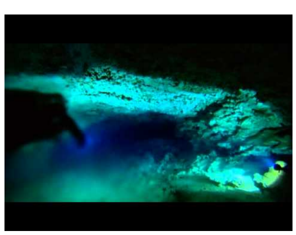


FIGURE 8.30
Ocean water is composed of many substances, many of them salts such as sodium, magnesium, and calcium chloride.

FIGURE 8.31
Because of the increased salinity, the water in the Dead Sea is very dense, it has such high salinity that people can easily float in it!

out the video below:



MEDIA
Click image to the left for more content.

Interactive ocean maps can show salinity, temperature, nutrients, and other characteristics: http://earthguide.ucsd.edu/earthguide/diagrams/levitus/index.html.

Density

With so many dissolved substances mixed in seawater, what is the **density** (mass per volume) of seawater relative to fresh water?

Water density increases as:

- salinity increases
- temperature decreases
- pressure increases

Differences in water density are responsible for deep ocean currents, as will be discussed in the "Deep Currents" lesson.

Vocabulary

- **density**: Mass per unit volume.
- **salinity**: A measure of the amount of dissolved salt in water; average ocean salinity is 3.5%.

Summary

- Water moving through rock and soil picks up ions that end up as salts in large water bodies.
- Ocean water contains salts, sugars, acids, bases, and organic molecules.
- Water density increases as salinity and pressure increase, or as temperature decreases.

Practice

Use this resource to answer the questions that follow.

Ocean Chemistry

http://www.youtube.com/watch?v=KUadxcKtH-g

MEDIA

Click image to the left for more content.

1. What happens to water as it cools?
2. What plays a crucial role in ocean movement?
3. What does algae require?
4. What do diatoms require?
5. Why is calcium important to organisms in the oceans?
6. Why is phosphate required?
7. How does carbon enter the oceans?
8. What problems does increased ocean acidity cause?

9. What is a dead zone?
10. Where is nitrogen fixed in the ocean?
11. Where does the iron in oceans come from?
12. Why are there plans to seed areas of the ocean with iron?

Review

1. Streams aren't salty, so why is the ocean salty?
2. In a region of the ocean where evaporation is high, what happens to the density of the water?
3. What would need to happen for the all of the oceans to become more saline?

8.12 Ocean Zones

- Identify and describe the vertical and horizontal ocean zones.

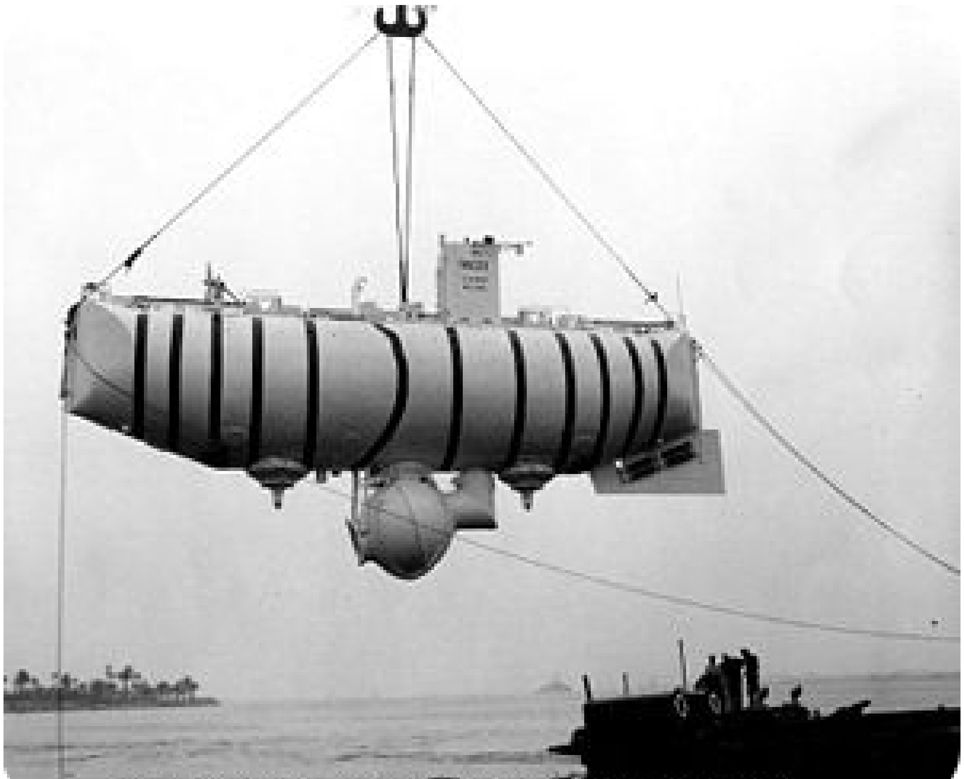


Photo # NH 96801 Trieste hoisted out of water, circa 1958-59

There's a trench in the bottom of the sea. Would you like to visit it?

In 1960, two men in a specially designed submarine called the Trieste descended into a submarine trench called the Challenger Deep (10,910 meters). The depth of this dive remains a record. No craft exists today that can reach that depth. Would you like to go to the bottom of the ocean in that vessel?

Divisions of the Ocean

Oceanographers divide the ocean into zones both vertically and horizontally.

Vertical Divisions

To better understand regions of the ocean, scientists define the **water column** by depth. They divide the entire ocean into two zones vertically, based on light level. Large lakes are divided into similar regions.

- Sunlight only penetrates the sea surface to a depth of about 200 m, creating the **photic zone** ("photic" means light). Organisms that photosynthesize depend on sunlight for food and so are restricted to the photic zone. Since tiny photosynthetic organisms, known as phytoplankton, supply nearly all of the energy and nutrients to the rest of the marine food web, most other marine organisms live in or at least visit the photic zone.

- In the **aphotic zone** there is not enough light for photosynthesis. The aphotic zone makes up the majority of the ocean, but has a relatively small amount of its life, both in diversity of type and in numbers. The aphotic zone is subdivided based on depth (**Figure** 8.32).

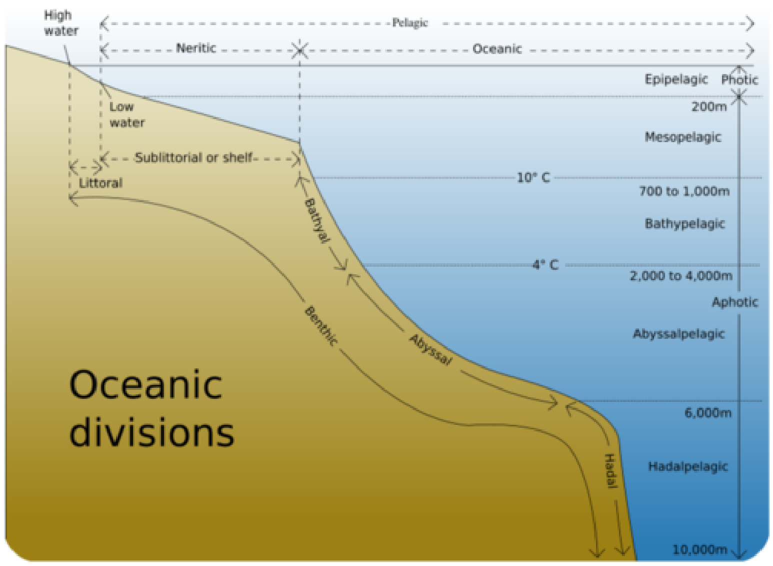


FIGURE 8.32
Vertical and horizontal ocean zones.

The average depth of the ocean is 3,790 m, a lot more shallow than the deep trenches but still an incredible depth for sea creatures to live in. What makes it so hard to live at the bottom of the ocean? The three major factors that make the deep ocean hard to inhabit are the absence of light, low temperature, and extremely high pressure.

Horizontal Divisions

The seabed is divided into the zones described above, but ocean itself is also divided horizontally by distance from the shore.

- Nearest to the shore lies the **intertidal zone** (also called the littoral zone), the region between the high and low tidal marks. The hallmark of the intertidal is change: water is in constant motion in the form of waves, tides, and currents. The land is sometimes under water and sometimes exposed.
- The **neritic zone** is from low tide mark and slopes gradually downward to the edge of the seaward side of the continental shelf. Some sunlight penetrates to the seabed here.
- The **oceanic zone** is the entire rest of the ocean from the bottom edge of the neritic zone, where sunlight does not reach the bottom. The sea bed and water column are subdivided further, as seen in the figure above.

Vocabulary

- **aphotic zone**: The zone in the water column deeper than 200 m where sunlight does not penetrate.
- **intertidal zone**: The part of the ocean closest to the shore, between low and high tide.
- **neritic zone**: The part of the ocean where the continental shelf gradually slopes seaward. Sunlight can penetrate to the bottom in much of the neritic zone.
- **oceanic zone**: The open ocean, where sunlight does not reach the seabed.
- **photic zone**: The upper 200 m of the ocean, where sunlight penetrates.
- **water column**: A vertical column of ocean water, divided into different zones according to their depth.

Summary

- The most important vertical distinction in the oceans is between the small surface zone that has light, the photic zone, and the entire rest of the ocean without light, the aphotic zone.
- The ocean is divided into horizontal zones based on the depth of water beneath: the intertidal, neritic, and oceanic.
- Why does most of the life in the oceans live in or at least visit the surface?

Practice

Use this resource to answer the questions that follow.

The Layers of the Ocean

http://www.youtube.com/watch?v=UEh9cx-b8Og

MEDIA

Click image to the left for more content.

1. Where can 90% of the of the ocean's life be found?
2. What is the twilight zone?
3. What is the dark zone?
4. Why is little life found in the dark zone?
5. What is the abyss?
6. What are trenches?

Review

1. Why is there so little life at the bottom of the ocean?
2. Compare and contrast the intertidal, neritic, and oceanic zones.
3. Do you think that the line between the photic and aphotic zones is solid and that life is either in one or the other, or do you think the divisions are more gradational? Why?

8.13 Wind Waves

- Describe the characteristics of ocean waves.
- Explain how wind forms ocean waves.

If ocean waves are caused by wind, how can there be strong waves on calm days?

Waves form where there are winds. Energy from the wind is transferred to the water and then that is transferred to nearby water molecules. The wave moves as a transfer of energy across the sea. Once the wave starts, it doesn't need more wind to keep it going.

Ocean Waves

Waves have been discussed in previous concepts and lessons in several contexts: seismic waves traveling through the planet, sound waves traveling through seawater, and ocean waves eroding beaches. Waves transfer energy, and the size of a wave and the distance it travels depends on the amount of energy that it carries. This lesson studies the most familiar waves, those on the ocean's surface.

Building Big Waves

Ocean waves originate from wind blowing – steady winds or high storm winds – over the water. Sometimes these winds are far from where the ocean waves are seen. What factors create the largest ocean waves?

The largest wind waves form when the wind

- is very strong
- blows steadily for a long time

- blows over a long distance

The wind could be strong, but if it gusts for just a short time, large waves won't form.

Wind blowing across the water transfers energy to that water. The energy first creates tiny ripples, which make an uneven surface for the wind to catch so that it may create larger waves. These waves travel across the ocean out of the area where the wind is blowing.

Remember that a wave is a transfer of energy. Do you think the same molecules of water that start out in a wave in the middle of the ocean later arrive at the shore? The molecules are not the same, but the energy is transferred across the ocean.

Shape of a Wave

Water molecules in waves make circles or ellipses (**Figure** 8.33). Energy transfers between molecules, but the molecules themselves mostly bob up and down in place.

In this animation, a water bottle bobs in place like a water molecule: http://www.onr.navy.mil/focus/ocean/motion/waves1.htm.

An animation of motion in wind waves from the Scripps Institution of Oceanography: http://earthguide.ucsd.edu/earthguide/diagrams/waves/swf/wave_wind.html.

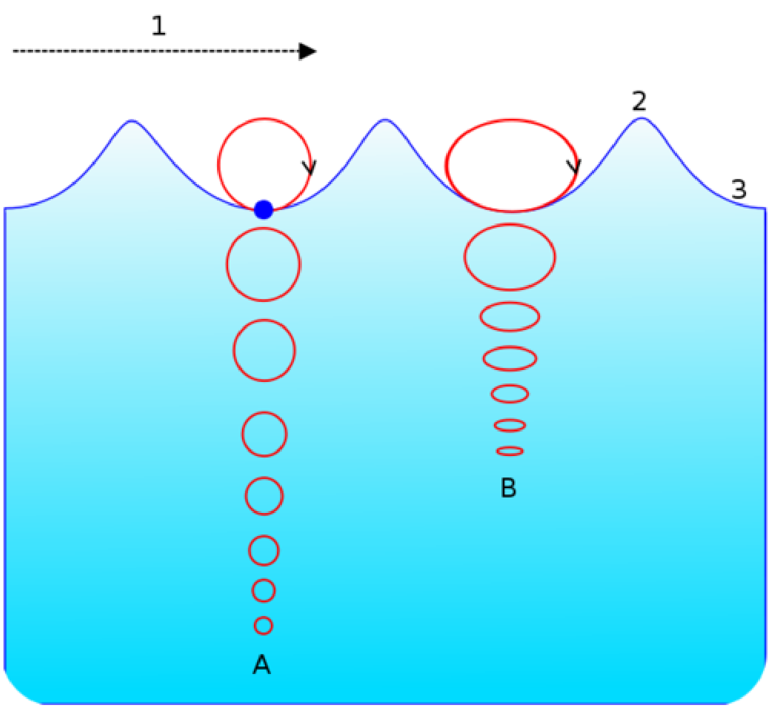


FIGURE 8.33
The circles show the motion of a water molecule in a wind wave. Wave energy is greatest at the surface and decreases with depth. "A" shows that a water molecule travels in a circular motion in deep water. "B" shows that molecules in shallow water travel in an elliptical path because of the ocean bottom.

An animation of a deep water wave is seen here: http://en.wikipedia.org/wiki/File:Deep_water_wave.gif.

An animation of a shallow water wave is seen here: http://commons.wikimedia.org/wiki/File:Shallow_water_wave.gif.

Waves Break

When does a wave break? Do waves only break when they reach shore? Waves break when they become too tall to be supported by their base. This can happen at sea but happens predictably as a wave moves up a shore. The energy at the bottom of the wave is lost by friction with the ground, so that the bottom of the wave slows down but the top of the wave continues at the same speed. The crest falls over and crashes down.

Storm Surge

Some of the damage done by storms is from **storm surge**. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft), which can be devastating in a shallow land area when winds, waves, and rain are intense.

A wild video of "Storm Surge" can be seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/.

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves.

Learn more by watching this video at http://www.kqed.org/quest/television/science-of-big-waves.

MEDIA
Click image to the left for more content.

Vocabulary

- **storm surge**: Water that is pushed in a pile near shore by storm winds causing sea level to rise locally.
- **wave**: A change in the shape of water caused by energy from wind.

Summary

- The largest wind waves are built when a strong wind blows for a long time over a large area.
- When a wave breaks onshore it is not the water but the energy that has traveled from where the wave formed.
- A wave breaks when it is too tall to be supported by its base, which is common as a wave moves up the shore.

Practice

Use these resources to answer the questions that follow.

http://www.ehow.com/video_4908368_causes-waves_.html

MEDIA
Click image to the left for more content.

1. What can cause waves?

2. What three factors effect the size and strength of waves?

3. How can large waves be created

http://www.youtube.com/watch?v=ouoodQg3XD0

MEDIA

Click image to the left for more content.

4. What causes the overturning of wave?

http://www.wpri.com/dpp/news/local_news/south_county/westerly-storm-surge-explained

Adobe Flash

MEDIA

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5. What is storm surge?

6. What generates a storm surge?

Review

1. Do waves break in the oceans or do waves only break when they reach shore?

2. When a hurricane reaches land, the damage done to coastal development often depends on how high the tide is. Why would this make a difference?

3. Describe how a wave that forms in the central Pacific travels to and breaks at the beach in San Diego, California.

8.14 Tides

- Define tides.
- Describe types of tides.
- Explain why tides occur.

How could a tide be so extreme?

These two photos show high tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet. Why is this tidal range so extreme? Why aren't all tidal ranges so great? Tidal range depends on many factors, including the slope of the continental margin.

The Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primary cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 8.34). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much, but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. These two water bulges on opposite sides of the Earth aligned

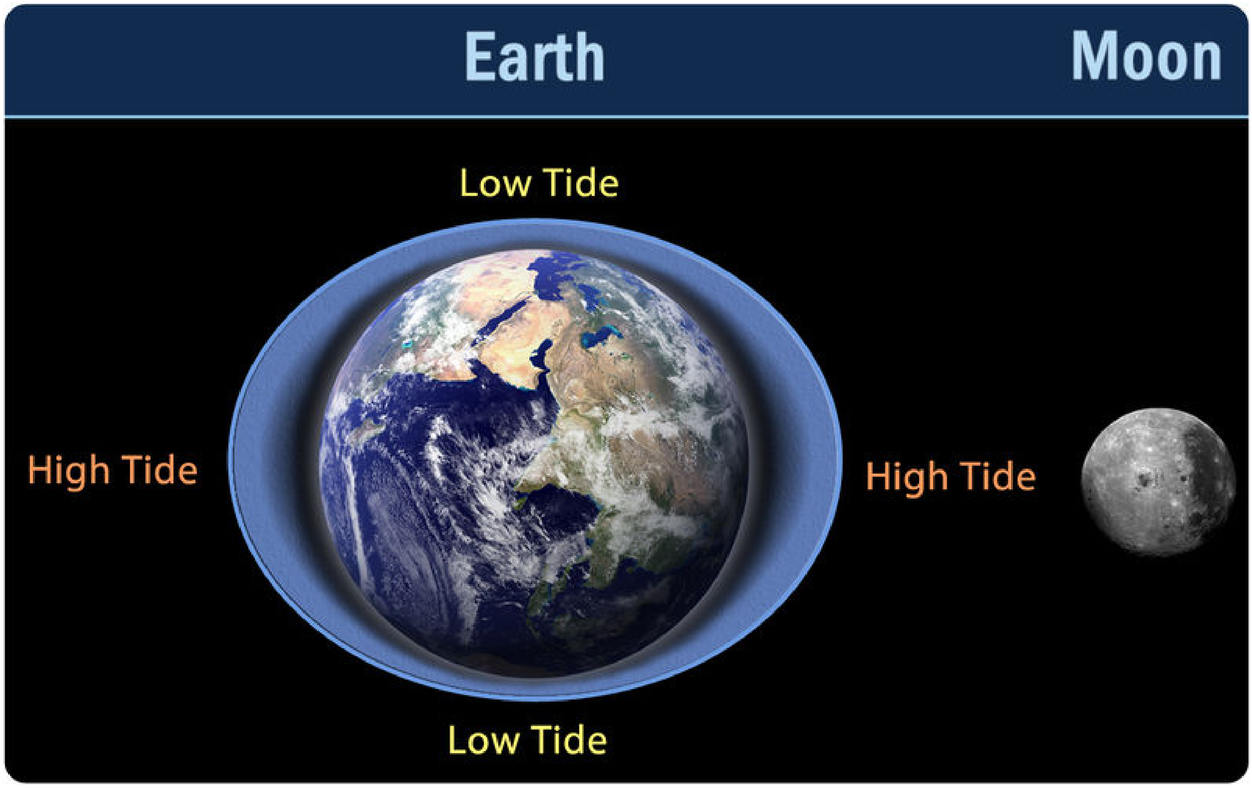

FIGURE 8.34
The gravitational attraction of the Moon to ocean water creates the high and low tides.

with the Moon are the **high tides**. The places directly in between the high tides are **low tides**. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides approximately every day.

High tides occur about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth, so the Moon is over the same location every 24 hours and 50 minutes. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

The gravity of the Sun also pulls Earth's water towards it and causes its own tides. Because the sun is so far away, its pull is smaller than the Moon's.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

Tidal Range

The **tidal range** is the difference between the ocean level at high tide and the ocean level at low tide (**Figure** 8.35). The tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

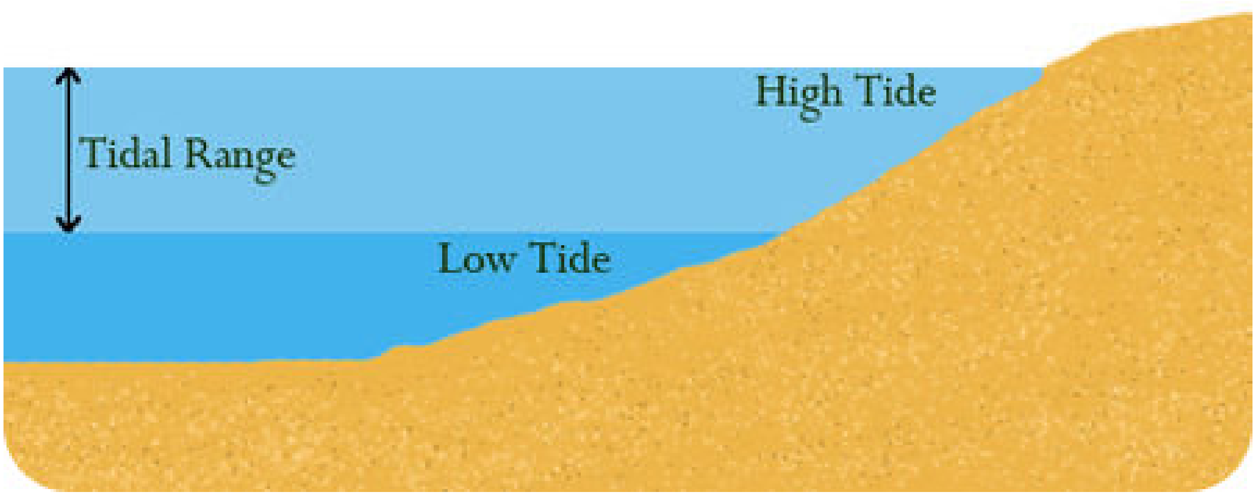

FIGURE 8.35
The tidal range is the difference between the ocean level at high tide and low tide.

Monthly Tidal Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive, so when the gravitational pull of both bodies is in the same direction, the high tides are higher and the low tides lower than at other times through the month (**Figure** 8.36). These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90^o angle (**Figure** 8.37). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range is relatively small.

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/focus/ocean/motion/tides1.htm.

A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html.

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif.

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html.

Studying ocean tides' rhythmic movements helps scientists understand the ocean and the sun/moon/earth system. This QUEST video explains how tides work, and visits the oldest continually operating tidal gauge in the Western Hemisphere.

Watch it at http://www.kqed.org/quest/television/science-on-the-spot-watching-the-tides.

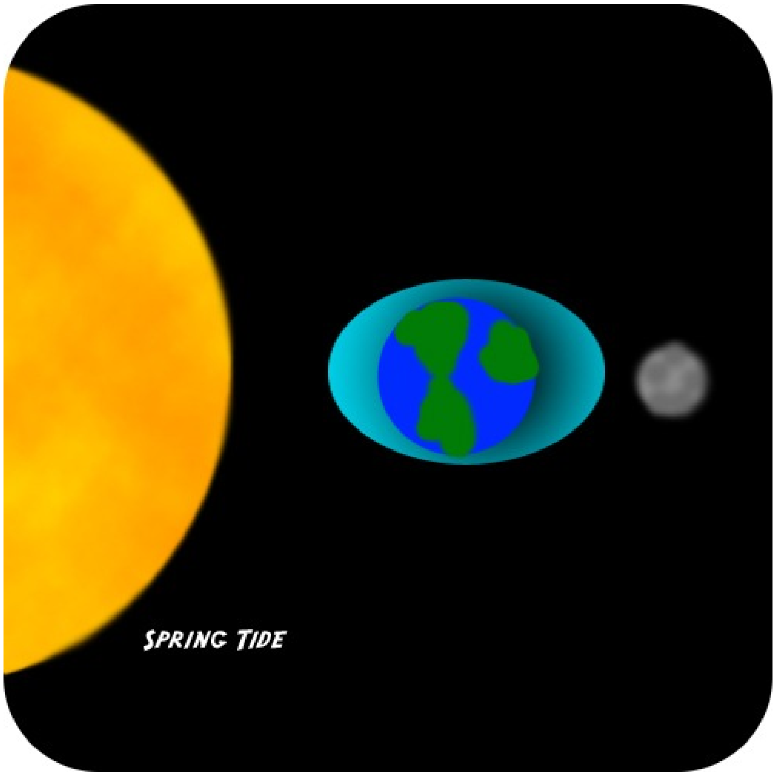

FIGURE 8.36
A spring tide occurs when the gravitational pull of both Moon and the Sun is in the same direction, making high tides higher and low tides lower and creating a large tidal range.

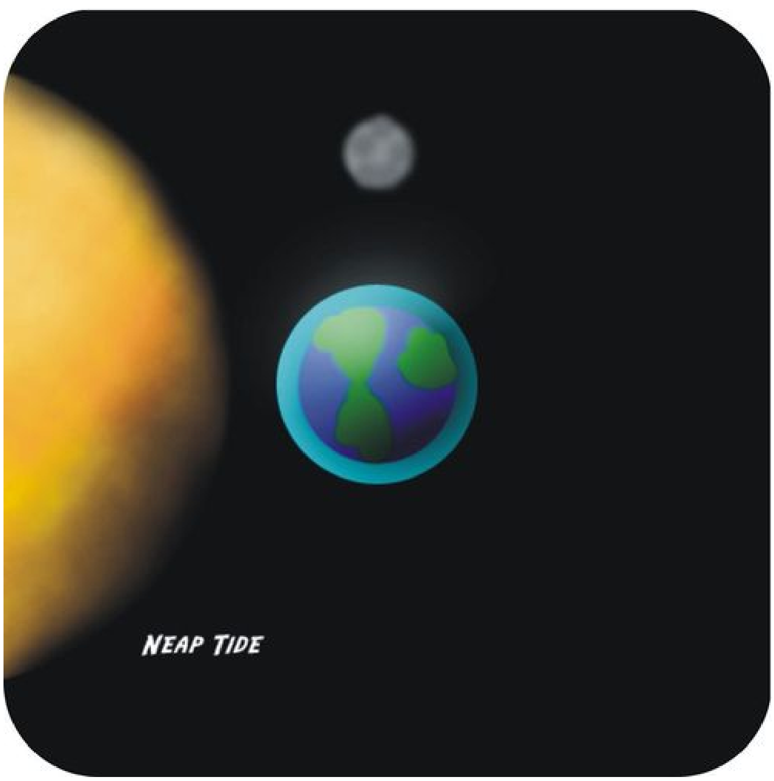

FIGURE 8.37
A neap tide occurs when the high tide of the Sun adds to the low tide of the Moon and vice versa, so the tidal range is relatively small.

MEDIA
Click image to the left for more content.

Vocabulary

- **high tide**: The highest water levels during a day caused by the gravitational pull of the Moon.
- **low tide**: The lowest water levels during a day when high tide is one-quarter of the way around Earth's sphere.
- **neap tide**: The smallest tidal range in a lunar month occurring at the first- and third-quarter moons when the Sun and Moon are at 90^o relative to each other, relative to Earth.
- **spring tide**: A large tidal range that occurs when the Moon, Sun, and Earth area aligned; this happens at full and new moon phases.
- **tidal range**: The difference between the high and low tide in a day.
- **tide**: The regular rising and falling of Earth's surface waters twice a tidal day as a result of the Moon's and Sun's gravitational attraction.

Summary

- The primary cause of tides is the gravitational attraction of the Moon, which causes two high and two low tides a day.
- When the Sun's and Moon's tides match, there are spring tides; when they are opposed, there are neap tides.
- The difference between the daily high and the daily low is the tidal range.

Practice

Use this resource to answer the questions that follow.

http://www.teachertube.com/viewVideo.php?video_id=655#38;title=The_Mystery_of_Earth_s_Tides

1. How often do tides occur?

2. What are tides?

3. What is a tidal bulge?

4. What causes tides?

5. How is the tidal bulge created?

Review

1. Using the terminology of waves, describe how the gravitational attraction of the Moon and Sun make a high tide and a low tide.

2. Describe the causes of spring and neap tides.

3. What are the possible reasons that the Bay of Fundy has such a large tidal range?

8.15 Surface Ocean Currents

- Define major and local surface currents.
- Explain how major and local surface currents are created.

Why is so much trash so far from land?

The Great Pacific Garbage Patch is a region in the center of the north Pacific Ocean where plastic bits and chemicals are concentrated. Trash from the countries bordering the region enters the oceans and is transported into the center of the North Pacific Gyre, where it remains. Seabirds may get sick from ingesting so much plastic instead of food. More about the patch can be found in Concept Human Impacts on Earth's Systems.

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on weather; they remain unchanged even in large storms because they depend on factors that do not change.

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

Surface currents are extremely important because they distribute heat around the planet and are a major factor influencing climate around the globe.

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time and are related to the unequal heating of Earth by the Sun — that is, more solar radiation strikes the equator than the polar regions — and the rotation of the Earth — that is, the **Coriolis effect**. Coriolis was described in "Concept Earth as a Planet." The causes of the global wind patterns will be described in detail in "Concept Atmospheric Processes."

Water in the surface currents is pushed in the direction of the major wind belts:

- trade winds: east to west between the equator and 30^oN and 30^oS
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50^o and 60^o north and south of the equator and the north and south pole

Shape of the Ocean Basins

When a surface current collides with land, the current must change direction (**Figure** 8.38). In the figure below, the Atlantic South Equatorial Current travels westward along the equator until it reaches South America. At Brazil, some of it goes north and some goes south. Because of Coriolis effect, the water goes right in the Northern Hemisphere and left in the Southern Hemisphere.

Gyres

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (**Figure** 8.39). The Antarctic Circumpolar Current is unique because it travels uninhibited around the globe. Why is it the only current to go all the way around?

This video shows the surface ocean currents set by global wind belts **(5a)**: http://www.youtube.com/watch?v=Hu_Ga0JYFNg (1:20).

MEDIA

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Local Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines (**Figure** 8.40). Two are **longshore currents** and **rip currents**.

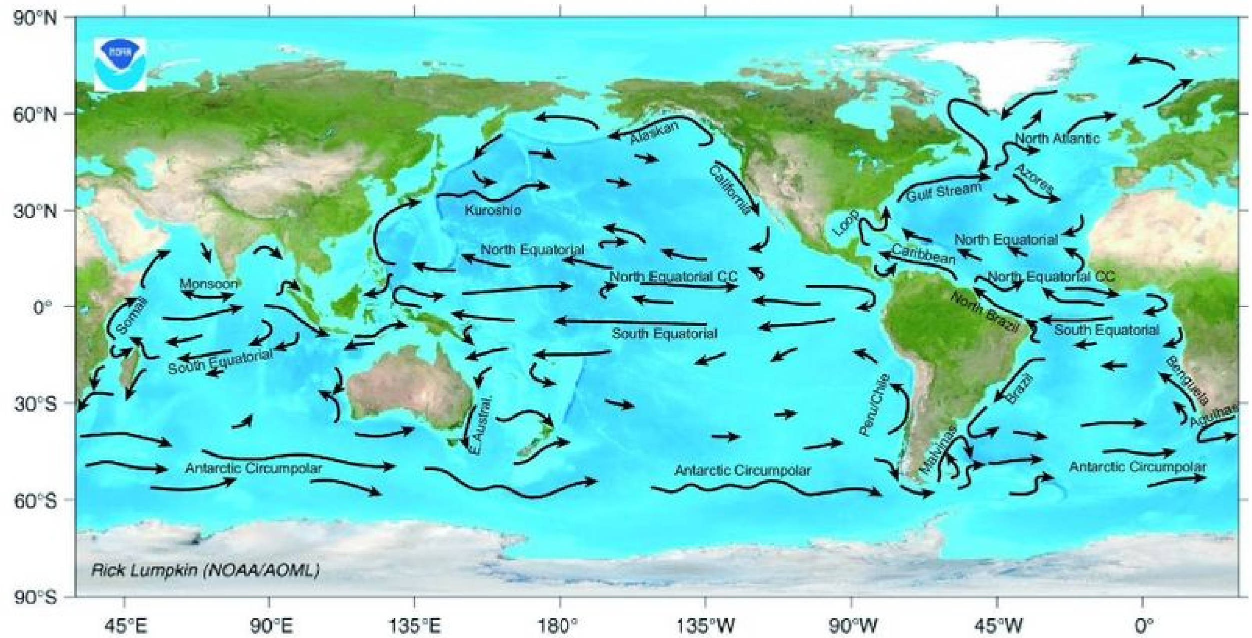


FIGURE 8.38
The major surface ocean currents.

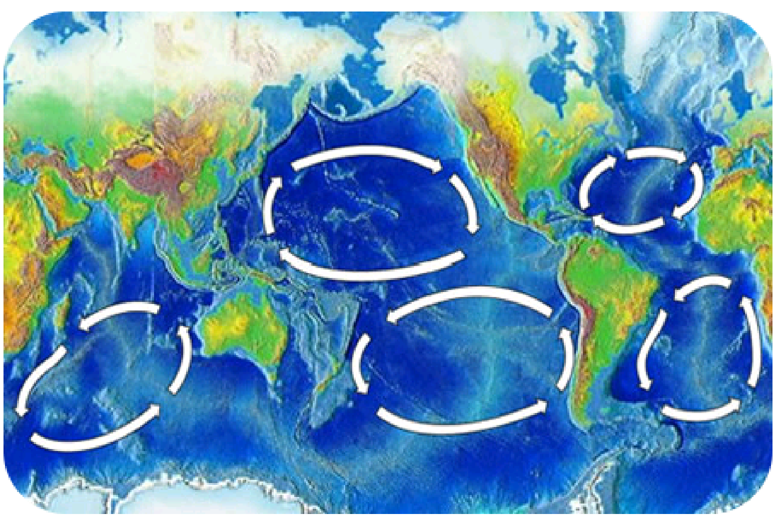


FIGURE 8.39
The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

Rip currents are potentially dangerous currents that carry large amounts of water offshore quickly. Look at the rip-current animation to determine what to do if you are caught in a rip current: http://www.onr.navy.mil/focus/ocean/motion/currents2.htm. Each summer in the United States at least a few people die when they are caught in rip currents.

This animation shows the surface currents in the Caribbean, the Gulf of Mexico, and the Atlantic Ocean off of the southeastern United States: http://polar.ncep.noaa.gov/ofs/viewer.shtml?-gulfmex-cur-0-large-rundate=latest.

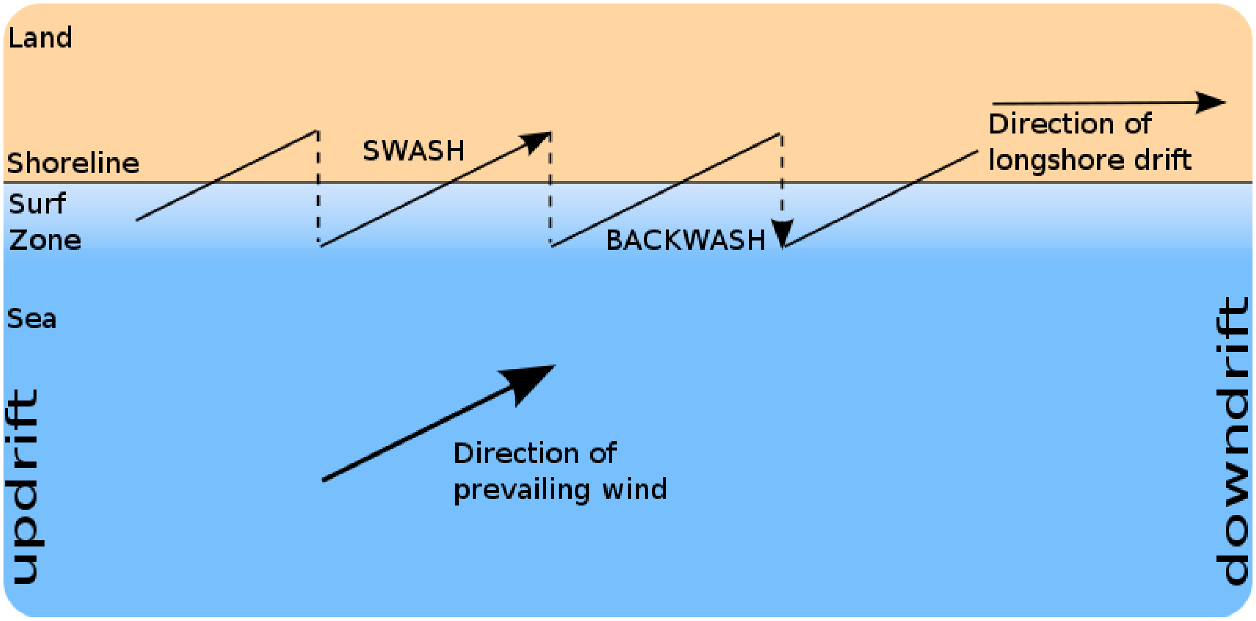


FIGURE 8.40
Longshore currents move water and sediment parallel to the shore in the direction of the prevailing local winds.

Vocabulary

- **Coriolis effect**: The apparent deflection of a freely moving object like water or air because of Earth's rotation.
- **gyre**: Five loops created by surface ocean currents.
- **longshore current**: Local surface currents that move along a shoreline in the direction of prevailing winds.
- **rip current**: A strong surface current that returns to the ocean from the shore.
- **surface current**: A horizontal movement of ocean water, caused by surface winds.

Summary

- Major surface ocean currents are the result of global wind patterns, Earth's rotation, and the shape of the ocean basins.
- Major surface currents circle the oceans in five gyres.
- Local surface currents, like longshore and rip currents, move near shorelines.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=YCorkyBe66o

MEDIA

Click image to the left for more content.

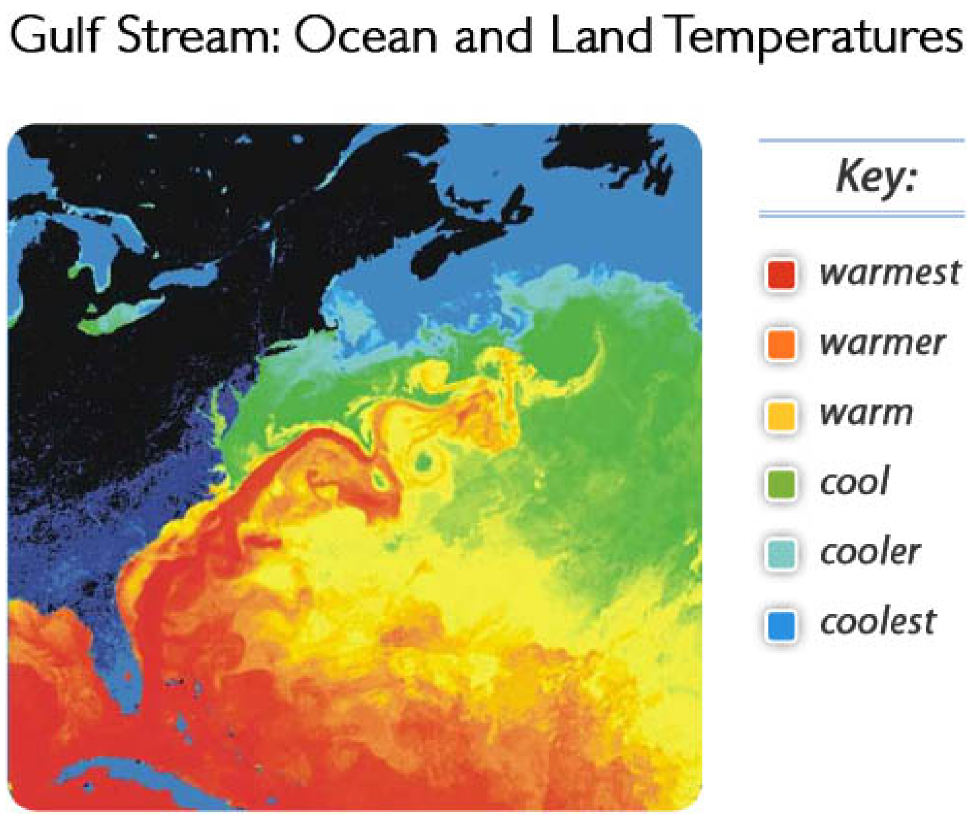
1. What is a surface current?
2. What is a thermocline?
3. Where is the thermocline?
4. How do surface currents form?
5. What factors determine the movement of surface currents?
6. Why are currents different temperatures?
7. How are the currents monitored?

Review

1. Describe the motion of a water particle that is stuck in a gyre in the North Pacific.
2. What should you do if you get stuck in a rip current?
3. What would happen if a major surface current did not run into a continent? Note that this is what happens with the Antarctic Circumpolar Current.

8.16 How Ocean Currents Moderate Climate

- Explain how ocean currents like the Gulf Stream influence Earth's climate.



Why is northwestern Europe relatively warm?

The Gulf Stream waters do a lot for Europe. The equatorial warmth this current brings to the North Atlantic moderates temperatures in northern Europe. In a satellite image of water temperature in the western Atlantic it is easy to pick out the Gulf Stream, which brings warmer waters from the equator up the coast of eastern North America.

Effect on Global Climate

Surface currents play an enormous role in Earth's climate. Even though the equator and poles have very different climates, these regions would have more extremely different climates if ocean currents did not transfer heat from the equatorial regions to the higher latitudes.

The Gulf Stream is a river of warm water in the Atlantic Ocean, about 160 kilometers wide and about a kilometer deep. Water that enters the Gulf Stream is heated as it travels along the equator. The warm water then flows up the east coast of North America and across the Atlantic Ocean to Europe (See opening image). The energy the Gulf Stream transfers is enormous: more than 100 times the world's energy demand.

The Gulf Stream's warm waters raise temperatures in the North Sea, which raises the air temperatures over land between 3 to 6^{o}C (5 to 11^{o}F). London, U.K., for example, is at about six degrees further south than Quebec, Canada.

However, London's average January temperature is 3.8^{o}C (38^{o}F), while Quebec's is only -12^{o}C (10^{o}F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

FIGURE 8.41
London, England in winter.

FIGURE 8.42
Quebec City, Quebec in winter.

Summary

- Water in the Gulf Stream travels along the equator and is heated as it goes.
- The Gulf Stream brings warm water north along the Atlantic coast of the United States and then across the northern Atlantic to the British Isles.
- A tremendous amount of energy is transferred from the equatorial regions to the polar regions by ocean currents.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Lb854zXy2IQ

MEDIA

Click image to the left for more content.

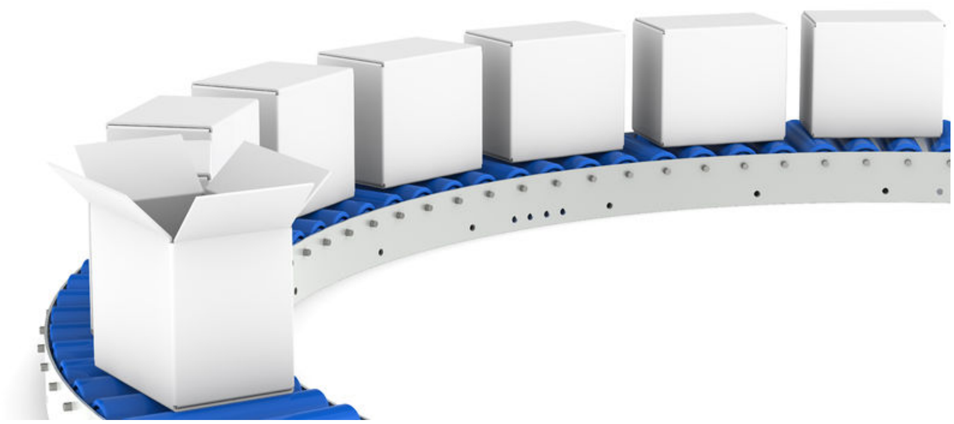
1. What occurred in the Atacoma desert in July 2011?
2. What was the weather like in Australia in August and September 2011?
3. What happened in the summer of 2011 in the United States?
4. How many temperature records were broken in 2011?
5. Why are scientists monitoring the Arctic ice?
6. What are the effects of the ice melt?
7. How is the Gulf Stream affected by the melting of the Arctic ice?

Review

1. Explain why England is relatively mild and rainy in winter but central Canada, at the same latitude and during the same season, is dry and frigid.
2. Where else do you think ocean currents might moderate global climate?
3. What would Earth be like if ocean water did not move?

8.17 Deep Ocean Currents

- Describe the processes that drive deep ocean currents.



How are ocean currents like a conveyor belt?

Seawater doesn't just circulate around the surface, it moves through the deep sea. Just like at the surface, normal circulation patterns transport much of the water. Seawater is moved as if on a conveyor through the surface and deep ocean, a trip that takes hundreds of years.

Deep Currents

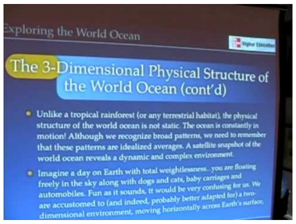
Thermohaline circulation drives deep ocean circulation. Thermo means heat and haline refers to salinity. Differences in temperature and in salinity change the density of seawater. So thermohaline circulation is the result of density differences in water masses because of their different temperature and salinity.

What is the temperature and salinity of very dense water? Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously, so same number of molecules takes up less space and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume, so the water is denser.

Downwelling

Changes in temperature and salinity of seawater take place at the surface. Water becomes dense near the poles. Cold polar air cools the water and lowers its temperature, increasing its salinity. Fresh water freezes out of seawater to become sea ice, which also increases the salinity of the remaining water. This very cold, very saline water is very dense and sinks. This sinking is called **downwelling**.

This video lecture discusses the vertical distribution of life in the oceans. Seawater density creates currents, which provide different habitats for different creatures **(5d)**: http://www.youtube.com/watch?v=LA1jxeXDsdA (6:12).



MEDIA

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Two things then happen. The dense water pushes deeper water out of its way and that water moves along the bottom of the ocean. This deep water mixes with less dense water as it flows. Surface currents move water into the space vacated at the surface where the dense water sank (**Figure** 8.43). Water also sinks into the deep ocean off of Antarctica.

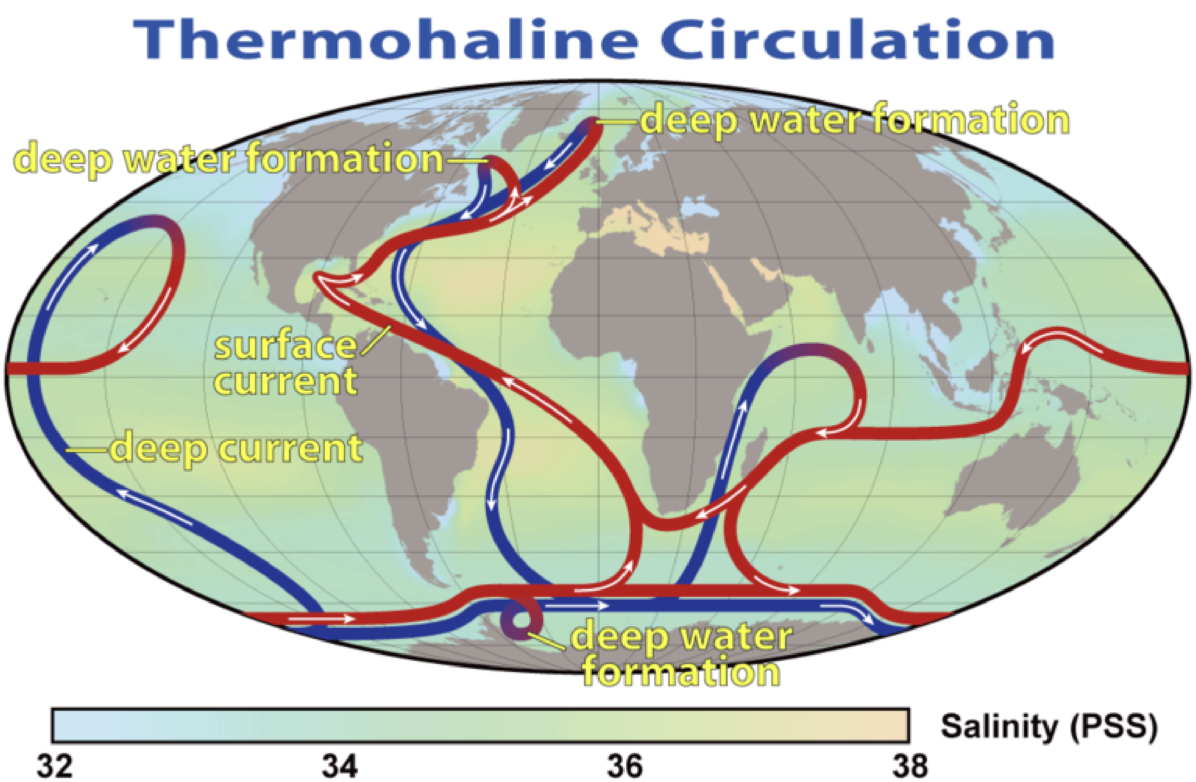


FIGURE 8.43

Cold water (blue lines) sinks in the North Atlantic, flows along the bottom of the ocean and upwells in the Pacific or Indian. The water then travels in surface currents (red lines) back to the North Atlantic. Deep water also forms off of Antarctica.

Upwelling

Since unlimited amounts of water cannot sink to the bottom of the ocean, water must rise from the deep ocean to the surface somewhere. This process is called **upwelling** (**Figure** 8.44).

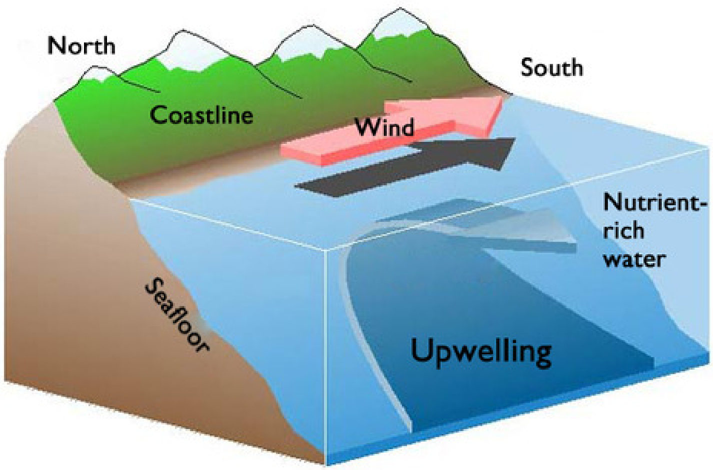


FIGURE 8.44
Upwelling forces denser water from below to take the place of less dense water at the surface that is pushed away by the wind.

Generally, upwelling occurs along the coast when wind blows water strongly away from the shore. This leaves a void that is filled by deep water that rises to the surface.

Upwelling is extremely important where it occurs. During its time on the bottom, the cold deep water has collected nutrients that have fallen down through the water column. Upwelling brings those nutrients to the surface. Those nutrients support the growth of plankton and form the base of a rich ecosystem. California, South America, South Africa, and the Arabian Sea all benefit from offshore upwelling.

An animation of upwelling is seen here: http://oceanservice.noaa.gov/education/kits/currents/03coastal4.html.

Upwelling also takes place along the equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the equator, so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

Vocabulary

- **downwelling**: Ocean water that sinks due to higher density.
- **thermohaline circulation**: Temperature and salinity (density) driven currents that drive deep ocean circulation.
- **upwelling**: Cold, nutrient-rich water that rises from oceanic depths.

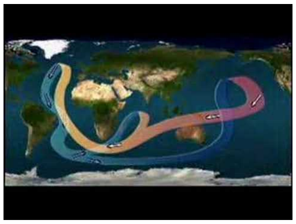
Summary

- Cooling or evaporation of fresh water from the sea surface makes surface water dense and causes it to sink.
- Downwelling of cold, dense water drives thermohaline circulation.
- Upwelling takes place at some coastlines or along the equator and brings cool, nutrient-rich water to the surface.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=FuOX23yXhZ8



MEDIA

Click image to the left for more content.

1. How does temperature effect the density of water?
2. How does salinity affect density?
3. What does the density difference create?
4. Where is the NADW?
5. Where is the AABW?
6. How long does take a water molecule to complete the circuit of the global conveyor belt?
7. What is an upwelling? What does it do?

Review

1. Why is upwelling important?
2. How does downwelling drive thermohaline circulation?
3. What would happen if water in the north Pacific no longer became cold and dense enough to sink?

Summary

What makes the dot blue, of course, is water. Water cycles through multiple reservoirs — glaciers, lakes, oceans, groundwater, and life, among others. As it cycles, it changes state between solid, liquid, and gas. Water is almost always moving, imperceptibly slowly as an ice crystal in a glacier or at rapid speeds in flooding stream or an ocean current. Surface water cycles through streams and into ponds and lakes. When too much water falls, the stream or even lake may flood. Water from the surface may filter through the ground to enter an aquifer. Streams eventually enter the ocean, which has motions of its own. Water travels in surface currents and may undergo downwelling to cycle through the deep ocean. Ocean currents are important to the planet, for example they moderate climate by bringing warm equatorial water toward the poles and cold polar water toward the equator.

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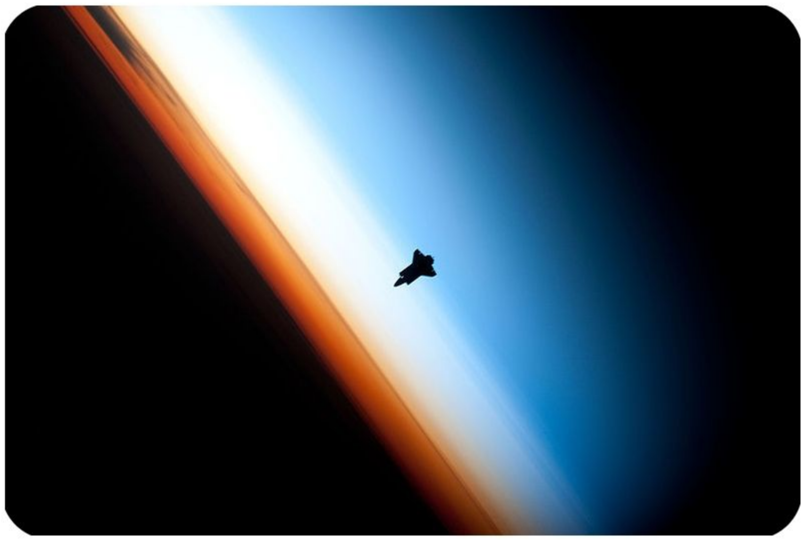
CHAPTER 9 Atmospheric Processes

Chapter Outline

Introduction



On the way to a rendezvous with the International Space Station, the space Shuttle Endeavor stood out against the layers of the atmosphere over the South Pacific. The orange lowest layer is the troposphere, which becomes the white stratosphere and then grades into the mesosphere. It's amazing that the properties of the atmosphere differ enough that they can show up as different colors in the sky.

9.1 Importance of the Atmosphere

- Describe Earth's atmosphere and explain the important roles it plays in sustaining life on Earth.

If Earth didn't have an atmosphere, would it always be cold?

This is a question commonly asked by 12-year-old girls being driven to school by their mothers. "Of course," the moms answer, "it would be extremely hot when the sun is out and bitter cold when it's dark." Does this conversation sound familiar?

What Is the Atmosphere?

Earth's **atmosphere** is a thin blanket of gases and tiny particles — together called air. We are most aware of air when it moves and creates wind. Earth's atmosphere, along with the abundant liquid water at Earth's surface, are the keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. For example, all living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock.

Let's consider some of the reasons we are lucky to have an atmosphere.

Gases Indispensable for Life on Earth

Without the atmosphere, Earth would look a lot more like the Moon. Atmospheric gases, especially carbon dioxide (CO_2) and oxygen (O_2), are extremely important for living organisms. How does the atmosphere make life possible? How does life alter the atmosphere?

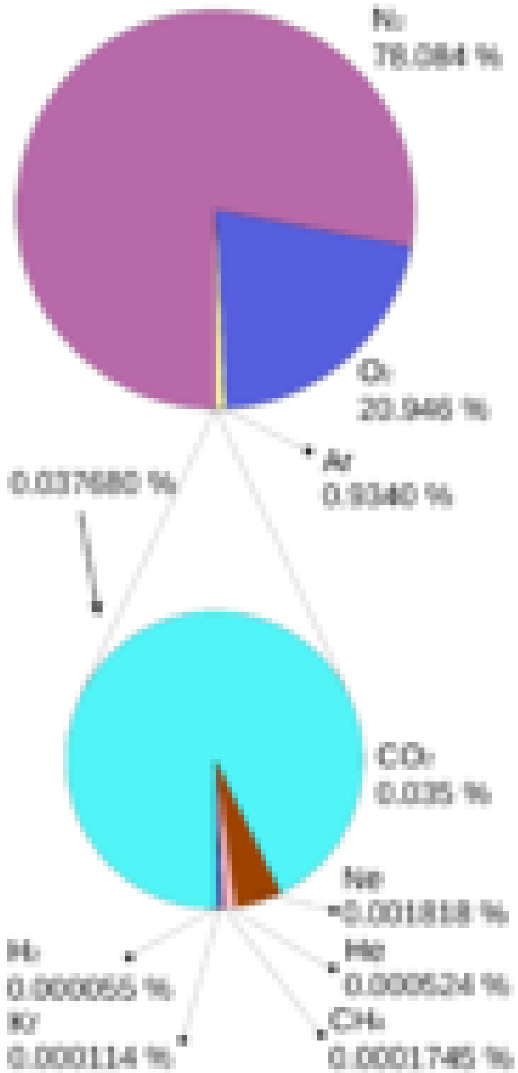


FIGURE 9.1
The composition of Earth's atmosphere.

Photosynthesis

In **photosynthesis**, plants use CO_2 and create O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere.

The chemical reaction for photosynthesis is:

$6CO_2 + 6H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6 \text{ (sugar)} + 6O_2$

Respiration

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{useable energy}$

How is respiration similar to and different from photosynthesis? They are approximately the reverse of each other. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2 (**Figure** 9.2).

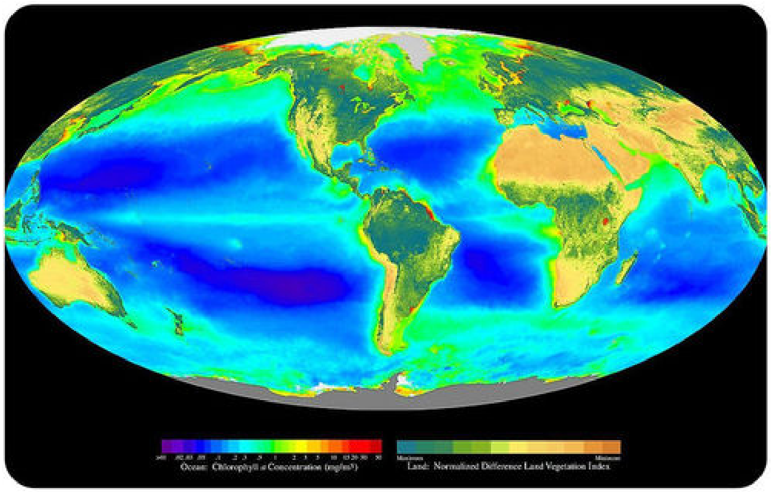


FIGURE 9.2
Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

Crucial Part of the Water Cycle

As part of the hydrologic cycle, water spends a lot of time in the atmosphere, mostly as water vapor. The atmosphere is an important reservoir for water.

Ozone Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high-energy **ultraviolet (UV) radiation** coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth. The highest concentration of ozone is in the ozone layer in the lower stratosphere.

Keeps Earth's Temperature Moderate

Along with the oceans, the atmosphere keeps Earth's temperatures within an acceptable range. Without an atmosphere, Earth's temperatures would be frigid at night and scorching during the day. If the 12-year-old in the scenario above asked why, she would find out. **Greenhouse gases** trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

Provides the Substance for Waves to Travel Through

The atmosphere is made of gases that take up space and transmit energy. Sound waves are among the types of energy that travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space (explosions in movies about space should be silent). Of course, no insect, bird, or airplane would be able to fly, because there would be no atmosphere to hold it up.

Vocabulary

- **atmosphere**: The layer of gases that surrounds a planet.
- **greenhouse gas**: Gases such as carbon dioxide and methane that absorb and hold heat from the sun's infrared radiation in the atmosphere.
- **ozone**: Three oxygen atoms bonded together in an O3 molecule. Ozone in the lower atmosphere is a pollutant but in the upper atmosphere protects life from ultraviolet radiation.
- **photosynthesis**: The process in which plants produce simple sugars (food energy) from carbon dioxide, water, and energy from sunlight. Photosynthesis uses carbon dioxide and releases oxygen.
- **respiration**: The process in which organisms convert sugar into useful food energy. Respiration burns oxygen and produces carbon dioxide.
- **ultraviolet (UV) radiation**: High energy radiation from the Sun that can be dangerous to Earth's life.

Summary

- The atmosphere is made of gases that are essential for photosynthesis and respiration, among other life activities.
- The atmosphere is a crucial part of the water cycle. It is an important reservoir for water and the source of precipitation.
- The atmosphere moderates Earth's temperature because greenhouse gases absorb heat.

Practice

Use these resources to answer the questions that follow.

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Photosynthesis**

1. How does photosynthesis occur?

2. What does photosynthesis create?

http://dsc.discovery.com/videos/assignment-discovery-shorts-06-07-07-08-cellular-respiration.html

MEDIA
Click image to the left for more content.

3. What is cellular respiration?

4. Why does glycolysis produce?

5. What are the 3 steps of cellular respiration?

Review

1. What gases are used and expelled by photosynthesis and respiration?

2. Where is the largest concentration of ozone and what value does it have?

3. How does the atmosphere keep Earth's temperature moderate?

9.2 Composition of the Atmosphere

- Describe the composition of the atmosphere.

Did life evolve to match the atmosphere or is the fit just coincidence?

Life as we know it would not survive if there were no ozone layer to protect it from high energy ultraviolet radiation. Most life needs oxygen to survive. Nitrogen is also needed, albeit in a different form from that found in the atmosphere. Greenhouse gases keep the temperature moderate so that organisms can live around the planet. Life evolved to match the conditions that were available and to some extent changed the atmosphere to suit its needs.

Composition of Air

Several properties of the atmosphere change with altitude, but the composition of the natural gases does not. The proportions of gases in the atmosphere are everywhere the same, with one exception. At about 20 km to 40 km above the surface, there is a greater concentration of ozone molecules than in other portions of the atmosphere. This is called the **ozone layer**.

Nitrogen and Oxygen

Nitrogen and oxygen together make up 99% of the planet's atmosphere. Nitrogen makes up the bulk of the atmosphere, but is not involved in geological or biological processes in its gaseous form. Nitrogen fixing is described in "Concept Life on Earth." Oxygen is extremely important because it is needed by animals for respiration. The rest of the gases are minor components but sometimes are very important (**Figure** 9.3).

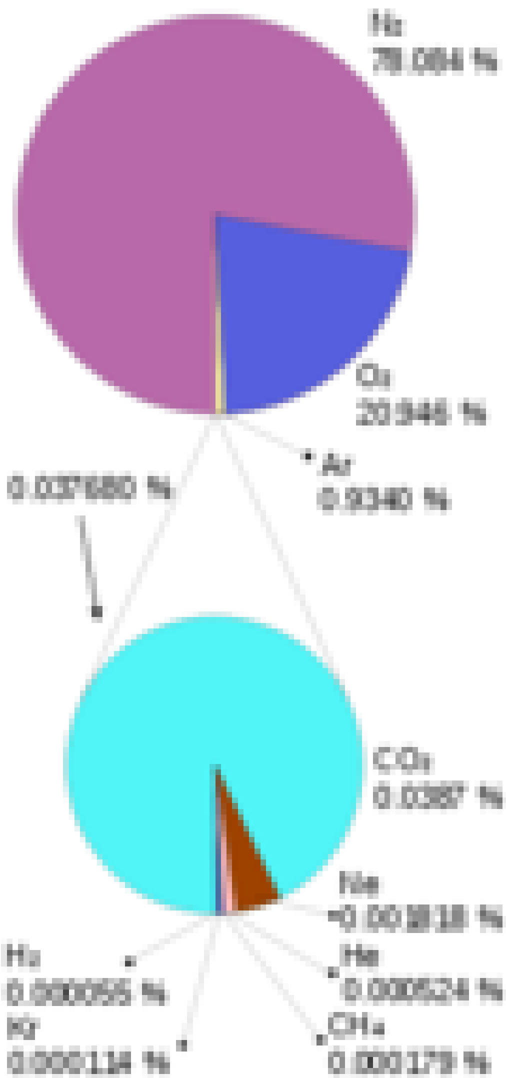


FIGURE 9.3
Nitrogen and oxygen make up 99% of the atmosphere; carbon dioxide is a very important minor component.

Water Vapor

Humidity is the amount of water vapor in the air. Humidity varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta, Georgia, where humidity is high, with a winter day in Phoenix, Arizona, where humidity is low. When the air is very humid, it feels heavy or sticky. Dry air usually feels more comfortable. When humidity is high, water vapor makes up only about 4% of the atmosphere.

Where around the globe is mean atmospheric water vapor higher and where is it lower (**Figure** 9.4)? Why? Higher humidity is found around the equatorial regions because air temperatures are higher and warm air can hold more moisture than cooler air. Of course, humidity is lower near the polar regions because air temperature is lower.

Greenhouse Gases

Remember that greenhouse gases trap heat in the atmosphere. Important natural greenhouse gases include carbon dioxide, methane, water vapor, and ozone. CFCs and some other man-made compounds are also greenhouse gases.

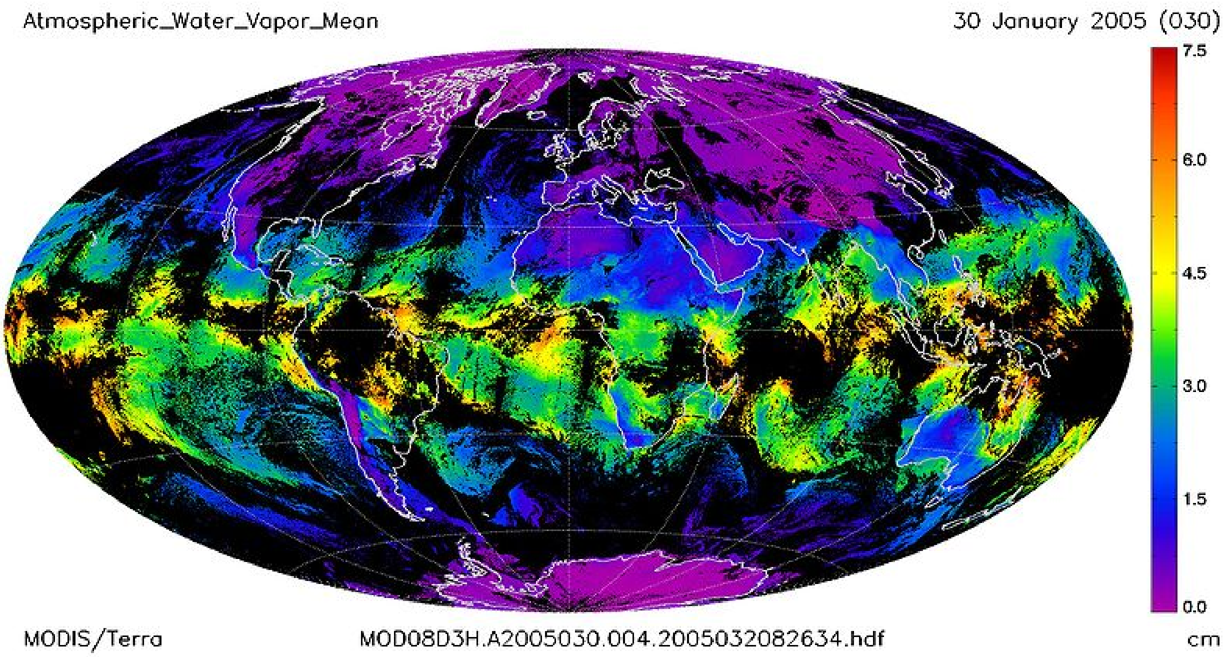


FIGURE 9.4

Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

Particulates

Some of what is in the atmosphere is not gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash, and other solids make up a small percentage of the atmosphere and are called **particulates**. Particles provide starting points (or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants.

Vocabulary

- **humidity**: The amount of water vapor held in the air.
- **ozone layer**: A layer of the stratosphere where ozone gas is more highly concentrated.
- **particulates**: Solid particles in the air, such as dust, salt, or ash.

Summary

- The major atmospheric gases are nitrogen and oxygen. The atmosphere also contains minor amounts of other gases, including carbon dioxide.
- Greenhouse gases trap heat in the atmosphere and include carbon dioxide, methane, water vapor, and ozone.
- Not everything in the atmosphere is gas; particulates are particles that are important as the nucleus of raindrops and snowflakes.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Ozone**

1. What is ozone?
2. Where is ozone found?
3. What does ozone do?
4. What does ozone consist of?
5. What does ozone absorb?

Review

1. What are the two major atmospheric gases and what roles do they play?
2. What are the important greenhouse gases?
3. What is humidity?

9.3 Pressure and Density of the Atmosphere

- Define air density and air pressure and explain how they change with increasing altitude.

Have your ears ever popped?

If your ears have ever "popped," you have experienced a change in air pressure. Ears "pop" because the air pressure is different on the inside and the outside.

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes**.

Density

The air density (the number of molecules in a given volume) decreases with increasing altitude. This is why people who climb tall mountains, such as Mt. Everest, have to set up camp at different elevations to let their bodies get used to the decreased air density (**Figure** 9.5).

Why does air density decrease with altitude? Gravity pulls the gas molecules towards Earth's center. The pull of gravity is stronger closer to the center, at sea level. Air is denser at sea level, where the gravitational pull is greater.

Pressure

Gases at sea level are also compressed by the weight of the atmosphere above them. The force of the air weighing down over a unit of area is known as its atmospheric pressure, or **air pressure**. Why are we not crushed? The molecules inside our bodies are pushing outward to compensate. Air pressure is felt from all directions, not just from above.

FIGURE 9.5
This bottle was closed at an altitude of 2,000 meters where air pressure is lower. When it was brought down to sea level, the higher air pressure caused the bottle to collapse.

At higher altitudes the atmospheric pressure is lower and the air is less dense than at lower altitudes. That's what makes your ears pop when you change altitude. Gas molecules are found inside and outside your ears. When you change altitude quickly, like when an airplane is descending, your inner ear keeps the density of molecules at the original altitude. Eventually the air molecules inside your ear suddenly move through a small tube in your ear to equalize the pressure. This sudden rush of air is felt as a popping sensation.

Vocabulary

- **air pressure**: The force of air pressing on a given area.
- **altitude**: Distance above sea level.

Summary

- Air density and pressure decrease with increasing altitude.
- Ears pop as air pressure inside and outside the ear equalizes.
- Gravity pulls more air molecules toward the center of the planet.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=7_yf-iRf8Vc

MEDIA

Click image to the left for more content.

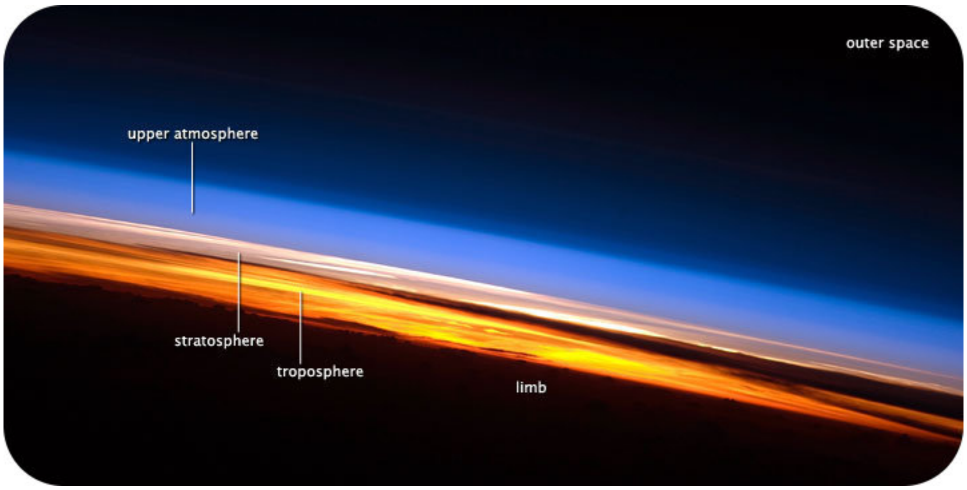
1. What is pressure?
2. What does air have?
3. Where does the atmosphere end?
4. What is air pressure?
5. What is the air pressure in Key West, Florida?
6. Explain the relationship between air pressure and altitude.

Review

1. Why does air density decrease with altitude?
2. Temperature also decreases with altitude. How does that relate to the change in air density?
3. Why are we not crushed by the weight of the atmosphere on our shoulders?

9.4 Temperature of the Atmosphere

- Define temperature gradient.
- Explain the relationship between air temperature and the layers of Earth's atmosphere.
- Describe the relationship between air temperature and density.



Did you know that you can see the layers of the atmosphere?

The layers of the atmosphere appear as different colors in this image from the International Space Station.

Air Temperature

The atmosphere is layered, corresponding with how the atmosphere's temperature changes with altitude. By understanding the way temperature changes with altitude, we can learn a lot about how the atmosphere works.

Warm Air Rises

Why does warm air rise (**Figure** 9.6)? Gas molecules are able to move freely, and if they are uncontained, as they are in the atmosphere, they can take up more or less space.

- When gas molecules are cool, they are sluggish and do not take up as much space. With the same number of molecules in less space, both air density and air pressure are higher.
- When gas molecules are warm, they move vigorously and take up more space. Air density and air pressure are lower.

Warmer, lighter air is more buoyant than the cooler air above it, so it rises. The cooler air then sinks down, because it is denser than the air beneath it. This is convection, which was described in "Concept Plate Tectonics."

Temperature Gradient

The property that changes most strikingly with altitude is air temperature. Unlike the change in pressure and density, which decrease with altitude, changes in air temperature are not regular. A change in temperature with distance is called a **temperature gradient**.

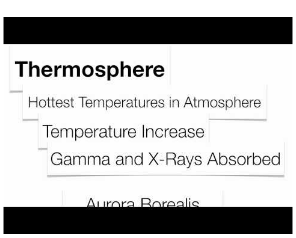
FIGURE 9.6
Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Layers

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** 9.7). The temperature gradient of each layer is different. In some layers, temperature increases with altitude and in others it decreases. The temperature gradient in each layer is determined by the heat source of the layer (See opening image).

Most of the important processes of the atmosphere take place in the lowest two layers: the troposphere and the stratosphere.

This video is very thorough in its discussion of the layers of the atmosphere. Remember that the chemical composition of each layer is nearly the same except for the ozone layer that is found in the stratosphere **(8a)**: http://www.youtube.com/watch?v=S-YAKZoy1A0#38;feature=related (6:44).



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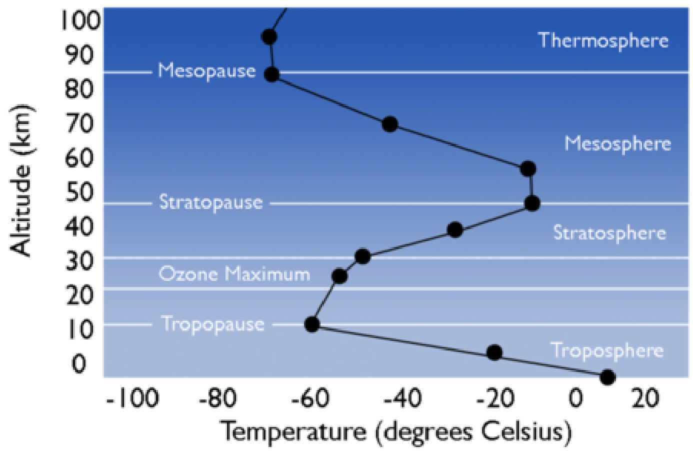


FIGURE 9.7

The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.

Vocabulary

- **temperature gradient**: The change in temperature with distance.

Summary

- Warm air rises, cool air sinks. Warm air has lower density.
- Different layers of the atmosphere have different temperature gradients.
- Temperature gradient is the change in temperature with distance.

Practice

Use this resource to answer the questions that follow

http://uccpbank.k12hsn.org/courses/APEnvironmentalScience/course%20files/multimedia/lesson19/animations/2d_Earths_Atmosphere.html

1. Explain the extent of the troposphere.
2. What is the tropopause?
3. What is the temperature range of the troposphere?
4. What drives the Earth's weather?
5. Explain the structure of the stratosphere.
6. What is the temperature range of the stratosphere?
7. What does the stratosphere contain?
8. Explain the structure of the mesosphere.
9. What is the temperature range of the mesosphere?
10. Where is the thermosphere?
11. What does the thermosphere contain?
12. What is the temperature of the thermosphere?

Review

1. What causes convection in the atmosphere?
2. Why do the different layers of the atmosphere have different temperature gradients?
3. How does temperature change with distance in the atmosphere?

9.5 Troposphere

- Describe the characteristics and importance of the troposphere.
- Explain temperature inversion and its role in the troposphere.

Why is the troposphere important?

All of the wind, rain, and snow on Earth, as well as all of the air you breathe, is in the troposphere. The troposphere is the lowest and most important layer of the atmosphere. In this photo, a cumulonimbus cloud close to the surface over western Africa extends upward through the troposphere but does not pass into the stratosphere.

Temperature Gradient

The temperature of the **troposphere** is highest near the surface of the Earth and decreases with altitude. On average, the temperature gradient of the troposphere is 6.5^oC per 1,000 m (3.6^oF per 1,000 ft) of altitude.

Earth's surface is the source of heat for the troposphere. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat, so there is more heat near the surface. The temperature is also higher near the surface because gravity pulls in more gases. The greater density of gases causes the temperature to rise.

Notice that in the troposphere warmer air is beneath cooler air. This condition is unstable since warm air is less dense than cool air. The warm air near the surface rises and cool air higher in the troposphere sinks, so air in the troposphere does a lot of mixing. This mixing causes the temperature gradient to vary with time and place. The rising and sinking of air in the troposphere means that all of the planet's weather takes place in the troposphere.

Temperature Inversion

Sometimes there is a temperature **inversion**, in which air temperature in the troposphere increases with altitude and warm air sits over cold air. Inversions are very stable and may last for several days or even weeks. Inversions form:

- Over land at night or in winter when the ground is cold. The cold ground cools the air that sits above it, making this low layer of air denser than the air above it.
- Near the coast, where cold seawater cools the air above it. When that denser air moves inland, it slides beneath the warmer air over the land.

Since temperature inversions are stable, they often trap pollutants and produce unhealthy air conditions in cities (**Figure** 9.8).

FIGURE 9.8
Smoke makes a temperature inversion visible. The smoke is trapped in cold dense air that lies beneath a cap of warmer air.

At the top of the troposphere is a thin layer in which the temperature does not change with height. This means that the cooler, denser air of the troposphere is trapped beneath the warmer, less dense air of the stratosphere. Air from the troposphere and stratosphere rarely mix.

Vocabulary

- **inversion**: A situation in which warm air lies above cold air and traps it.
- **troposphere**: The lowermost layer of the atmosphere; temperature decreases with altitude.

Summary

- In the troposphere warm air ordinarily sits below cooler air.
- With a temperature inversion, cold air sits below warm air and can't move.
- An inversion starts over land at night or in the winter, or near the coast.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-atmospheric-layers.html

MEDIA
Click image to the left for more content.

1. Who was Leon Teisserenc de Bort?
2. What instruments did de Bort use?
3. What is the extent of the first layer?
4. What does troposphere mean?
5. What occurs in the troposphere?
6. What was the legacy if de Bort's studies?

Review

1. How does an inversion form at a coastal area?
2. What is the source of heat in the troposphere?
3. Describe the temperature gradient found in the troposphere.

9.6 Stratosphere

- Describe the stratosphere and the ozone layer within it.
- Explain the ozone layer's importance to life on Earth.

The pilot says, "We are now at our cruising altitude of 30,000 feet." Why do planes fly so high?

That altitude gets them out of the troposphere and into the stratosphere. Although the arc that they must travel is greater the further from the surface they get, fuel costs are lower because there is less friction due to the lower air density. Also, there is little air turbulence, which makes the passengers happier.

Stratosphere

There is little mixing between the **stratosphere**, the layer above the troposphere, and the troposphere below it. The two layers are quite separate. Sometimes ash and gas from a large volcanic eruption may burst into the stratosphere. Once in the stratosphere, it remains suspended there for many years because there is so little mixing between the two layers.

Temperature Gradient

In the stratosphere, temperature increases with altitude. What is the heat source for the stratosphere? The direct heat source for the stratosphere is the Sun. Air in the stratosphere is stable because warmer, less dense air sits over cooler, denser air. As a result, there is little mixing of air within the layer.

The Ozone Layer

The **ozone layer** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The ozone layer has a low concentration of ozone; it's just higher than the concentration elsewhere. The thickness of the ozone layer varies by the season and also by latitude.

Ozone is created in the stratosphere by solar energy. Ultraviolet radiation splits an oxygen molecule into two oxygen atoms. One oxygen atom combines with another oxygen molecule to create an ozone molecule, O_3. The ozone is unstable and is later split into an oxygen molecule and an oxygen atom. This is a natural cycle that leaves some ozone in the stratosphere.

The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) radiation. Because of this, the ozone layer protects life on Earth. High-energy UV light penetrates cells and damages DNA, leading to cell death (which we know as a bad sunburn). Organisms on Earth are not adapted to heavy UV exposure, which kills or damages them. Without the ozone layer to reflect UVC and UVB radiation, most complex life on Earth would not survive long.

Vocabulary

- **ozone layer**: A layer of the stratosphere where ozone gas is more highly concentrated.
- **stratosphere**: Above the troposphere; temperature increases with altitude because of the presence of ozone.

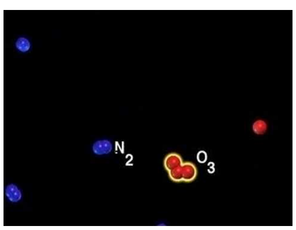
Summary

- There is little mixing between the troposphere, where all the turbulence is, and the stratosphere.
- Ozone gas protects life on Earth from harmful UV light, which damages cells.
- The ozone layer, in the stratosphere, has a higher concentration of ozone than other spots in the atmosphere.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=LNEm_2vOMqo



MEDIA

Click image to the left for more content.

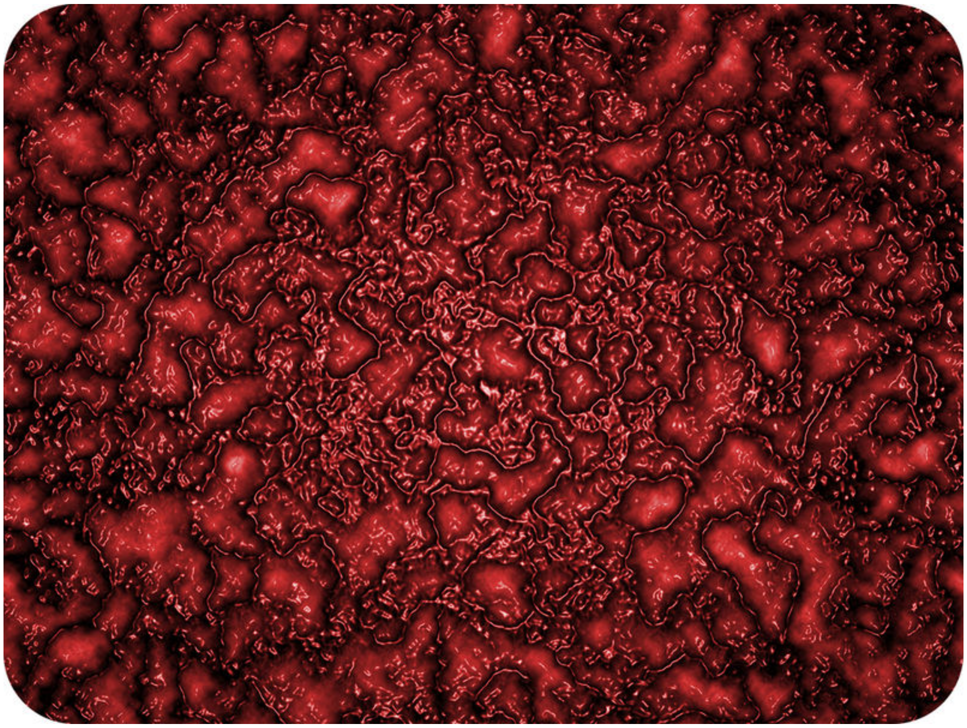
1. Where is the stratosphere located?
2. How is ozone created?
3. How is stable ozone created?
4. What does ozone become after it is broken apart?
5. Why is ozone important?

Review

1. Why doesn't air mix between the troposphere and stratosphere?
2. Why does one part of the stratosphere earn the name ozone layer?
3. What is the natural cycle that creates and destroys ozone molecules?

9.7 Mesosphere

- Describe the mesosphere.



What can make your blood boil?

Believe it or not, if you were in the mesosphere without a space suit, your blood would boil! This is because the pressure is so low that liquids would boil at normal body temperature.

Mesosphere

Above the stratosphere is the **mesosphere**. Temperatures in the mesosphere decrease with altitude. Because there are few gas molecules in the mesosphere to absorb the Sun's radiation, the heat source is the stratosphere below. The mesosphere is extremely cold, especially at its top, about -90^{o}C (-130^{o}F).

Air Density

The air in the mesosphere has extremely low density: 99.9% of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low (**Figure** 9.9). A person traveling through the mesosphere would experience severe burns from ultraviolet light since the ozone layer, which provides UV protection, is in the stratosphere below. There would be almost no oxygen for breathing. And, of course, your blood would boil at normal body temperature.

Vocabulary

- **mesosphere**: Layer between the stratosphere and thermosphere; temperature decreases with altitude.

FIGURE 9.9
Although the mesosphere has extremely low pressure, it occasionally has clouds. The clouds in the photo are mesopheric clouds called **noctilucent clouds**.

- **noctilucent cloud**: Seen only rarely, these clouds are the highest in the atmosphere.

Summary

- The mesosphere has a very low density of gas molecules.
- Temperature decreases in the mesosphere with altitude because the heat source is the stratosphere.
- The mesosphere is no place for human life!

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=mUZ4faPCiDY

MEDIA
Click image to the left for more content.

1. Where is the mesophere found?
2. What does it protect us from?
3. What are noctilucent clouds?
4. When can noctilucent clouds be seen?
5. Why can they only be seen at that time?

Review

1. Why would a person get severe burns in the mesosphere?

2. Why would a person's blood boil in the mesosphere?
3. How can meteors burn in the mesosphere when the air density is so low?

9.8 Thermosphere and Beyond

- Describe the characteristics of the far outer atmosphere.
- Explain how aurora form.

How can people live in the thermosphere?

The inhabitants of the International Space Station and other space stations live in the thermosphere. Of course, they couldn't survive in the thermosphere environment without being inside the station or inside a space suit, but right now people are living that far from Earth's surface.

Thermosphere

The density of molecules is so low in the **thermosphere** that one gas molecule can go about 1 km before it collides with another molecule. Since so little energy is transferred, the air feels very cold (See opening image).

Ionosphere

Within the thermosphere is the **ionosphere**. The ionosphere gets its name from the solar radiation that ionizes gas molecules to create a positively charged ion and one or more negatively charged electrons. The freed electrons travel within the ionosphere as electric currents. Because of the free ions, the ionosphere has many interesting characteristics.

At night, radio waves bounce off the ionosphere and back to Earth. This is why you can often pick up an AM radio station far from its source at night.

Magnetosphere

The Van Allen radiation belts are two doughnut-shaped zones of highly charged particles that are located beyond the atmosphere in the **magnetosphere**. The particles originate in solar flares and fly to Earth on the solar wind. Once trapped by Earth's magnetic field, they follow along the field's magnetic lines of force. These lines extend from above the equator to the North Pole and also to the South Pole, then return to the equator.

Aurora

When massive solar storms cause the Van Allen belts to become overloaded with particles, the result is the most spectacular feature of the ionosphere — the nighttime **aurora** (**Figure** 9.10). The particles spiral along magnetic field lines toward the poles. The charged particles energize oxygen and nitrogen gas molecules, causing them to light up. Each gas emits a particular color of light.

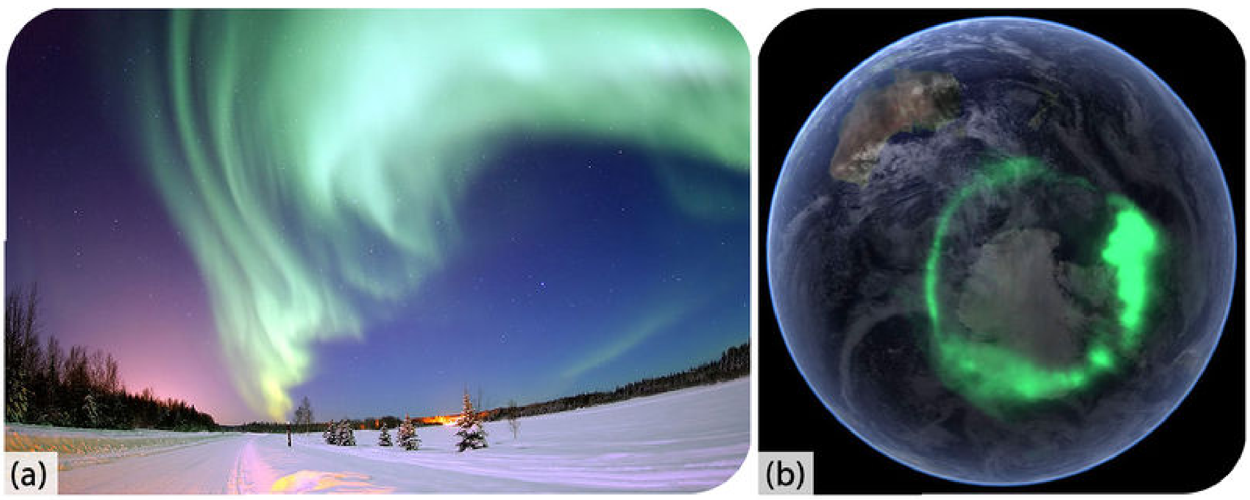


FIGURE 9.10

(a) Spectacular light displays are visible as the aurora borealis or northern lights in the Northern Hemisphere. (b) The aurora australis or southern lights encircles Antarctica.

What would Earth's magnetic field look like if it were painted in colors? It would look like the aurora! This QUEST video looks at the aurora, which provides clues about the solar wind, Earth's magnetic field and Earth's atmosphere.

Watch it at http://science.kqed.org/quest/video/illuminating-the-northern-lights/.

Adobe Flash

MEDIA

Click image to the left for more content.

Exosphere

There is no real outer limit to the **exosphere**, the outermost layer of the atmosphere; the gas molecules finally become so scarce that at some point there are no more. Beyond the atmosphere is the solar wind. The **solar wind** is made of high-speed particles, mostly protons and electrons, traveling rapidly outward from the Sun.

Vocabulary

- **aurora**: A spectacular light display that occurs in the ionosphere near the poles.
- **exosphere**: The outermost layer of the atmosphere; the gas molecules are extremely far apart.
- **ionosphere**: An ionized layer within the thermosphere.
- **magnetosphere**: Charged particles beyond the atmosphere that are held in place by Earth's magnetic field.
- **solar wind**: High-speed protons and electrons that fly through the solar system from the Sun. The solar wind extends millions of kilometers out into space and can reach out into the solar system.
- **thermosphere**: The outer atmosphere where gases are extremely thinly distributed.

Summary

- The solar wind is made of high speed particles from the Sun that travel through the solar system.
- The particles that create the aurora travel along Earth's magnetic field lines.
- Solar radiation ionizes gas molecules that travel as electric currents.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=lT3J6a9p_o8

MEDIA

Click image to the left for more content.

1. Where does the aurora borealis begin?
2. What occurs in the sun to release energy?
3. What is plasma? What does it do?
4. What is a solar storm?
5. How long does it take a solar storm to reach Earth?
6. What protects us from solar storms?
7. What causes the night time aurora?

Review

1. How did the ionosphere get its name?
2. Why and when can you pick up AM radio stations far from their sources?

3. What causes the aurora and where in the atmosphere does it take place?

9.9 Electromagnetic Energy in the Atmosphere

- Identify and define types of electromagnetic radiation.

Does cell phone use cause brain tumors?

Many studies have been done to see if the radio frequency radiation emitted by cell phones causes brain tumors. As yet the results have mostly shown no link, although one study seemed to show some connection. The largest amount of radiation comes when the phone first connects to a new cell phone tower, so avoid talking while driving — which is good for other reasons as well — or when the signal is poor and the phone must emit more radiation for it to work. There is a link between having a cell phone in your pocket and a decrease in bone density in the pelvis. What can cause these problems? What is electromagnetic radiation?

Energy

Energy travels through space or material. This is obvious when you stand near a fire and feel its warmth or when you pick up the handle of a metal pot even though the handle is not sitting directly on the hot stove. Invisible energy waves can travel through air, glass, and even the vacuum of outer space. These waves have electrical and magnetic properties, so they are called **electromagnetic waves**. The transfer of energy from one object to another through electromagnetic waves is known as **radiation**.

Different wavelengths of energy create different types of electromagnetic waves (**Figure** 9.11).

- The wavelengths humans can see are known as **visible light**. When viewed together, all of the wavelengths of visible light appear white. But a prism or water droplets can break the white light into different wavelengths so that separate colors appear (**Figure** 9.12). What objects can you think of that radiate visible light? Two include the Sun and a light bulb.

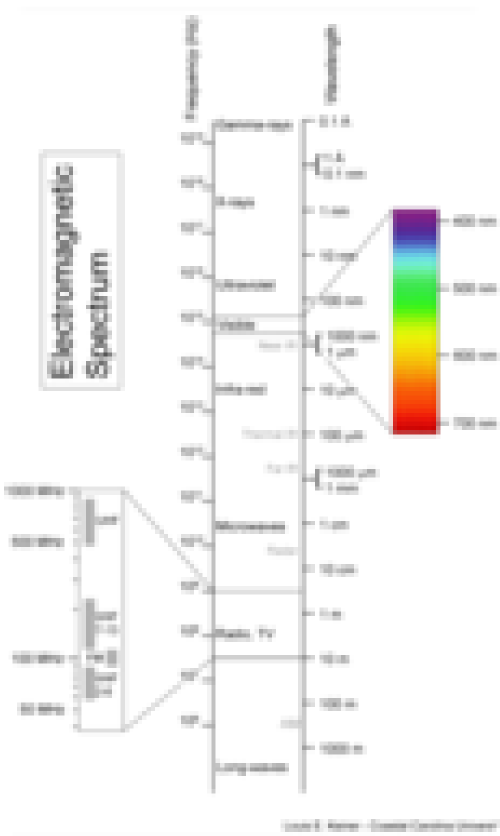


FIGURE 9.11
The electromagnetic spectrum; short wavelengths are the fastest with the highest energy.

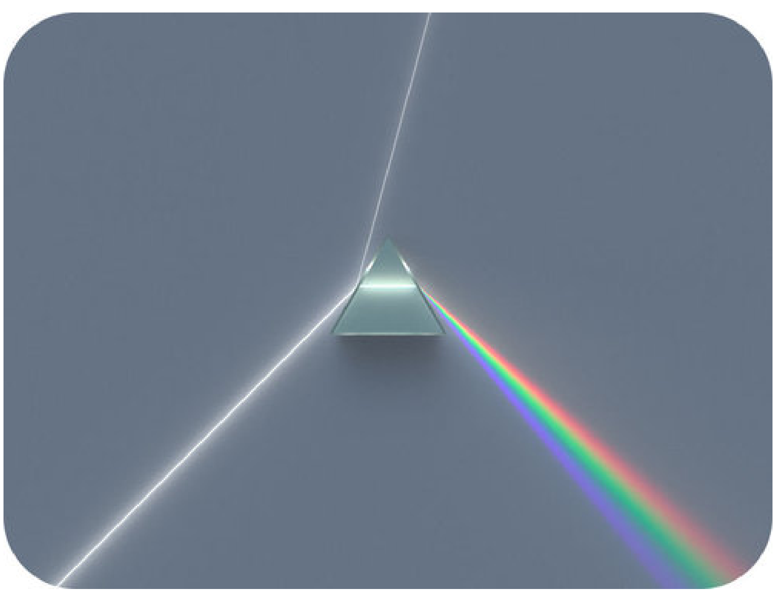


FIGURE 9.12
A prism breaks apart white light.

- The longest wavelengths of visible light appear red. Infrared wavelengths are longer than visible red. Snakes can see infrared energy. We feel infrared energy as heat.
- Wavelengths that are shorter than violet are called ultraviolet.

Can you think of some objects that appear to radiate visible light, but actually do not? The Moon and the planets do not emit light of their own; they reflect the light of the Sun. **Reflection** is when light (or another wave) bounces back from a surface. **Albedo** is a measure of how well a surface reflects light. A surface with high albedo reflects a large percentage of light. A snow field has high albedo.

One important fact to remember is that energy cannot be created or destroyed — it can only be changed from one form to another. This is such a fundamental fact of nature that it is a law: the law of conservation of energy.

In photosynthesis, for example, plants convert solar energy into chemical energy that they can use. They do not create new energy. When energy is transformed, some nearly always becomes heat. Heat transfers between materials easily, from warmer objects to cooler ones. If no more heat is added, eventually all of a material will reach the same temperature.

Vocabulary

- **albedo**: The amount of light that reflects off a surface; snow and ice have high albedo.
- **electromagnetic wave**: Waves with both electrical and magnetic properties; travel by radiation.
- **radiation**: The movement of energy through empty space between objects by electromagnetic waves.
- **reflection**: Bouncing back. A wave bounces off a reflective surface, just as a light wave bounces off a mirror.
- **visible light**: The portion of light in the electromagnetic spectrum that is visible to humans.

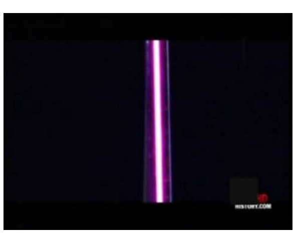
Summary

- Energy travels in waves with electrical and magnetic properties and so is called electromagnetic radiation.
- The wavelengths of visible light vary from long wavelength red to short wavelength violet. Infrared and ultraviolet wavelengths continue outward at longer and shorter wavelengths.
- The law of conservation of energy states that energy cannot be created or destroyed, it can only change forms.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=kfS5Qn0wn2o



MEDIA

Click image to the left for more content.

1. What is the electromagnetic spectrum?
2. What is the visible spectrum?
3. Why is the visible spectrum important?
4. What pattern is unique to hydrogen?

http://www.youtube.com/watch?v=QgzggbEQ2MY

MEDIA

Click image to the left for more content.

5. What is albedo?
6. How is albedo expressed?
7. What is the albedo of snow?
8. How is the Earth's albedo determined?
9. What does MODIS do?
10. What is the Earth's average temperature?
11. What happens when the rain forests are cut down?
12. What is the average albedo of the Earth?

Review

1. How is the light from the Sun different from the light from the Moon?
2. How does the energy that comes off a surface with high albedo differ from the energy that comes off a surface with low albedo?
3. How does a child kicking a soccer ball illustrate the law of conservation of energy?

9.10 Temperature and Heat in the Atmosphere

- Explain the relationship between temperature and heat.

A candle flame or a bathtub full of hot water: which has higher heat and which has the higher temperature?

The flame has higher temperature, but less heat because the hot region is very small. The bathtub has lower temperature, but more heat because it has many more vibrating atoms. Which has greater total energy? The bathtub.

Temperature

Temperature is a measure of how fast the atoms in a material are vibrating. High temperature particles vibrate faster than low temperature particles. Rapidly vibrating atoms smash together, which generates heat. As a material cools down, the atoms vibrate more slowly and collide less frequently. As a result, they emit less heat. What is the difference between heat and temperature?

- Temperature measures how fast a material's atoms are vibrating.
- Heat measures the material's total energy.

Heat

Heat energy is transferred between physical entities. Heat is taken in or released when an object changes state, or changes from a gas to a liquid, or a liquid to a solid. This heat is called **latent heat**. When a substance changes state, latent heat is released or absorbed. A substance that is changing its state of matter does not change temperature. All of the energy that is released or absorbed goes toward changing the material's state.

For example, imagine a pot of boiling water on a stove burner: that water is at 100^{o}C (212^{o}F). If you increase the temperature of the burner, more heat enters the water. The water remains at its boiling temperature, but the additional energy goes into changing the water from liquid to gas. With more heat the water evaporates more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

Substances also differ in their **specific heat**, the amount of energy needed to raise the temperature of one gram of the material by 1.0^{o}C (1.8^{o}F). Water has a very high specific heat, which means it takes a lot of energy to change the temperature of water. Let's compare a puddle and asphalt, for example. If you are walking barefoot on a sunny day, which would you rather walk across, the shallow puddle or an asphalt parking lot? Because of its high specific heat, the water stays cooler than the asphalt, even though it receives the same amount of solar radiation.

Vocabulary

- **heat**: Energy associated with the movement of atoms or molecules that can be transferred.
- **latent heat**: Energy absorbed or released as material changes from solid to liquid or liquid to gas.
- **specific heat**: The amount of energy needed to raise the temperature of 1 gram of material by 1^{o}C.
- **temperature**: A physical property of matter that expresses how hot or cold it is.

Summary

- Temperature the speed of vibration of the molecules that make up a substance. Heat is the energy transferred between physical entities.
- Latent heat is released or absorbed when a substance changes states.
- Specific heat is the amount of energy needed to raise the temperature of one gram of the material by 1.0^{o}C (1.8^{o}F).

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=v1zOnyC4RgQ

MEDIA

Click image to the left for more content.

1. What is temperature?
2. What determines heat?
3. How is temperature measured?
4. What is heat?
5. What is kinetic energy?
6. What does temperature measure?

Review

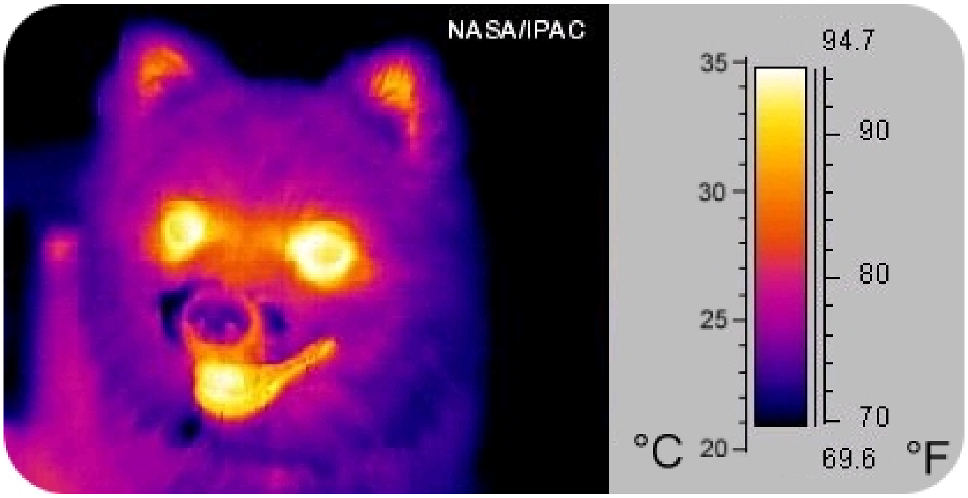
1. How does evaporative cooling work? Why do you think it is only effective in hot, dry areas?

2. What happens to the temperature of a substance as it changes state from liquid to solid? What happens to its latent heat?

3. As a substance changes state from liquid to solid, what happens to the molecules that make it up?

9.11 Solar Energy on Earth

- Describe different types of solar energy, including ultraviolet and infrared.



What's wrong with this dog?

Nothing! The sensor is detecting infrared radiation from the dog — in other words, heat. The Sun emits infrared radiation among other wavelengths too.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun (**Figure** 9.13). About 44% of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths.

Ultraviolet

Of the solar energy that reaches the outer atmosphere, **ultraviolet (UV)** wavelengths have the greatest energy. Only about 7% of solar radiation is in the UV wavelengths. The three types are:

- UVC: the highest energy ultraviolet, does not reach the planet's surface at all.
- UVB: the second highest energy, is also mostly stopped in the atmosphere.
- UVA: the lowest energy, travels through the atmosphere to the ground.

Infrared

The remaining solar radiation is the longest wavelength, **infrared**. Most objects radiate infrared energy, which we feel as heat.

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases (**Figure** 9.14). Ozone completely removes UVC, most UVB, and some UVA from incoming sunlight. O_2, CO_2, and H_2O also filter out some wavelengths.

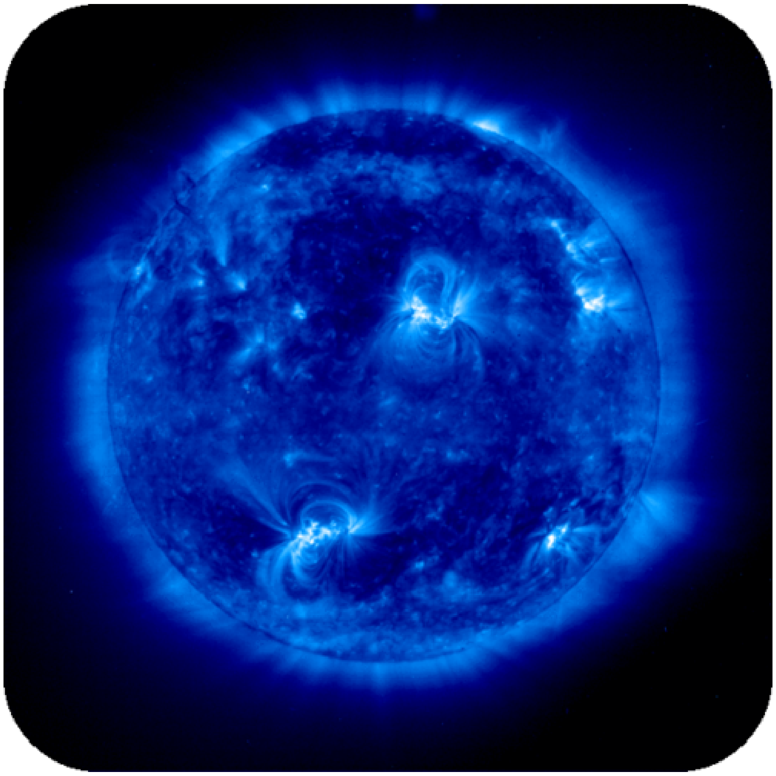


FIGURE 9.13
An image of the sun taken by the SOHO spacecraft. The sensor is picking up only the 17.1 nm wavelength, in the ultraviolet wavelengths.

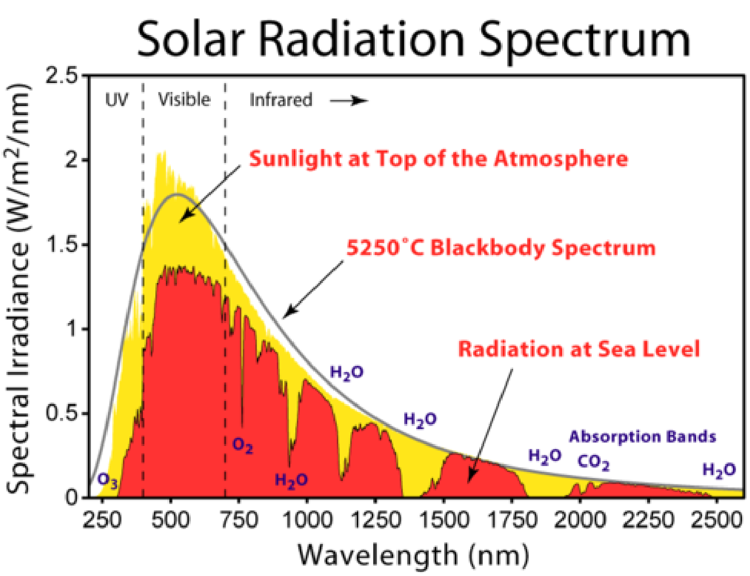


FIGURE 9.14
Atmospheric gases filter some wavelengths of incoming solar energy. Yellow shows the energy that reaches the top of the atmosphere. Red shows the wavelengths that reach sea level. Ozone filters out the shortest wavelength UV and oxygen filters out most infrared.

Vocabulary

- **infrared**:Electromagnetic waves with frequencies between radio waves and red light.
- **ultraviolet (UV)**: Electromagnetic radiation having wavelengths shorter than the violet.

Summary

- Ultraviolet radiation has the highest energy; infrared the lowest.
- Ultraviolet is divided into three categories based on wavelength: UVC, with the highest energy, UVB, and UVA, with the lowest energy.
- Infrared has longer wavelengths than red light and is felt as heat.

Practice

Use these resources to answer the questions that follow.

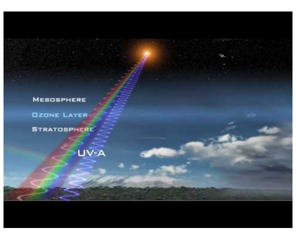
http://www.youtube.com/watch?v=i8caGm9Fmh0

MEDIA
Click image to the left for more content.

1. What is infrared light?
2. How can we sense infrared light?
3. What can be used to see infrared light?
4. What happens to infrared radiation when it get to the Earth?
5. What heats the lower atmosphere?
6. What is the Earth's radiation budget?
7. What does near infrared measure?
8. What can studying infrared tell us abut the Earth?

Ultraviolet Waves

http://www.youtube.com/watch?v=QW5zeVy8aE0



MEDIA
Click image to the left for more content.

9. What are ultraviolet waves?
10. What are three regions of ultraviolet waves?
11. Describe UVA.
12. What problem can UVB cause?
13. Why don't UVC rays reach the Earth?
14. What have scientists discovered with ultraviolet waves?

Review

1. Why does more solar radiation of all wavelengths come into the exosphere than reaches Earth's surface?
2. Why does ultraviolet radiation, especially UVC, damage life?
3. Look at the graph above. What happens to the highest wavelengths of energy at Earth's surface?

9.12 Heat Transfer in the Atmosphere

- Explain how conduction and convection work in the atmosphere.

What could cause such a spectacular, swirling funnel of air?

For many people, this sight is unfamiliar. It is a tornado. Tornadoes happen when heat is rapidly transferred between layers in the atmosphere.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth or another medium. What follows is a review of the way heat flows, but applied to the atmosphere.

Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In **conduction**, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes, where air density is higher. This transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

Heat transfer by movement of heated materials is called **convection**. Heat that radiates from the ground initiates convection cells in the atmosphere (**Figure** 9.15).

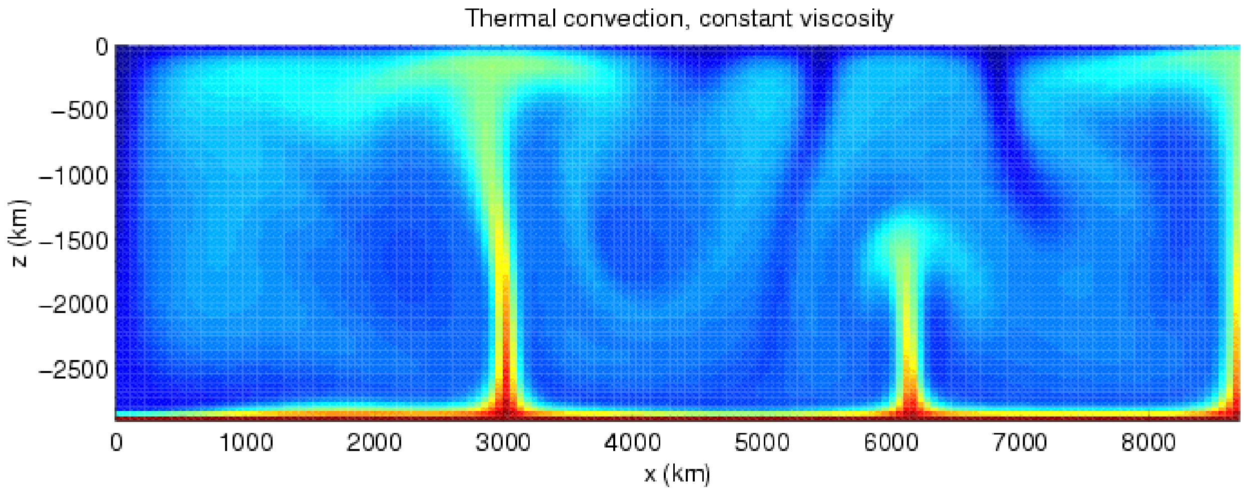


FIGURE 9.15

Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

What Drives Atmospheric Circulation?

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most solar radiation? The Sun's rays strike the surface most directly at the equator.

The difference in solar energy received at different latitudes drives atmospheric circulation.

Vocabulary

- **conduction**: The process in which energy moves from a location of higher temperature to a location of lower temperature as heat. The material does not move, just the heat.
- **convection**: The movement of material due to differences in temperature.
- **radiation**: The movement of energy through empty space between objects by electromagnetic waves.

Summary

- In conduction, substances must be in direct contact as heat moves from areas of more heat to areas of less heat.
- In convection, materials move depending on their heat relative to nearby materials.
- The equator receives more solar energy than other latitudes.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ajQ3hm5JidU

MEDIA

Click image to the left for more content.

1. What powers our weather?
2. What does heat cause?
3. How does the tilt of the Earth affect heating?
4. What causes wind?
5. What occurs in the water?

Review

1. What is moving in conduction? What is moving in convection?
2. The poles experience 24 hours of daylight in their summer. Why do poles receive less solar radiation than the equator?
3. What drives atmospheric circulation?

9.13 Heat Budget of Planet Earth

- Explain Earth's heat budget and its relationship to solar radiation.

How does heat on Earth resemble a household budget?

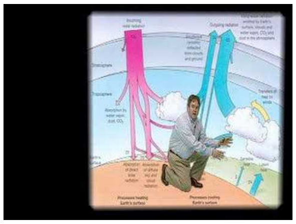
The heat left on Earth is heat in minus heat out. If more energy comes into the system than goes out of the system, the planet warms. If less energy goes into the system than goes out of the system, the planet cools. Replace the word "money" for "heat" and "on Earth" to "in your bank account" and you describe a household budget. Of course, Earth's heat budget is a lot more complex than a simple household budget.

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

The basics of Earth's annual heat budget are described in this video **(4b)**: http://www.youtube.com/watch?v=mjj2i3hNQF0#38;feature=related (5:40).



MEDIA
Click image to the left for more content.

The Heat Budget

Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception), because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See **Table** 9.1

TABLE 9.1: The Amount of Incoming Solar Energy

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

This animation shows the average surface temperature across the planet as it changes through the year: Monthly Mean Temperatures (http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif) .

The difference in solar energy received at different latitudes drives atmospheric circulation.

Summary

- Incoming solar radiation is absorbed by atmospheric gases, reflected by clouds, or scattered.
- Much of the radiation that strikes the ground is radiated back into the atmosphere as heat.
- More solar radiation strikes the equator than the poles.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=JFfD6jn_OvA

MEDIA
Click image to the left for more content.

1. What does CERES measure?
2. What does the acronym CERES stand for?
3. What is the ideal radiation budget?
4. How much of the sun's radiation is reflected?
5. How much energy does the ocean absorb?
6. What are scientists finding with CERES?
7. Why is the Earth warming?
8. What is a carbon footprint?

Review

1. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?
2. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?
3. What happens to sunlight that strikes the ground?

9.14 Greenhouse Effect

- Describe the greenhouse effect.
- Explain how human actions contribute to the greenhouse effect.

How does the atmosphere resemble a greenhouse?

To extend the growing season, many farmers use greenhouses. A greenhouse traps heat so that days that might be too cool for a growing plant can be made to be just right. Similar to a greenhouse, greenhouse gases in the atmosphere keep Earth warm.

The Greenhouse Effect

The exception to Earth's temperature being in balance is caused by greenhouse gases. But first the role of greenhouse gases in the atmosphere must be explained.

Greenhouse gases warm the atmosphere by trapping heat. Some of the heat that radiates out from the ground is trapped by greenhouse gases in the troposphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of **insulation** by greenhouse gases is called the **greenhouse effect** (**Figure** 9.16). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

Greenhouse Gases

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. **Table** 9.2 shows how each greenhouse gas naturally enters the atmosphere.

TABLE 9.2: Greenhouse Gas Entering the Atmosphere

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

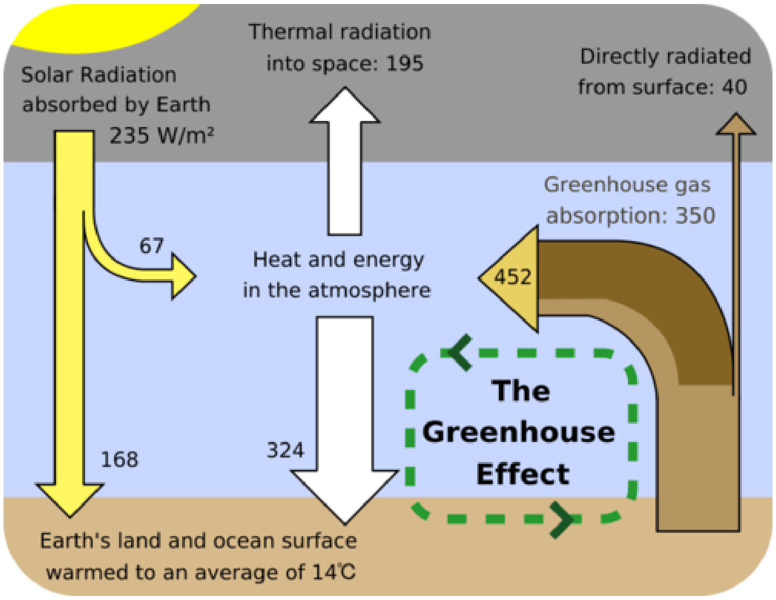


FIGURE 9.16
The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

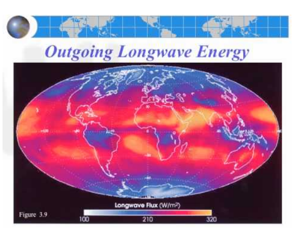
Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 2 1/2 times higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

This PowerPoint review, *Atmospheric Energy and Global Temperatures*, looks at the movement of energy through the atmosphere **(6a)**: http://www.youtube.com/watch?v=p6xMF_FFUU0 (8:17).



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Vocabulary

- **greenhouse effect**: The trapping of heat by greenhouse gases in the atmosphere; moderates temperatures.
- **insulation**: A material that inhibits conduction of heat or electricity.

Summary

- Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs).
- Tropospheric greenhouse gases trap heat in the atmosphere; greenhouse gases vary in their heat-trapping abilities.
- Levels of greenhouse gases in the atmosphere are increasing due to human activities.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Sciencehttp://www.hippocampus.org/Earth Science → Environmental Science → Search: **Greenhouse Effects** (first resource, starts with "About 50% of solar radiation...")

1. How much solar radiation is absorbed by the surface of the Earth?

2. What reflects the radiation?

3. How is most radiation re-emitted?

4. What is the net effect of this heating?

5. What are the primary greenhouse gases?

Review

1. If you were trying to keep down global temperature and you had a choice between adding 100 methane molecules or 1 CFC-12 molecule to the atmosphere, which would you choose?

2. What is the greenhouse effect?

3. How does Earth's atmosphere resemble a greenhouse?

9.15 Circulation in the Atmosphere

- Explain why atmospheric circulation occurs.

Why do we say Earth's temperature is moderate?

It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air poleward and frigid polar air toward the equator. If the planet had an atmosphere that was stagnant, the difference in temperature between the two regions would be much greater.

Air Pressure Zones

Within the troposphere are convection cells (**Figure** 9.17). Air heated at the ground rises, creating a **low pressure zone**. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere; horizontal flow is called **advection**. The air cools until it descends. When the air reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

Warm air can hold more moisture than cool air. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Wind

Air moving between large high and low pressure systems at the bases of the three major convection cells creates the global wind belts. These planet-wide air circulation systems profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

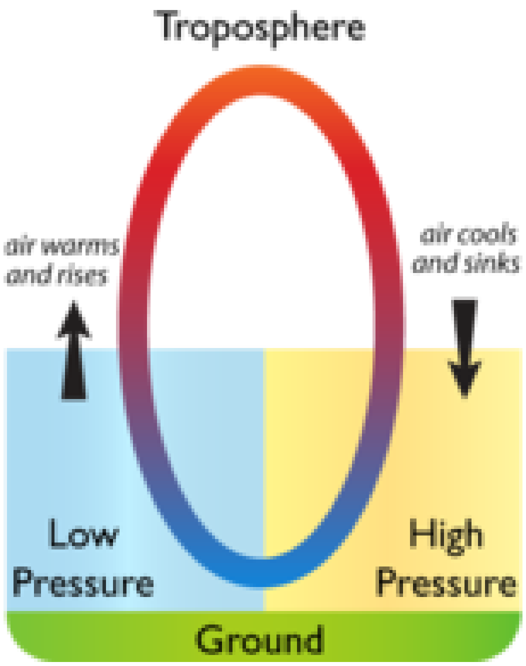


FIGURE 9.17
Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

An online guide to air pressure and winds from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/home.rxml.

Atmospheric Circulation

Two Convection Cells

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense, and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator.

Plus Coriolis Effect

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis effect must be taken into account.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis effect (**Figure** 9.18). Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30^oN latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0^o and 30^oN.

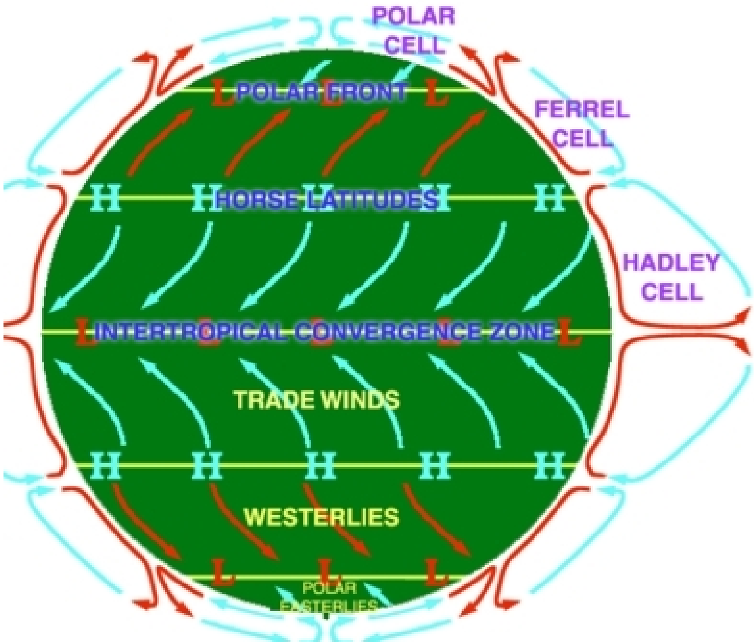


FIGURE 9.18
The atmospheric circulation cells, showing direction of winds at Earth's surface.

Equals Three Convection Cells

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30^oN and 50^o to 60^oN. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50^oN to 60^oN and the North Pole, where cold air descends.

Plus Three in the Southern Hemisphere

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis effect makes objects appear to deflect to the left. The total number of atmospheric circulation cells around the globe is six.

Vocabulary

- **advection**: Horizontal movement of a fluid or the transport of a substance in the flow.
- **high pressure zone**: A region where relatively cool, dense air is sinking.
- **low pressure zone**: A region where relatively warm, lower density air is rising.

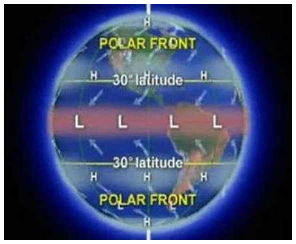
Summary

- The atmosphere has six major convection cells, three in the northern hemisphere and three in the southern.
- Coriolis effect results in there being three convection cells per hemisphere rather than one.
- Winds blow at the base of the atmospheric convection cells.

Practice

Use this resource to answer the questions that follow.

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



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1. Where is insolation strongest?
2. What type of pressure occurs at the equator?
3. What type of pressure occurs at the poles?
4. What are Hadley cells?
5. Where does convection occur?
6. How do surface winds move?
7. What is the polar front?
8. How does air move at high altitudes?

Review

1. Diagram and label the parts of a convection cell in the troposphere.
2. How many major atmospheric convection cells would there be without Coriolis effect? Where would they be?
3. How does Coriolis effect change atmospheric convection?

9.16 Global Wind Belts

- Identify and define global winds.
- Explain how atmospheric circulation creates global winds, and how global winds influence climate.

Why were winds so important to the early explorers?

When Columbus sailed the ocean blue, and for centuries before and after, ocean travel depended on the wind. Mariners knew how to get where they were going and at what time of the year based on experience with the winds. Winds were named for their usefulness to sailors, such as the trade winds that facilitated commerce between people on opposite shores.

Global Wind Belts

Global winds blow in belts encircling the planet. Notice that the locations of these wind belts correlate with the atmospheric circulation cells. Air blowing at the base of the circulation cells, from high pressure to low pressure, creates the global wind belts.

The global wind belts are enormous and the winds are relatively steady (**Figure** 9.19).

The Global Winds

Let's look at the global wind belts in the Northern Hemisphere.

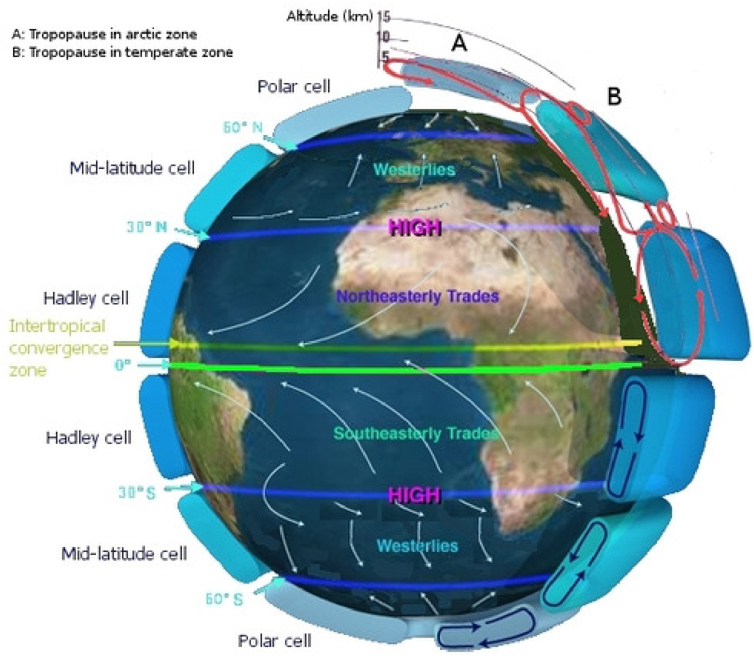
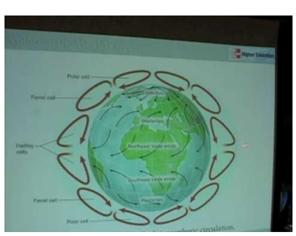


FIGURE 9.19
The major wind belts and the directions that they blow.

- In the Hadley cell air should move north to south, but it is deflected to the right by Coriolis. So the air blows from northeast to the southwest. This belt is the trade winds, so called because at the time of sailing ships they were good for trade.
- In the Ferrel cell air should move south to north, but the winds actually blow from the southwest. This belt is the westerly winds or westerlies.
- In the Polar cell, the winds travel from the northeast and are called the polar easterlies.

The wind belts are named for the directions from which the winds come. The westerly winds, for example, blow from west to east. These names hold for the winds in the wind belts of the Southern Hemisphere as well.

This video lecture discusses the 3-cell model of atmospheric circulation and the resulting global wind belts and surface wind currents **(5a)**: http://www.youtube.com/watch?v=HWFDKdxK75E#38;feature=related (8:45).



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Global Winds and Precipitation

The high and low pressure areas created by the six atmospheric circulation cells also determine in a general way the amount of precipitation a region receives. Rain is common in low pressure regions due to rising air. Air sinking in high pressure areas causes evaporation; these regions are usually dry. These features have a great deal of influence on climate.

Polar Front

The **polar front** is the junction between the Ferrell and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrell Cell runs into relatively cold, dry air of the Polar cell. The weather where these two meet is extremely variable, typical of much of North America and Europe.

Jet Stream

The polar **jet stream** is found high up in the atmosphere where the two cells come together. A jet stream is a fast-flowing river of air at the boundary between the troposphere and the stratosphere. Jet streams form where there is a large temperature difference between two air masses. This explains why the polar jet stream is the world's most powerful (**Figure** 9.20).

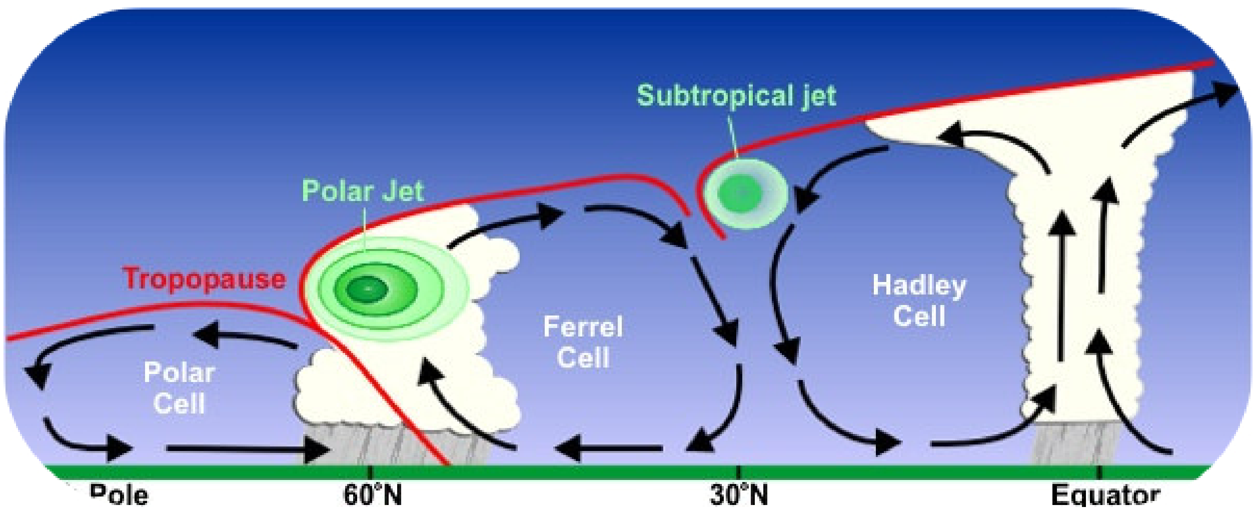


FIGURE 9.20
A cross section of the atmosphere with major circulation cells and jet streams. The polar jet stream is the site of extremely turbulent weather.

Jet streams move seasonally just as the angle of the Sun in the sky moves north and south. The polar jet stream, known as "the jet stream," moves south in the winter and north in the summer between about 30^oN and 50^o to 75^oN.

Vocabulary

- **jet stream**: A fast-flowing river of air high in the atmosphere, where air masses with two very different sets of temperature and humidity characteristics move past each other.
- **polar front**: The meeting zone between cold continental air and warmer subtropical air at around 50^oN and 50^oS.

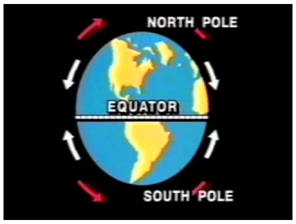
Summary

- Global winds blow from high to low pressure at the base of the atmospheric circulation cells.

- The winds at the bases of the cells have names: the Hadley cell is the trade winds, the Ferrel Cell is the westerlies, and the polar cell is the polar easterlies.
- Where two cells meet, weather can be extreme, particularly at the polar front.

Practice

Use this resource to answer the questions that follow.



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1. What creates wind?
2. What are monsoons? How are they created?
3. What are local and regional winds?
4. What are the global wind patterns?
5. In what direction does the Earth rotate?
6. What is the Coriolis effect?
7. What are the Westerlies?

Review

1. What is a jet stream? What is "the" jet stream?
2. Why does a flight across the United States from San Francisco to New York City takes less time than the reverse trip?
3. Where on a circulation cell is there typically precipitation and where is there typically evaporation?

9.17 Local Winds

- Describe the different types of local winds and explain how they are created.
- Explain how types of local winds influence climate.

How can they stand up?

When you try to walk against a 20 mile an hour wind it's not easy. Just standing up is like walking really fast!

Local Winds

Local winds result from air moving between small low and high pressure systems. High and low pressure cells are created by a variety of conditions. Some local winds have very important effects on the weather and climate of some regions.

Land and Sea Breezes

Since water has a very high specific heat, it maintains its temperature well. So water heats and cools more slowly than land. If there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it, high and low pressure regions form. This creates local winds.

- **Sea breezes** blow from the cooler ocean over the warmer land in summer. Where is the high pressure zone and where is the low pressure zone? (**Figure** 9.21). Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10^{o}C (9 to 18^{o}F).
- **Land breezes** blow from the land to the sea in winter. Where is the high pressure zone and where is the low pressure zone? Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

Land and sea breezes create the pleasant climate for which Southern California is known. The effect of land and sea breezes are felt only about 50 to 100 km (30 to 60 miles) inland. This same cooling and warming effect occurs to a smaller degree during day and night, because land warms and cools faster than the ocean.

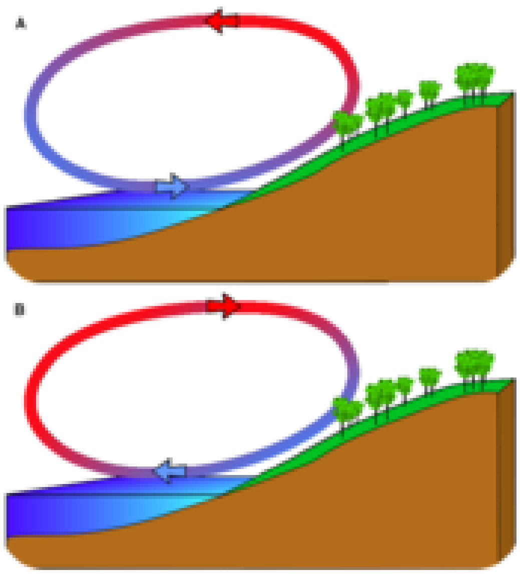


FIGURE 9.21
How do sea and land breezes moderate coastal climates?

Monsoon Winds

Monsoon winds are larger scale versions of land and sea breezes; they blow from the sea onto the land in summer and from the land onto the sea in winter. Monsoon winds occur where very hot summer lands are next to the sea. Thunderstorms are common during monsoons (**Figure** 9.22).

FIGURE 9.22
In the southwestern United States relatively cool moist air sucked in from the Gulf of Mexico and the Gulf of California meets air that has been heated by scorching desert temperatures.

The most important monsoon in the world occurs each year over the Indian subcontinent. More than two billion residents of India and southeastern Asia depend on monsoon rains for their drinking and irrigation water. Back in the days of sailing ships, seasonal shifts in the monsoon winds carried goods back and forth between India and Africa.

Mountain and Valley Breezes

Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises and draws the cool air up from the valley, creating a **valley breeze**. At night the mountain slopes cool more quickly than the nearby valley, which causes a **mountain breeze** to flow downhill.

Katabatic Winds

Katabatic winds move up and down slopes, but they are stronger mountain and valley breezes. Katabatic winds form over a high land area, like a high plateau. The plateau is usually surrounded on almost all sides by mountains. In winter, the plateau grows cold. The air above the plateau grows cold and sinks down from the plateau through gaps in the mountains. Wind speeds depend on the difference in air pressure over the plateau and over the surroundings. Katabatic winds form over many continental areas. Extremely cold katabatic winds blow over Antarctica and Greenland.

Chinook Winds (Foehn Winds)

Chinook winds (or **Foehn winds**) develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the mountains, it cools and contracts. If the air is humid, it may form clouds and drop rain or snow. When the air sinks on the leeward side of the mountains, it forms a high pressure zone. The windward side of a mountain range is the side that receives the wind; the leeward side is the side where air sinks.

The descending air warms and creates strong, dry winds. Chinook winds can raise temperatures more than 20^{o}C (36^{o}F) in an hour and they rapidly decrease humidity. Snow on the leeward side of the mountain melts quickly. If precipitation falls as the air rises over the mountains, the air will be dry as it sinks on the leeward size. This dry, sinking air causes a **rainshadow effect** (**Figure** 9.23), which creates many of the world's deserts.

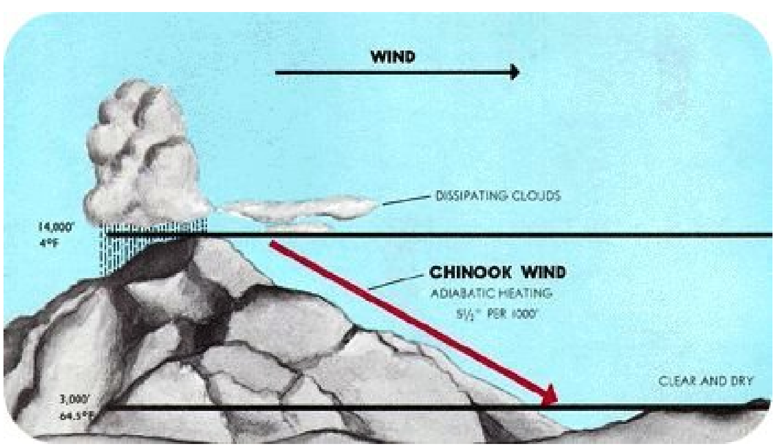


FIGURE 9.23

As air rises over a mountain it cools and loses moisture, then warms by compression on the leeward side. The resulting warm and dry winds are Chinook winds. The leeward side of the mountain experiences rainshadow effect.

Santa Ana Winds

Santa Ana winds are created in the late fall and winter when the Great Basin east of the Sierra Nevada cools, creating a high pressure zone. The high pressure forces winds downhill and in a clockwise direction (because of

Coriolis). The air pressure rises, so temperature rises and humidity falls. The winds blow across the Southwestern deserts and then race downhill and westward toward the ocean. Air is forced through canyons cutting the San Gabriel and San Bernardino mountains. (**Figure** 9.24).

FIGURE 9.24
The winds are especially fast through Santa Ana Canyon, for which they are named. Santa Ana winds blow dust and smoke westward over the Pacific from Southern California.

The Santa Ana winds often arrive at the end of California's long summer drought season. The hot, dry winds dry out the landscape even more. If a fire starts, it can spread quickly, causing large-scale devastation (**Figure** 9.25).

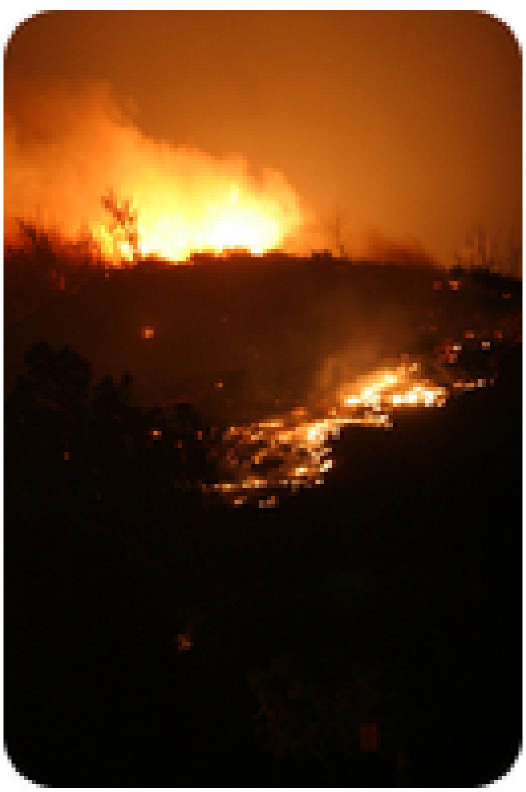


FIGURE 9.25
In October 2007, Santa Ana winds fueled many fires that together burned 426,000 acres of wild land and more than 1,500 homes in Southern California.

Desert Winds

High summer temperatures on the desert create high winds, which are often associated with monsoon storms. Desert winds pick up dust because there is not as much vegetation to hold down the dirt and sand. (**Figure** 9.26). A **haboob** forms in the downdrafts on the front of a thunderstorm.

FIGURE 9.26
A haboob in the Phoenix metropolitan area, Arizona.

Dust devils, also called whirlwinds, form as the ground becomes so hot that the air above it heats and rises. Air flows into the low pressure and begins to spin. Dust devils are small and short-lived, but they may cause damage.

Vocabulary

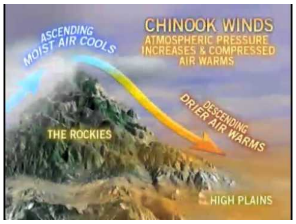
- **Chinook (foehn) wind**: Winds that form when low pressure draws air over a mountain range.
- **haboob**: Desert sandstorms that form in the downdrafts of a thunderstorm.
- **katabatic wind**: Winds that move down a slope.
- **land breeze**: A wind that blows from land to sea in winter when the ocean is warmer than the land.
- **monsoon**: Hot land draws cool air off a nearby sea creating large winds and often rain.
- **mountain breeze**: A wind that blows from a mountain to a valley at night when mountain air is cooler.
- **rainshadow effect**: A location of little rain on the leeward side of a mountain range due to descending air.
- **Santa Ana winds**: Hot winds that blow east to west into Southern California in fall and winter.
- **sea breeze**: A wind that blows from sea to land in summer when the land is warmer than the ocean.
- **valley breeze**: An uphill airflow.

Summary

- Water has high specific heat, so its temperature changes very slowly relative to the temperature of the land. This is the reason for sea and land breezes and monsoon winds.
- The cause of all of these winds is the differential heating of Earth's surface, whether it's due to the difference in water and land, the difference with altitude, or something else.
- Winds blow up and down slope, on and off land and sea, through deserts or over mountain passes.

Practice

Use these resources to answer the questions that follow.



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1. What are Chinook winds?
2. Where do Chinook winds occur?
3. Explain how Chinook winds work.

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4. What are the Santa Ana winds?
5. Where do the Santa Ana winds occur?
6. What causes the Santa Ana winds?
7. Explain how the Santa Ana winds affects the weather.
8. What can be caused by the Santa Ana winds?

Review

1. How does the high specific heat of water result in the formation of sea and land breezes?
2. Describe the conditions that lead to Santa Ana winds.
3. How do Chinook winds lead to rainshadow effect?

9.18 Weather versus Climate

- Define weather and climate, and explain the relationship between them.

What's the weather like?

If someone across country asks you what the weather is like today, you need to consider several factors. Air temperature, humidity, wind speed, the amount and types of clouds, and precipitation are all part of a thorough weather report.

What is Weather?

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place. A location's weather depends on:

- air temperature
- air pressure
- fog
- humidity
- cloud cover
- precipitation
- wind speed and direction

All of these characteristics are directly related to the amount of energy that is in the system and where that energy is. The ultimate source of this energy is the Sun.

Weather is the change we experience from day to day. Weather can change rapidly.

What is Climate?

Although almost anything can happen with the weather, **climate** is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (**Figure** 9.27).

FIGURE 9.27
Winter weather at Lake Tahoe doesn't much resemble winter weather in San Diego even though they're both in California.

Climate is the long-term average of weather in a particular spot. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good! A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation.

The climate for a particular place is steady, and changes only very slowly. Climate is determined by many factors, including the angle of the Sun, the likelihood of cloud cover, and the air pressure. All of these factors are related to the amount of energy that is found in that location over time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Vocabulary

- **climate**: The long-term average of weather for a region. Climate changes relatively slowly.
- **weather**: The temporary state of the atmosphere in a region.

Summary

- A region's weather depends on its air temperature, air pressure, humidity, precipitation, wind speed and direction, and other factors.
- Climate is the long-term average of weather.
- Weather can change in minutes, but climate changes very slowly.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/science/earth-sci/climate-weather-sci/

1. What is climate?
2. How many climate zones are there? List examples.
3. What did climate determine in the past?
4. Why doesn't climate have as much influence today?
5. What is weather?
6. What problems can severe weather cause?
7. Why is an accurate weather forecast important?
8. What tools do meteorologists use?

Review

1. When you're in a cold place in December and you're planning a vacation for February, are you interested in a location's weather or climate? If it's a summer day and you want to take a picnic are you concerned with weather or climate?
2. What factors account for a location's weather?
3. If climate is the long-term average of weather, how can climate change?

9.19 Clouds

- Define humidity, and explain the relationship of humidity to cloud formation.
- Explain how clouds form and describe their influence on weather.
- Describe different types of clouds and fog.

Have you ever looked at the sky and found shapes in the clouds?

Clouds have a great effect on the weather and climate, but they can also be lovely (if they're not pouring rain on you). It's fun to sit and watch the clouds go by.

Humidity

Humidity is the amount of water vapor in the air in a particular spot. We usually use the term to mean **relative humidity**, the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. If the humidity today is 80%, it means that the air contains 80% of the total amount of water it can hold at that temperature. What will happen if the humidity increases to more than 100%? The excess water condenses and forms precipitation.

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity (**Figure** 9.28). The temperature at which air becomes saturated with water is called the air's **dew point**. This term makes sense, because water condenses from the air as dew if the air cools down overnight and reaches 100% humidity.

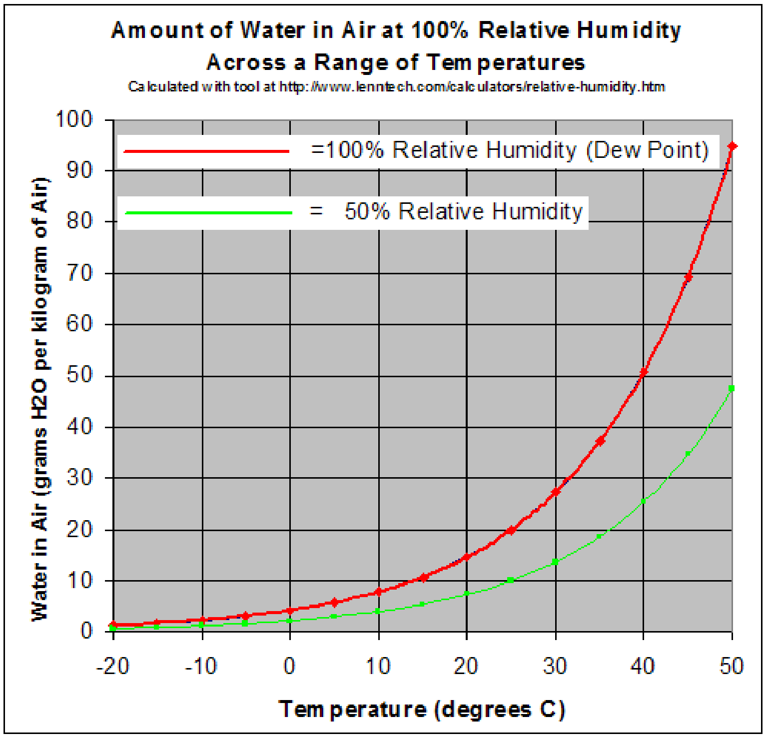


FIGURE 9.28

This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius.

Clouds

Water vapor is not visible unless it condenses to become a cloud. Water vapor condenses around a nucleus, such as dust, smoke, or a salt crystal. This forms a tiny liquid droplet. Billions of these water droplets together make a cloud.

Formation

Clouds form when air reaches its dew point. This can happen in two ways: (1) Air temperature stays the same but humidity increases. This is common in locations that are warm and humid. (2) Humidity remains the same, but temperature decreases. When the air cools enough to reach 100% humidity, water droplets form. Air cools when it comes into contact with a cold surface or when it rises.

Rising air creates clouds when it has been warmed at or near the ground level and then is pushed up over a mountain or mountain range or is thrust over a mass of cold, dense air.

Effects on Weather

Clouds have a big influence on weather:

- by preventing solar radiation from reaching the ground.
- by absorbing warmth that is re-emitted from the ground.
- as the source of precipitation.

When there are no clouds, there is less insulation. As a result, cloudless days can be extremely hot, and cloudless nights can be very cold. For this reason, cloudy days tend to have a lower range of temperatures than clear days.

Types of Clouds

Clouds are classified in several ways. The most common classification used today divides clouds into four separate cloud groups, which are determined by their altitude (**Figure** 9.29).

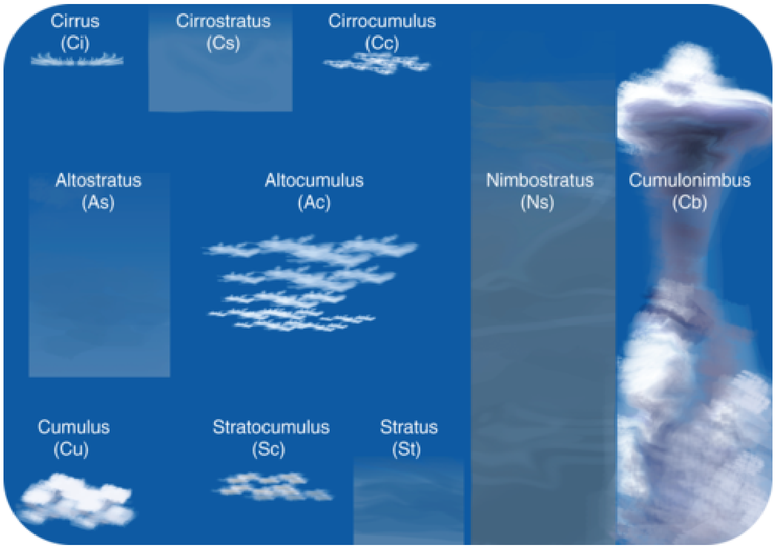


FIGURE 9.29
The four cloud types and where they are found in the atmosphere.

- High clouds form from ice crystals where the air is extremely cold and can hold little water vapor. Cirrus, cirrostratus, and cirrocumulus are all names of high clouds.
- Middle clouds, including altocumulus and altostratus clouds, may be made of water droplets, ice crystals or both, depending on the air temperatures. Thick and broad altostratus clouds are gray or blue-gray. They often cover the entire sky and usually mean a large storm, bearing a lot of precipitation, is coming.
- Low clouds are nearly all water droplets. Stratus, stratocumulus, and nimbostratus clouds are common low clouds. Nimbostratus clouds are thick and dark. They bring steady rain or snow.
- Vertical clouds, clouds with the prefix "cumulo-," grow vertically instead of horizontally and have their bases at low altitude and their tops at high or middle altitude. Clouds grow vertically when strong air currents are rising upward.

An online guide to cloud development and different cloud types from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/home.rxml.

Fog

Fog (**Figure** 9.30) is a cloud located at or near the ground . When humid air near the ground cools below its dew point, fog is formed. Each type of fog forms in a different way.

- Radiation fog forms at night when skies are clear and the relative humidity is high. As the ground cools, the bottom layer of air cools below its dew point. Tule fog is an extreme form of radiation fog found in some regions.
- San Francisco, California, is famous for its summertime advection fog. Warm, moist Pacific Ocean air blows over the cold California current and cools below its dew point. Sea breezes bring the fog onshore.
- Steam fog appears in autumn when cool air moves over a warm lake. Water evaporates from the lake surface and condenses as it cools, appearing like steam.

FIGURE 9.30
(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake. (d) Upslope fog around the peak of Mt. Lushan in China.

- Warm humid air travels up a hillside and cools below its dew point to create upslope fog.

Fog levels are declining along the California coast as climate warms. The change in fog may have big ecological changes for the state.

Learn more at http://www.kqed.org/quest/television/science-on-the-spot-science-of-fog.

MEDIA
Click image to the left for more content.

Vocabulary

- **cloud**: Tiny water or ice particles that are grouped together in the atmosphere.
- **dew point**: The temperature at which air is saturated with water vapor; when it has 100% humidity.
- **fog**: Air condensed below its dew point that is near the ground like a cloud.
- **relative humidity**: The amount of water vapor in the air relative to the maximum amount of water vapor that the air could contain at that temperature.

Summary

- Air reaches its dew point when humidity increases or temperature decreases. Water droplets form when the air reaches 100% humidity.
- Clouds block solar radiation, absorb heat from the ground and are the source of snow and rain.
- Fog forms when there is a difference in temperature between the land and the air.

Practice

Use this resource to answer the questions that follow.

http://www.atmosphere.mpg.de/enid/1__Clouds/-_Formation_of_clouds_t9.html

1. What is a cloud?

2. What causes clouds to form?

3. What is the Foehn effect?

4. What causes a front to form?

5. Explain what causes fog.

Review

1. Imagine a place with a daytime temperature of 45 degrees F. How will the nighttime temperature change if the sky is cloudy? How will it change if the sky is clear?

2. What set of conditions causes tule fog?

3. The low temperature a few degrees above freezing last night. Why is your car covered with frost this morning?

9.20 Precipitation

- Describe different types of precipitation and the conditions that create them.

Do you live in a place that gets lots of rain?

In some places it rains so much that people barely notice it. In others it rains so little that a rainy day is revered. Rain is not the only type of precipitation; see a few below.

Precipitation

Precipitation (**Figure** 9.31) is an extremely important part of weather. Water vapor condenses and usually falls to create precipitation.

Dew and Frost

Some precipitation forms in place. **Dew** forms when moist air cools below its dew point on a cold surface. **Frost** is dew that forms when the air temperature is below freezing.

Precipitation From Clouds

The most common precipitation comes from clouds. **Rain** or snow droplets grow as they ride air currents in a cloud and collect other droplets (**Figure** 9.32). They fall when they become heavy enough to escape from the rising air currents that hold them up in the cloud. One million cloud droplets will combine to make only one rain drop! If temperatures are cold, the droplet will hit the ground as **snow**.

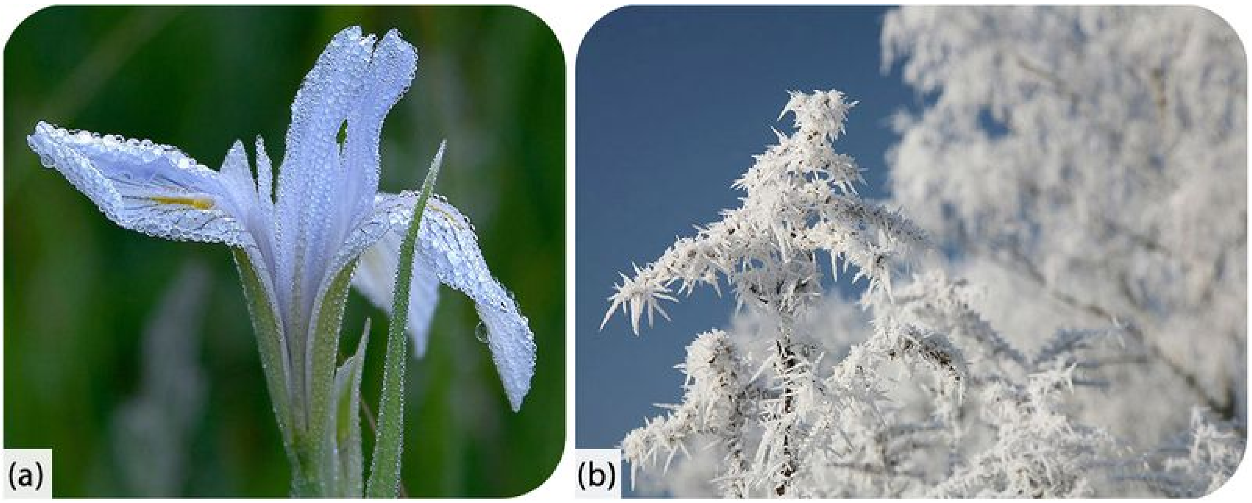


FIGURE 9.31

(a) Dew on a flower. (b) Hoar frost.

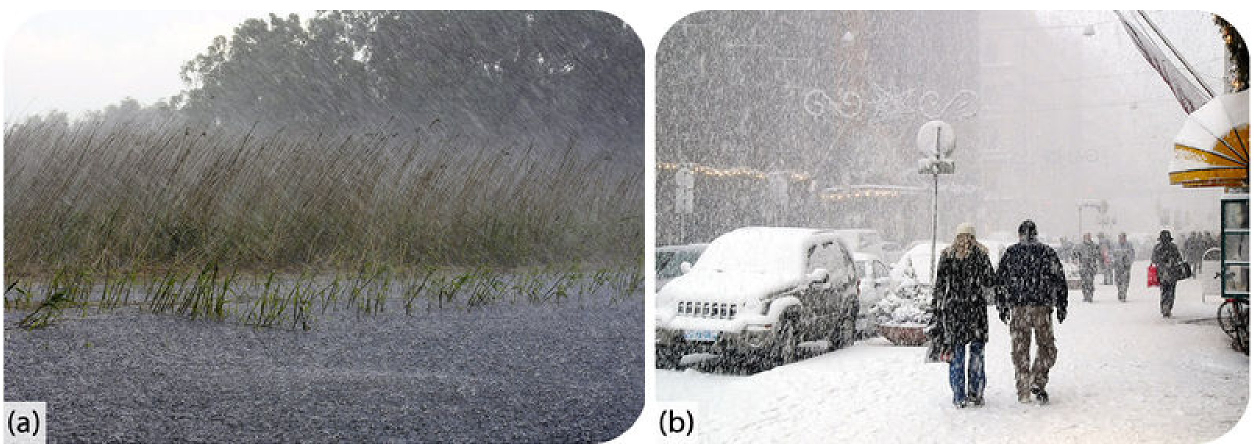


FIGURE 9.32

(a) Rain falls from clouds when the temperature is fairly warm. (b) Snow storm in Boston, Massachusetts.

Other less common types of precipitation are **sleet** (**Figure** 9.33). Sleet is rain that becomes ice as it hits a layer of freezing air near the ground. If a frigid raindrop freezes on the frigid ground, it forms **glaze**. **Hail** forms in cumulonimbus clouds with strong updrafts. An ice particle travels until it finally becomes too heavy and it drops.

An online guide from the University of Illinois to different types of precipitation is seen here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/prcp/home.rxml.

FIGURE 9.33
(a)Sleet. (b) Glaze. (c) Hail. This large hail stone is about 6 cm (2.5 inches) in diameter.

Vocabulary

- **dew**: Moisture from water vapor that condenses on an object that is below the dewpoint temperature.
- **frost**: Ice crystals that form on an exposed surface when the temperature of the surface is below freezing.
- **glaze**: A coating of ice due to freezing of liquid raindrops.
- **hail**: Balls of ice formed as water freezes and in layers in the strong updrafts of thunderstorms.
- **precipitation**: Water that falls from the sky as rain, snow, sleet, or hail.
- **rain**: Liquid water that falls from the atmosphere.
- **sleet**: Raindrops that freeze to ice before striking the ground.
- **snow**: Frozen precipitation in patterns.

Summary

- A surface can be colder than the surrounding air, causing the air to cool below its dew point.
- Rain droplets caught up in air currents within a cloud get larger by the addition of condensed droplets until they are too heavy and they fall.
- If the ground is very cold, rain can freeze to become sleet or glaze.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=kFFHo4T-g4E

MEDIA
Click image to the left for more content.

1. What is precipitation?

2. What is the most common form of precipitation?
3. What is hail?
4. What is sleet?
5. What is snow?

Review

1. Describe how raindrops form.
2. Why does hail only come from cumulonimbus clouds?
3. How does sleet form?

9.21 Air Masses

- Explain how air masses form, move, and influence weather.

Why do these air balloons rise?

Warm air rises and cool air sinks. In a hot air balloon, a heater heats the air inside the balloon. When the weight of the warm air plus the balloon is less than the weight of the cooler air outside the balloon, the balloon will rise. Air masses work on the same principles, rising and falling when they confront an obstacle, such as another air mass.

What is an Air Mass?

An **air mass** is a batch of air that has nearly the same temperature and humidity (**Figure** 9.34). An air mass acquires these characteristics above an area of land or water known as its source region. When the air mass sits over a region for several days or longer, it picks up the distinct temperature and humidity characteristics of that region.

Air Mass Formation

Air masses form over a large area; they can be 1,600 km (1,000 miles) across and several kilometers thick. Air masses form primarily in high pressure zones, most commonly in polar and tropical regions. Temperate zones are ordinarily too unstable for air masses to form. Instead, air masses move across temperate zones, so the middle latitudes are prone to having interesting weather.

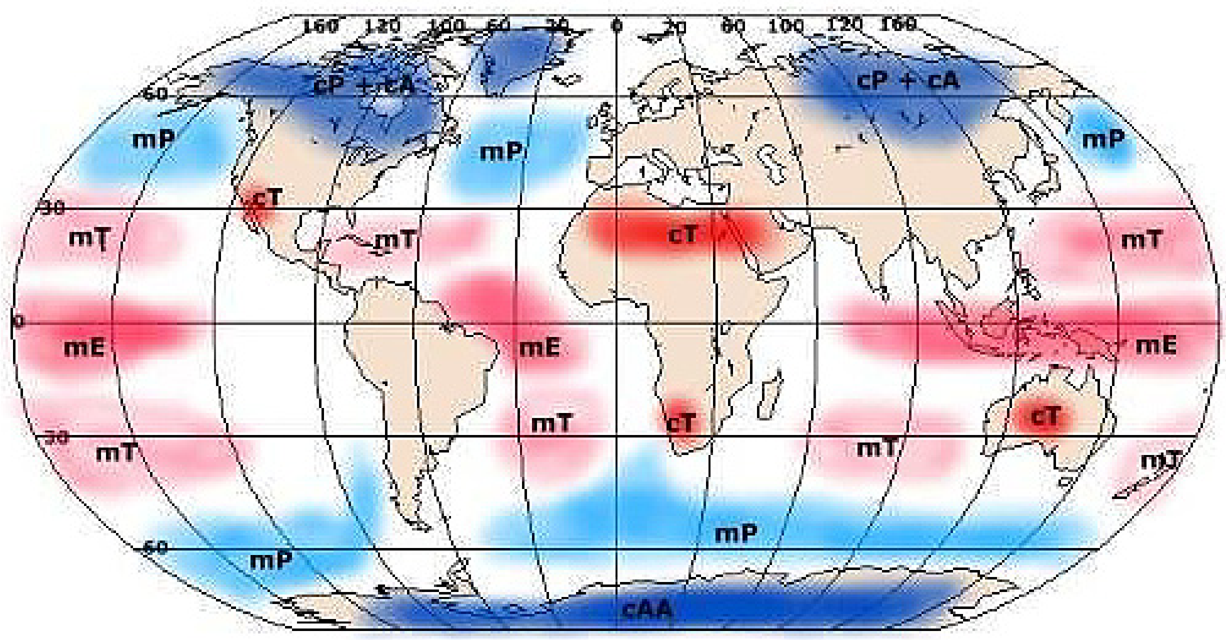


FIGURE 9.34

The source regions of air masses found around the world. Symbols: (1) origin over a continent (c) or an ocean (m, for maritime); (2) arctic (A), polar (P,) tropical (T), and equatorial (E); (3) properties relative to the ground it moves over: k, for colder, w for warmer.

What does an air mass with the symbol cPk mean? The symbol cPk is an air mass with a continental polar source region that is colder than the region it is now moving over.

Air Mass Movement

Air masses are slowly pushed along by high-level winds. When an air mass moves over a new region, it shares its temperature and humidity with that region. So the temperature and humidity of a particular location depends partly on the characteristics of the air mass that sits over it.

Storms

Storms arise if the air mass and the region it moves over have different characteristics. For example, when a colder air mass moves over warmer ground, the bottom layer of air is heated. That air rises, forming clouds, rain, and sometimes thunderstorms. How would a moving air mass form an inversion? When a warmer air mass travels over colder ground, the bottom layer of air cools and, because of its high density, is trapped near the ground.

Moderate Temperature

In general, cold air masses tend to flow toward the equator and warm air masses tend to flow toward the poles. This brings heat to cold areas and cools down areas that are warm. It is one of the many processes that act to balance out the planet's temperatures.

Figures and animations explain weather basics at this USA Today site: http://www.usatoday.com/weather/wstorm0.htm.

An online guide from the University of Illinois about air masses and fronts is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/af/home.rxml.

Vocabulary

- **air mass**: A large mass of air with the same temperature and humidity characteristics.

Summary

- An air mass has roughly the same temperature and humidity.
- Air masses form over regions where the air is stable for a long enough time that the air can take on the characteristics of the region.
- Air masses move when they are pushed by high level winds.

Practice

Use this resource to answer the questions that follow.

http://video.about.com/weather/Types-of-Air-Masses.htm

1. What is air mass?
2. What determines the types of air masses?
3. What is continental air?
4. What is maritine air?
5. What is tropical air?
6. What is polar air?
7. List the four types of air masses and give the abbreviation for each.
8. What characterizes arctic air?
9. What characterizes equatorial air?

Review

1. How do the movements of air masses moderate temperature?
2. Why do air masses form mostly in high pressure areas?
3. What is the relationship between air masses and storms?

9.22 Weather Fronts

- Define different types of fronts.
- Explain how fronts create changes in weather.

How is a meteorological front like a military front?

In military usage, a front is where two opposing forces meet. This bayonet charge of French soldiers is opposing the Germans along the Western Front during World War I. How does a weather front resemble this?

Fronts

Two air masses meet at a **front**. At a front, the two air masses have different densities and do not easily mix. One air mass is lifted above the other, creating a low pressure zone. If the lifted air is moist, there will be condensation and precipitation. Winds are common at a front. The greater the temperature difference between the two air masses, the stronger the winds will be. Fronts are the main cause of stormy weather.

There are four types of fronts, three moving and one stationary. With cold fronts and warm fronts, the air mass at the leading edge of the front gives the front its name. In other words, a cold front is right at the leading edge of moving cold air and a warm front marks the leading edge of moving warm air.

Stationary Front

At a **stationary front** the air masses do not move (**Figure** 9.35). A front may become stationary if an air mass is stopped by a barrier, such as a mountain range. A stationary front may bring days of rain, drizzle, and fog. Winds usually blow parallel to the front, but in opposite directions. After several days, the front will likely break apart.

Cold Fronts

When a cold air mass takes the place of a warm air mass, there is a **cold front** (**Figure** 9.36).

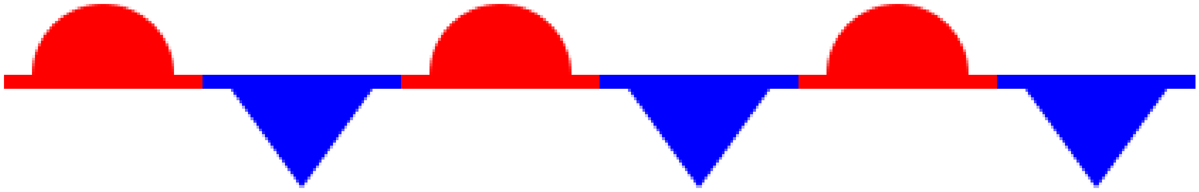


FIGURE 9.35
The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

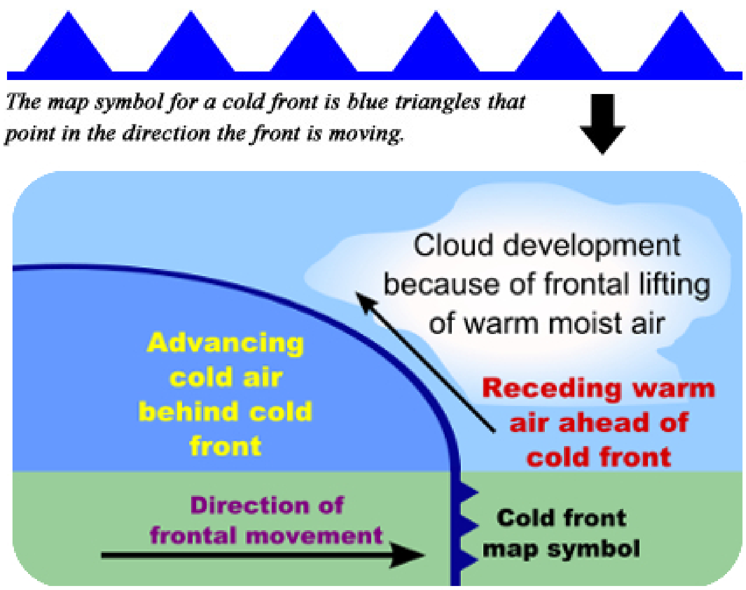


FIGURE 9.36
The cold air mass is dense, so it slides beneath the warm air mass and pushes it up.

Imagine that you are standing in one spot as a cold front approaches. Along the cold front, the denser, cold air pushes up the warm air, causing the air pressure to decrease (**Figure** 9.36). If the humidity is high enough, some types of cumulus clouds will grow. High in the atmosphere, winds blow ice crystals from the tops of these clouds to create cirrostratus and cirrus clouds. At the front, there will be a line of rain showers, snow showers, or thunderstorms with blustery winds (**Figure** 9.37). A **squall line** is a line of severe thunderstorms that forms along a cold front. Behind the front is the cold air mass. This mass is drier, so precipitation stops. The weather may be cold and clear or only partly cloudy. Winds may continue to blow into the low pressure zone at the front.

The weather at a cold front varies with the season.

- Spring and summer: the air is unstable so thunderstorms or tornadoes may form.
- Spring: if the temperature gradient is high, strong winds blow.
- Autumn: strong rains fall over a large area.
- Winter: the cold air mass is likely to have formed in the frigid arctic, so there are frigid temperatures and heavy snows.

FIGURE 9.37

A squall line.

Warm Fronts

At a **warm front**, a warm air mass slides over a cold air mass (**Figure** 9.38). When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable.

Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition from cold air to warm air takes place over a long distance, so the first signs of changing weather appear long before the front is actually over you. Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.

Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. The clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog (**Figure** 9.39).

Occluded Front

An **occluded front** usually forms around a low pressure system (**Figure** 9.40). The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again.

Coriolis effect curves the boundary where the two fronts meet towards the pole. If the air mass that arrives third is colder than either of the first two air masses, that air mass slip beneath them both. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass rides over the other air mass. This is called a warm occlusion

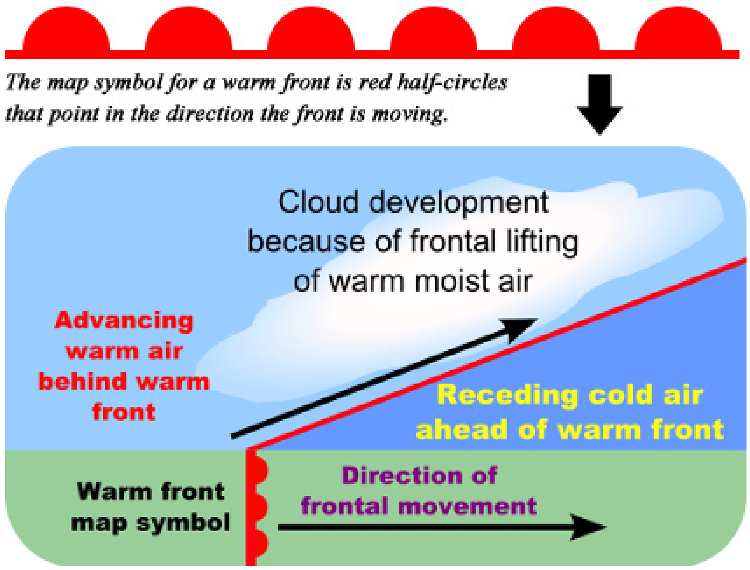


FIGURE 9.38
Warm air moves forward to take over the position of colder air.

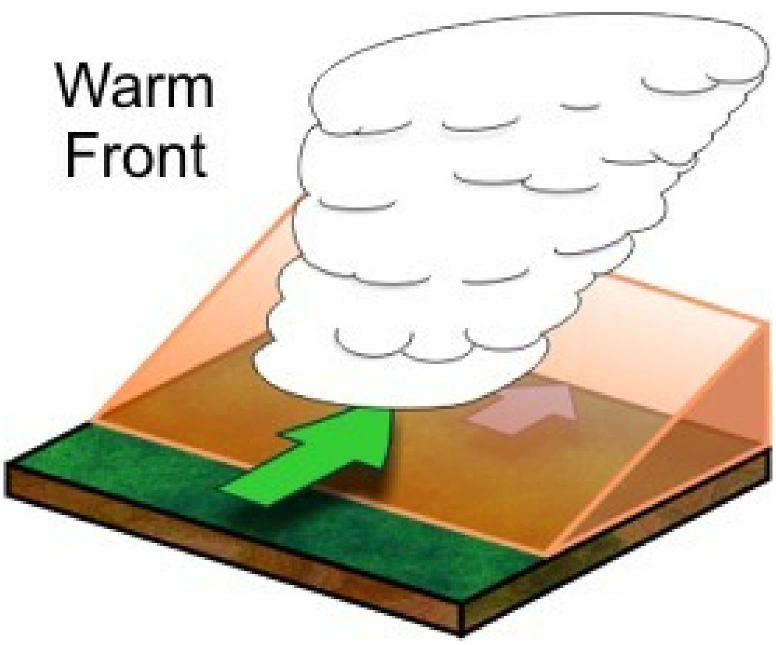


FIGURE 9.39
Cumulus clouds build at a warm front.

(**Figure** 9.41).

The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical. The Pacific Coast has frequent occluded fronts.

Vocabulary

- **cold front**: A front in which a cold air mass pushes a warm air mass upward.
- **front**: The meeting place of two air masses with different characteristics.
- **occluded front**: A front in which a cold front overtakes a warm front.

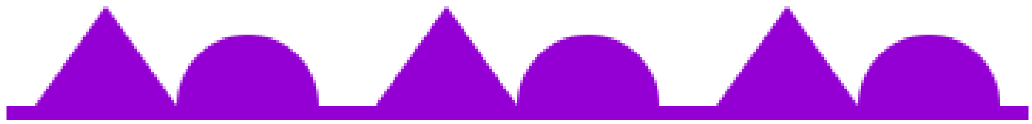


FIGURE 9.40
The map symbol for an occluded front is mixed cold front triangles and warm front domes.

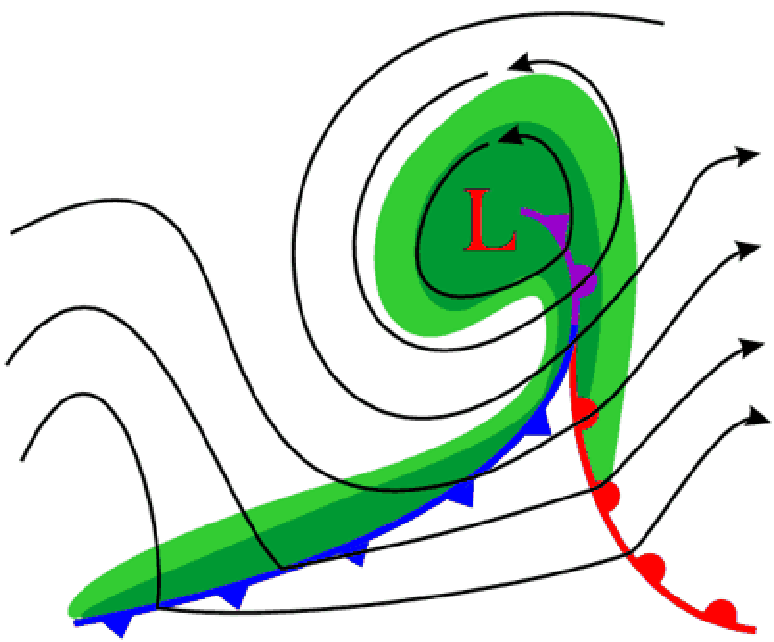


FIGURE 9.41
An occluded front with the air masses from front to rear in order as cold, warm, cold.

- **squall line**: A line of thunderstorms that forms at the edge of a cold front.
- **stationary front**: A stalled front in which the air does not move.
- **warm front**: A front in which a warm air mass replaces a cold air mass.

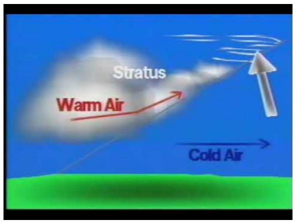
Summary

- Much of the weather occurs where at fronts where air masses meet.
- In a warm front a warm air mass slides over a cold air mass. In a cold front a cold air mass slides under a warm air mass.
- An occluded front has three air masses, cold, warm, and cold.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=vPC5i6w3yDI



MEDIA

Click image to the left for more content.

1. What is a front?
2. How does a cold front form?
3. What forms along a cold front?
4. How does a warm front form?
5. What type of clouds form at warm fronts?
6. What type of precipitation is produced from a warm front?
7. What is a stationary front?
8. What type of weather can occur at an occluded front?

Review

1. What characteristics give warm fronts and cold fronts their names?
2. How does Coriolis effect create an occluded front?
3. Describe the cloud sequence that goes along with a warm front.

9.23 Thunderstorms

- Explain how thunderstorms form, grow, and produce lightning and thunder.

What lives fast and dies young?

That describes most thunderstorms. Thunderstorms can be very intense but may last for only a matter of minutes. They're fun (and dangerous) while they're active, though.

Thunderstorms

Thunderstorms are extremely common. Worldwide there are 14 million per year — that's 40,000 per day! Most drop a lot of rain on a small area quickly, but some are severe and highly damaging.

Thunderstorm Formation

Thunderstorms form when ground temperatures are high, ordinarily in the late afternoon or early evening in spring and summer. The two figures below show two stages of thunderstorm buildup (**Figure** 9.42).

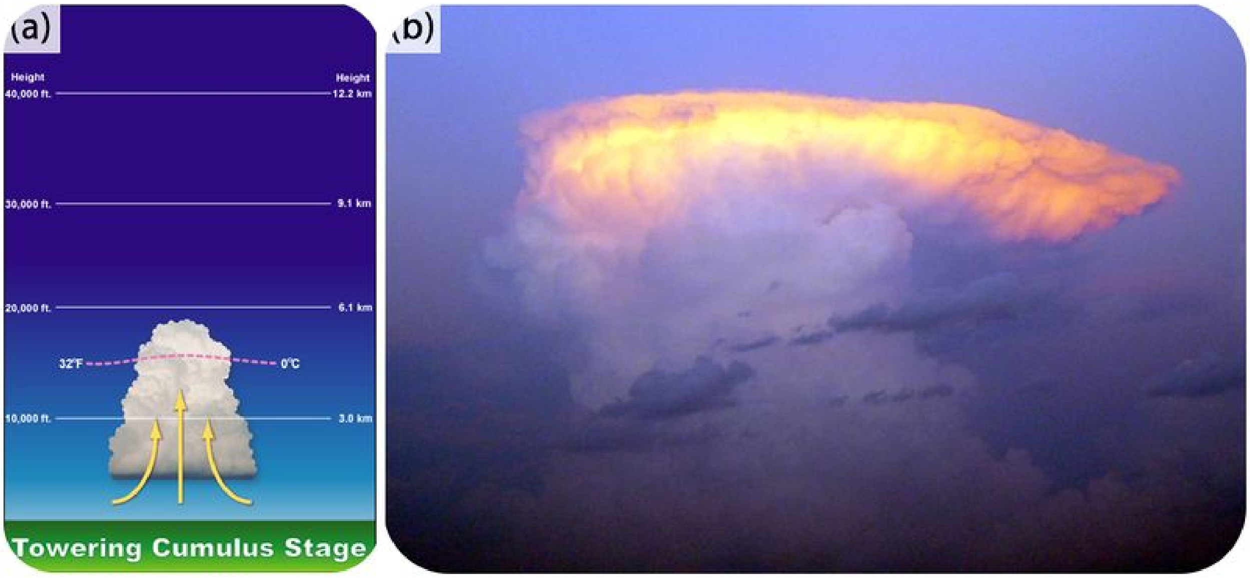


FIGURE 9.42

(a) Cumulus and cumulonimbus clouds. (b) A thunderhead.

Growth

As temperatures increase, warm, moist air rises. These updrafts first form cumulus and then cumulonimbus clouds. Winds at the top of the stratosphere blow the cloud top sideways to make the anvil shape that characterizes a cloud as a thunderhead. As water vapor condenses to form a cloud, the latent heat makes the air in the cloud warmer than the air outside the cloud. Water droplets and ice fly up through the cloud in updrafts. When these droplets get heavy enough, they fall.

This starts a downdraft, and soon there is a convection cell within the cloud. The cloud grows into a cumulonimbus giant. Eventually, the drops become large enough to fall to the ground. At this time, the thunderstorm is mature, and it produces gusty winds, lightning, heavy precipitation, and hail (**Figure** 9.43).

The End

The downdrafts cool the air at the base of the cloud, so the air is no longer warm enough to rise. As a result, convection shuts down. Without convection, water vapor does not condense, no latent heat is released, and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it begins, but other thunderstorms may start in the same area.

Severe Thunderstorms

With severe thunderstorms, the downdrafts are so intense that when they hit the ground, warm air from the ground is sent upward into the storm. The warm air gives the convection cells more energy. Rain and hail grow huge before gravity pulls them to Earth. Severe thunderstorms can last for hours and can cause a lot of damage because of high winds, flooding, intense hail, and tornadoes.

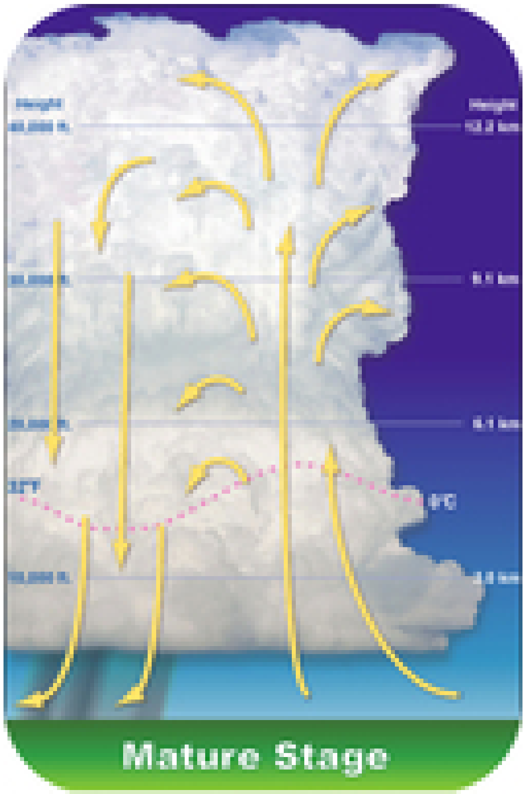


FIGURE 9.43
A mature thunderstorm with updrafts and downdrafts that reach the ground.

Squall Lines

Thunderstorms can form individually or in squall lines along a cold front. In the United States, squall lines form in spring and early summer in the Midwest, where the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada (**Figure** 9.44).

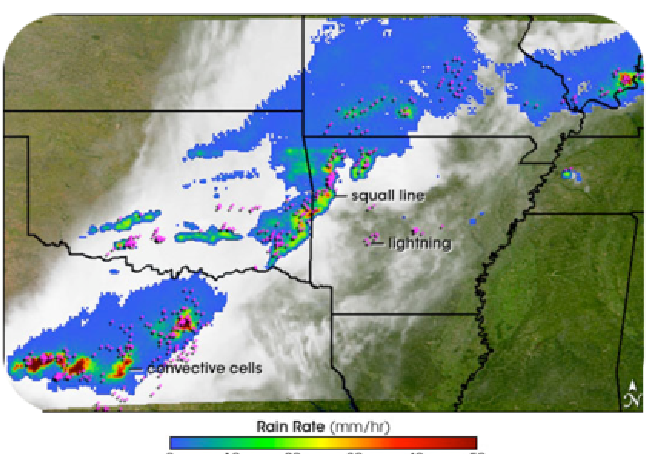


FIGURE 9.44
Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Lightning and Thunder

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result (**Figure** 9.45). The electrical discharge may be between one part of the cloud and another, two clouds, or a cloud and the ground.

FIGURE 9.45
Lightning over Pentagon City in Arlington, Virginia.

Lightning heats the air so that it expands explosively. The loud clap is **thunder**. Light waves travel so rapidly that lightning is seen instantly. Sound waves travel much more slowly, so a thunderclap may come many seconds after the lightning is spotted.

Damage

Thunderstorms kill approximately 200 people in the United States and injure about 550 Americans per year, mostly from lightning strikes. Have you heard the common misconception that lightning doesn't strike the same place twice? In fact, lightning strikes the New York City's Empire State Building about 100 times per year (**Figure** 9.46).

An online guide to severe storms from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/home.rxml.

Vocabulary

- **lightning**: A huge discharge of electricity typical of thunderstorms.
- **thunder**: The loud clap produced by lightning.
- **thunderstorm**: Storms caused by upwelling air; cumulonimbus clouds, thunder, and lightning.

Summary

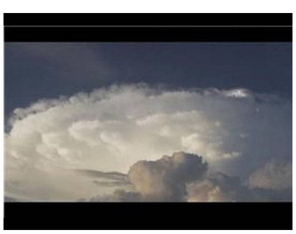
- Thunderstorms grow where ground temperatures are extremely high.

FIGURE 9.46
Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

- Convection in the cloud causes raindrops or hailstones to grow. Downdrafts ultimately end convection.
- Squall lines are long lines of thunderstorms that form along a cold front.

Practice

Use this resource to answer the questions that follow.



MEDIA
Click image to the left for more content.

1. What causes thunderstorms to develop?
2. What determines the severity of the storm?
3. What causes the air to rise?
4. What causes the air mass to cool?
5. What causes lightning and thunder?

Review

1. Why are thunderstorms so common?
2. What is the energy source that feeds a thunderstorm?
3. What causes a thunderstorm to end?

9.24 Tornadoes

- Explain how and where tornadoes form.
- Describe how the severity of tornadoes is measured and the damage they can cause.

Who killed the Wicked Witch of the East?

Dorothy's house flies up in a tornado to the magical land of Oz. When the tornado ends, the house it falls on the witch. Dorothy becomes a hero for killing the tyrannical witch, but despite that yearns for home. In the real world, tornadoes do kill, but houses don't usually fly, and wicked witches usually avoid tornadoes.

Tornadoes

Tornadoes, also called twisters, are fierce products of severe thunderstorms (**Figure** 9.47). As air in a thunderstorm rises, the surrounding air races in to fill the gap. This forms a tornado, a funnel-shaped, whirling column of air extending downward from a cumulonimbus cloud.

A tornado lasts from a few seconds to several hours. The average wind speed is about 177 kph (110 mph), but some winds are much faster. A tornado travels over the ground at about 45 km per hour (28 miles per hour) and goes about 25 km (16 miles) before losing energy and disappearing (**Figure** 9.48).

FIGURE 9.47
The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

FIGURE 9.48
This tornado struck Seymour, Texas, in 1979.

Damage

An individual tornado strikes a small area, but it can destroy everything in its path. Most injuries and deaths from tornadoes are caused by flying debris (**Figure** 9.49). In the United States an average of 90 people are killed by tornadoes each year. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes.

Location

Tornadoes form at the front of severe thunderstorms. Lines of these thunderstorms form in the spring where where maritime tropical (mT) and continental polar (cP) air masses meet. Although there is an average of 770 tornadoes annually, the number of tornadoes each year varies greatly (**Figure** 9.50).

April 2011

In late April 2011, severe thunderstorms pictured in the satellite image spawned the deadliest set of tornadoes in more than 25 years. In addition to the meeting of cP and mT mentioned above, the jet stream was blowing strongly

FIGURE 9.49
Tornado damage at Ringgold, Georgia in April 2011.

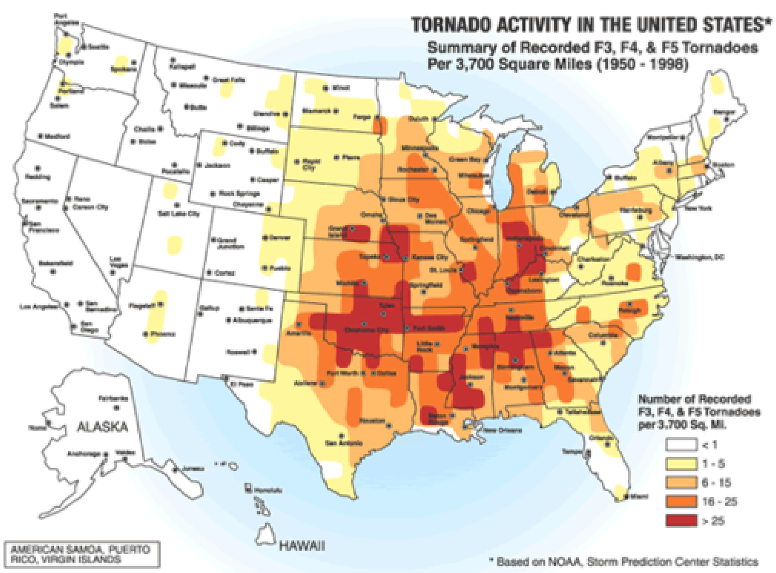


FIGURE 9.50
The frequency of F3, F4, and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska, and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur.

in from the west. The result was more than 150 tornadoes reported throughout the day (**Figure** 9.51).

The entire region was alerted to the possibility of tornadoes in those late April days. But meteorologists can only predict tornado danger over a very wide region. No one can tell exactly where and when a tornado will touch down. Once a tornado is sighted on radar, its path is predicted and a warning is issued to people in that area. The exact path is unknown because tornado movement is not very predictable.

Tornado catchers capture footage inside a tornado on this National Geographic video: http://ngm.nationalgeographic.com/ngm/0506/feature6/multimedia.html.

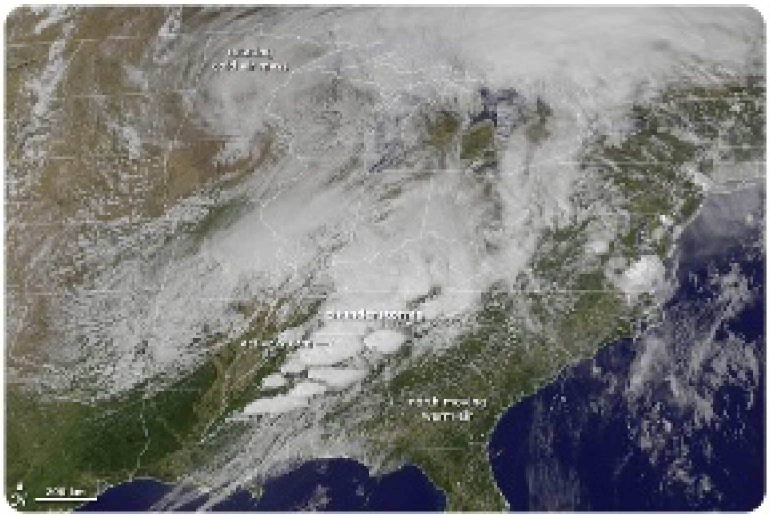


FIGURE 9.51
April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. Warm moist air blowing north from the Atlantic Ocean and Gulf of Mexico is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

Fujita Scale

The intensity of tornadoes is measured on the Fujita Scale (see **Table** 9.3), which assigns a value based on wind speed and damage.

TABLE 9.3: The 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	254-33	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

Vocabulary

- **tornado**: Violently rotating funnel cloud that grows downward from a cumulonimbus cloud.

Summary

- A tornado is a whirling funnel of air extending down from a cumulonimbus cloud.
- The Fujita scale measures tornado intensity based on wind speed and damage.
- Tornadoes can only be predicted over a wide region.

Practice

4. What is a wind shear?
5. What causes a tornado to touch the ground?
6. When do tornadoes usually occur?

Review

1. What causes the tornadoes of Tornado Alley?
2. How does the Fujita scale resemble the scales for assessing earthquake intensity? Which does it most resemble?
3. What circumstances led to the intensity of tornado activity in April 2011?

9.25 Mid-Latitude Cyclones

- Describe mid-latitude cyclones and explain how and where they form.

Where were you on Halloween 2011?

If you live along the northeastern United States you may remember Halloween being postponed in 2011. A large and atypically early nor'easter dropped as much as 32 inches of snow, caused over three million people to lose power, and brought on 39 deaths. Like hurricanes, nor'easters are cyclones, but they form much further north.

Mid-Latitude Cyclones

Cyclones can be the most intense storms on Earth. A **cyclone** is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center. The swirling air rises and cools, creating clouds and precipitation.

Mid-latitude cyclones form at the polar front when the temperature difference between two air masses is large. These air masses blow past each other in opposite directions. Coriolis effect deflects winds to the right in the Northern Hemisphere, causing the winds to strike the polar front at an angle. Warm and cold fronts form next to each other. Most winter storms in the middle latitudes, including most of the United States and Europe, are caused by mid-latitude cyclones (**Figure** 9.52).

The warm air at the cold front rises and creates a low pressure cell. Winds rush into the low pressure and create a rising column of air. The air twists, rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Since the rising air is moist, rain or snow falls.

Mid-latitude cyclones form in winter in the mid-latitudes and move eastward with the westerly winds. These two- to five-day storms can reach 1,000 to 2,500 km (625 to 1,600 miles) in diameter and produce winds up to 125 km (75 miles) per hour.

Nor'easters

Mid-latitude cyclones are especially fierce in the mid-Atlantic and New England states, where they are called **nor'easters** because they come from the northeast. About 30 nor'easters strike the region each year. (**Figure** 9.53).

An online guide to mid-latitude cyclones from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cyc/home.rxml.

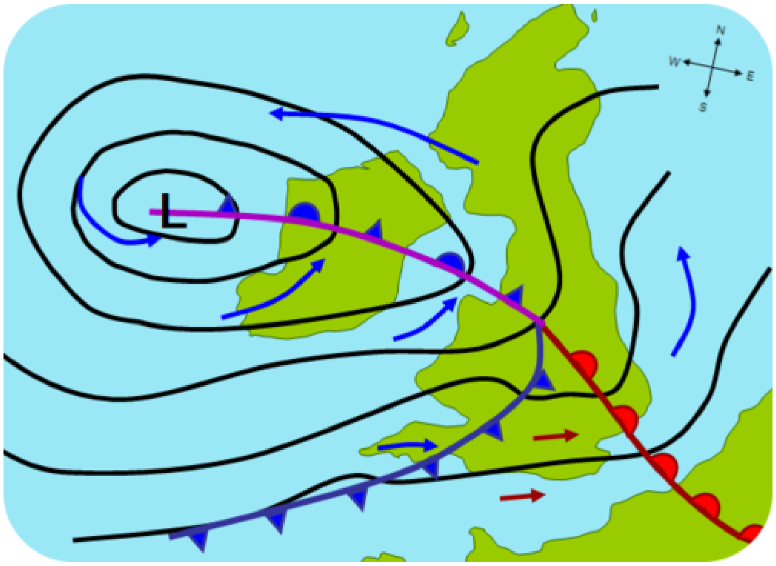


FIGURE 9.52
A hypothetical mid-latitude cyclone affecting the United Kingdom. The arrows point the wind direction and its relative temperature; L is the low pressure area. Notice the warm, cold, and occluded fronts.

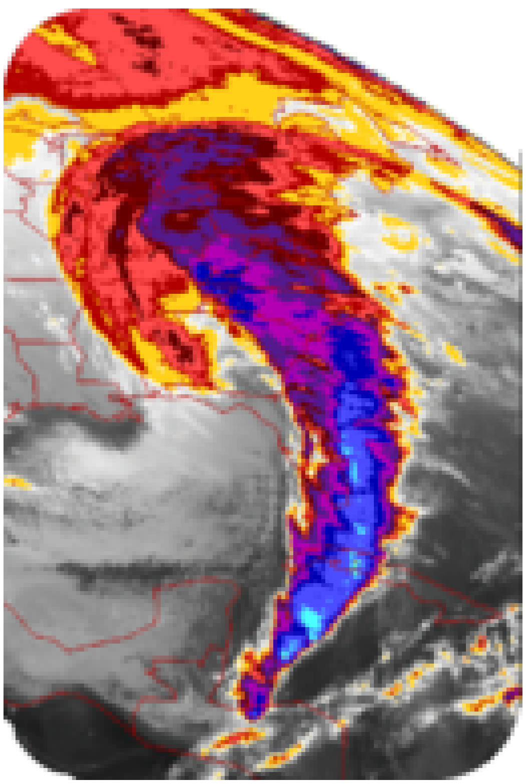


FIGURE 9.53
The 1993 "Storm of the Century" was a nor'easter that covered the entire eastern seaboard of the United States.

Vocabulary

- **cyclone**: Wind system that rotates around a low pressure center.
- **mid-latitude cyclone**: A cyclone that forms in the middle latitudes at the polar front.
- **nor'easter**: Mid-latitude cyclones that strike the northeastern United States.

Summary

- A cyclone is a system of winds rotating counter-clockwise (in the Northern Hemisphere) around an area of low pressure.
- A mid-latitude cyclone forms at the polar front when the temperature difference between air masses is very large.
- Nor'easters are mid-latitude cyclones that come from the northeast.

Practice

Use this resource to answer the questions that follow.

http://www.slideshare.net/lschmidt1170/midlatitude-cyclones

MEDIA

Click image to the left for more content.

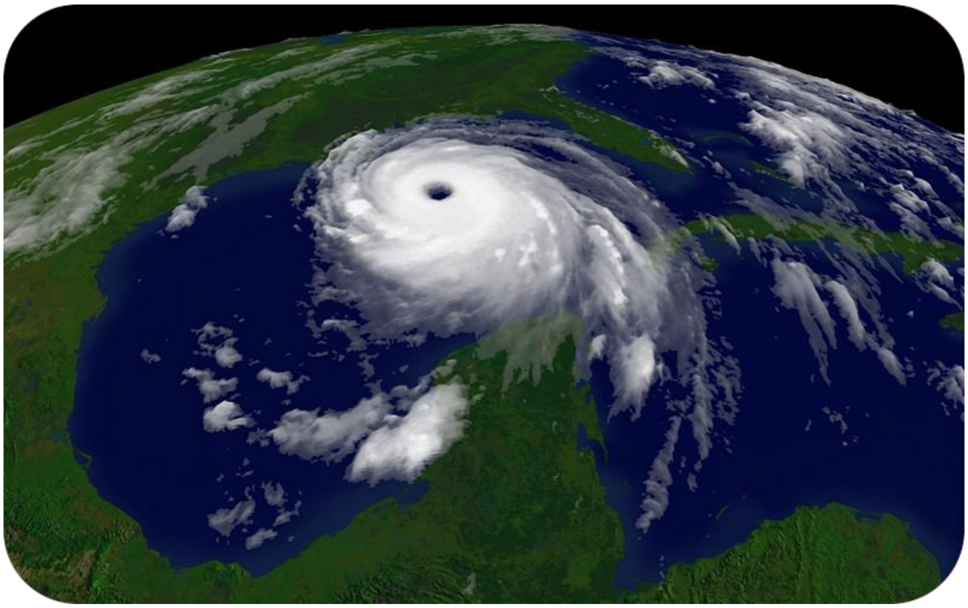
1. What is a midlatitude cyclone?
2. What is at the center of a midlatitude cyclone?
3. What does a mature midlatitude cyclone have?
4. Where is the heaviest precipication located in a midlatitude cyclone?
5. What does wind direction tell you?
6. What is a meteogram?

Review

1. Describe the circumstances that result in a nor'easter.
2. What is a cyclone?
3. What are the motions of air in a mid-latitude cyclone?

9.26 Hurricanes

- Explain how and where hurricanes form.
- Describe how hurricanes are measured and the damage that they can cause.



Why did New Orleans Mayor Ray Nagin call Hurricane Katrina "...a storm that most of us have long feared," as it approached New Orleans?

Hurricane Katrina nears its peak strength as it travels across the Gulf of Mexico. Hurricane Katrina was the most deadly and the most costly of the hurricanes that struck in the record-breaking 2005 season.

Hurricanes

Hurricanes — called typhoons in the Pacific — are also cyclones. They are cyclones that form in the tropics and so they are also called tropical cyclones. By any name, they are the most damaging storms on Earth.

Formation

Hurricanes arise in the tropical latitudes (between 10^o and 25^oN) in summer and autumn when sea surface temperature are 28^oC (82^oF) or higher. The warm seas create a large humid air mass. The warm air rises and forms a low pressure cell, known as a **tropical depression**. Thunderstorms materialize around the tropical depression.

If the temperature reaches or exceeds 28^oC (82^oF), the air begins to rotate around the low pressure (counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). As the air rises, water vapor condenses, releasing energy from latent heat. If wind shear is low, the storm builds into a hurricane within two to three days.

Hurricanes are huge and produce high winds. The exception is the relatively calm eye of the storm, where air is rising upward. Rainfall can be as high as 2.5 cm (1") per hour, resulting in about 20 billion metric tons of water released daily in a hurricane. The release of latent heat generates enormous amounts of energy, nearly the total annual electrical power consumption of the United States from one storm. Hurricanes can also generate tornadoes.

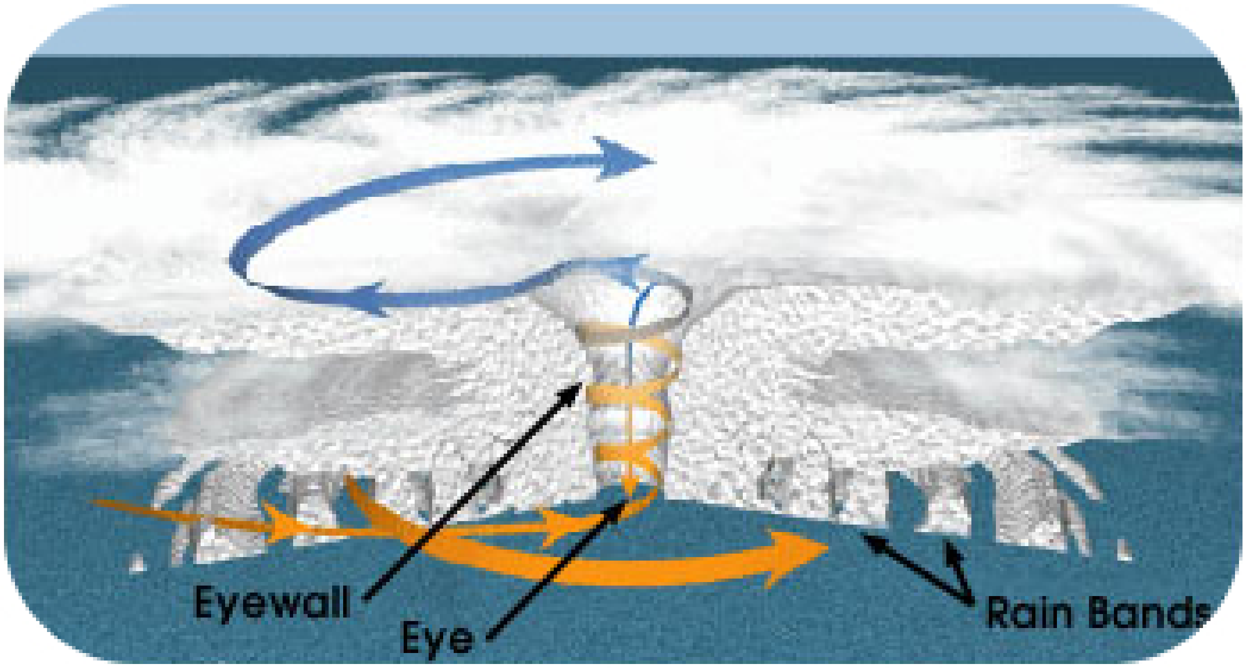


FIGURE 9.54

A cross-sectional view of a hurricane.

Hurricanes move with the prevailing winds. In the Northern Hemisphere, they originate in the trade winds and move to the west. When they reach the latitude of the westerlies, they switch direction and travel toward the north or northeast. Hurricanes may cover 800 km (500 miles) in one day.

Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** 9.4).

TABLE 9.4: Saffir-Simpson Hurricane Scale

Category	Kph	Mph	Estimated 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 9.4: (continued)

Category	Kph	Mph	Estimated 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

Damage

Damage from hurricanes comes from the high winds, rainfall, and storm surge. Storm surge occurs as the storm's low pressure center comes onto land, causing the sea level to rise unusually high. A storm surge is often made worse by the hurricane's high winds blowing seawater across the ocean onto the shoreline. Flooding can be devastating, especially along low-lying coastlines such as the Atlantic and Gulf Coasts. Hurricane Camille in 1969 had a 7.3 m (24 foot) storm surge that traveled 125 miles (200 km) inland.

The End

Hurricanes typically last for 5 to 10 days. The winds push them to the northwest and then to the northeast. Eventually a hurricane will end up over cooler water or land. At that time the hurricane's latent heat source shut downs and the storm weakens. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

There are about 100 hurricanes around the world each year, plus many smaller tropical storms and tropical depressions. As people develop coastal regions, property damage from storms continues to rise. However, scientists are becoming better at predicting the paths of these storms and fatalities are decreasing. There is, however, one major exception to the previous statement: Hurricane Katrina.

Hurricane Katrina

The 2005 Atlantic hurricane season was the longest, costliest, and deadliest hurricane season so far. Total damage from all the storms together was estimated at more than $128 billion, with more than 2,280 deaths. Hurricane Katrina was both the most destructive hurricane and the most costly (**Figure** 9.55).

News about Hurricane Katrina from the New Orleans Times-Picayune: http://www.nola.com/katrina/graphics/flashflood.swf.

An animation of a radar image of Hurricane Katrina making landfall is seen here: http://upload.wikimedia.org/wikipedia/commons/9/97/Hurricane_Katrina_LA_landfall_radar.gif.

NASA's short video, "In Katrina's Wake": http://www.youtube.com/watch?v=HZjqvqaLltI.

Hurricanes are explored in a set of National Geographic videos found at National Geographic Video: http://video.nationalgeographic.com/video/environment/environment-natural-disasters/hurricanes. At this link, watch the following videos:

- "Hurricanes 101" is an introduction to the topic.

FIGURE 9.55
Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

- "How Katrina Formed" looks at the history of Hurricane Katrina as it formed and passed through the Gulf coast.
- Follow that up with "Doomed New Orleans," which explores how the devastation to the city is a man-made disaster.
- "The Hurricane Ike of 1900" looks at what happened in the days when there was little warning before a hurricane hit a coastal city.

Lots of information about hurricanes is found in this online guide from the University of Illinois: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hurr/home.rxml.

Vocabulary

- **hurricane**: Cyclone that forms in the tropics and spins around a low-pressure center.
- **tropical depression**: A low pressure cell that rises in the tropics; thunderstorms arise here.

Summary

- Hurricanes are actually tropical cyclones because they originate in the tropical latitudes.
- The damage hurricanes cause is due largely to storm surge, but high wind speeds and rain also cause damage.
- Hurricane Katrina was so damaging because the levees that protected New Orleans broke.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What are hurricanes?
2. Where do most hurricanes begin to form?
3. What three components are required for a hurricane to form?
4. What direction do hurricanes spin?
5. What is the eye?
6. What are typhoons and cyclones?

Review

1. What is the difference between a hurricane and a mid-latitude cyclone?
2. How does a hurricane form? Where does the storm get its energy?
3. Under what circumstances does a hurricane die?

9.27 Blizzards

- Describe the conditions that define blizzards and explain how blizzards form.

What would cause a snow day in Greece?

Sometimes a snowstorm strikes a location that's usually snow-free. When that happens, for some reason air masses are not behaving normally. Usually an atypical snow is fun for the people who live there, especially since everything usually gets shut down — including schools!

Blizzards

A **blizzard** is distinguished by certain conditions:

- Temperatures below –7^{o}C (20^{o}F); –12^{o}C (10^{o}F) for a severe blizzard.
- Winds greater than 56 kmh (35 mph); 72 kmh (45 mph) for a severe blizzard.
- Snow so heavy that visibility is 2/5 km (1/4 mile) or less for at least three hours; near zero visibility for a severe blizzard.

Formation

Blizzards happen across the middle latitudes and toward the poles, usually as part of a mid-latitude cyclone. Blizzards are most common in winter, when the jet stream has traveled south and a cold, northern air mass comes into contact with a warmer, semitropical air mass (**Figure** 9.57). The very strong winds develop because of the pressure gradient between the low-pressure storm and the higher pressure west of the storm. Snow produced by the storm gets caught in the winds and blows nearly horizontally. Blizzards can also produce sleet or freezing rain.

FIGURE 9.56
A blizzard obscures the Capitol in Washington, DC.

FIGURE 9.57
Blizzard snows blanket the East Coast of the United States in February 2010.

Lake-Effect Snow

In winter, a continental polar air mass travels down from Canada. As the frigid air travels across one of the Great Lakes, it warms and absorbs moisture. When the air mass reaches the leeward side of the lake, it is very unstable and it drops tremendous amounts of snow. This **lake-effect snow** falls on the snowiest metropolitan areas in the United States: Buffalo and Rochester, New York (**Figure** 9.58).

Vocabulary

- **blizzard**: A large snow storm with high winds.
- **lake-effect snow**: Extreme snowfall caused by the evaporation of relatively warm, moist air into a cold front that then drops its snow on the leeward side of the lake.

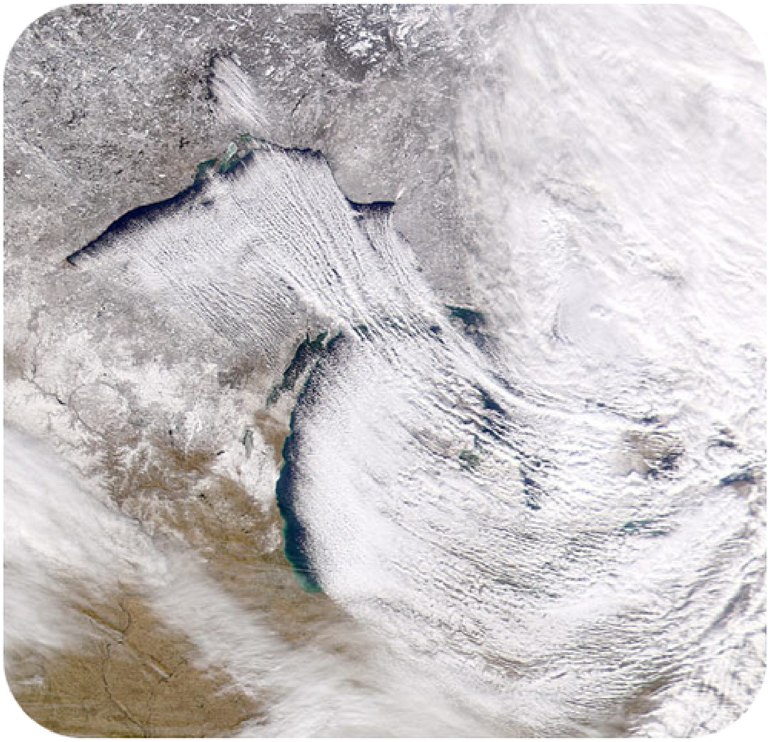


FIGURE 9.58
Frigid air travels across the Great Lakes and dumps lake-effect snow on the leeward side.

Summary

- Blizzards are often part of a mid-latitude cyclone where the jet stream brings cold air into contact with warm moist air.
- The difference in pressure between the air masses brings about strong winds.
- Cold polar air absorbs moisture as it travels over the Great Lakes and then dumps it as snow downwind to create lake-effect snow.

Practice

Use this resource to answer the questions that follow.

http://www.history.com/videos/science-of-a-blizzard#science-of-a-blizzard

MEDIA
Click image to the left for more content.

1. What is a blizzard?
2. What is the wind speed of a blizzard?
3. What causes a whiteout?
4. When do blizzards usually occur?
5. Where are blizzards most common?

6. What was the deadliest blizzard in history?

Review

1. Under what circumstances does a blizzard form?
2. What causes lake-effect snow?
3. What is a blizzard?

9.28 Heat Waves and Droughts

- Describe the causes of heat waves and droughts.

Why are these children playing in a fire hydrant?

The deadliest weather phenomena are not blizzards or hurricanes but heat waves. People who are poor or who live in areas where the weather is usually not hot may not have air conditioning. Children have a way of finding a solution to a problem that usually involves fun.

Heat Waves

A **heat wave** is different depending on its location. According to the World Meteorological Organization a region is in a heat wave if it has more than five consecutive days of temperatures that are more than 9^oF (5^oC)above average.

Heat waves have increased in frequency and duration in recent years. The summer 2011 North American heat wave brought record temperatures across the Midwestern and Eastern United States. Many states and localities broke records for temperatures and for most days above 100^oF.

Causes

A high pressure cell sitting over a region with no movement is the likely cause of a heat wave.

What do you think caused the heat wave in the image below (**Figure** 9.59)? A high pressure zone kept the jet stream further north than normal for August.

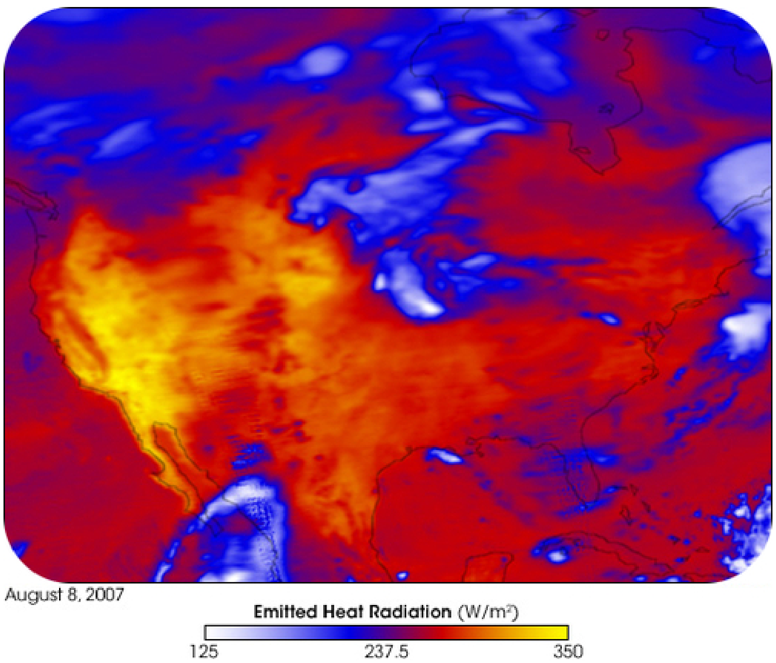


FIGURE 9.59
A heat wave over the United States as indicated by heat radiated from the ground. The bright yellow areas are the hottest and the blue and white are coolest.

Droughts

Droughts also depend on what is normal for a region. When a region gets significantly less precipitation than normal for an extended period of time, it is in drought. The Southern United States is experiencing an ongoing and prolonged drought.

Drought has many consequences. When soil loses moisture it may blow away, as happened during the Dust Bowl in the United States in the 1930s. Forests may be lost, dust storms may become common, and wildlife are disturbed. Wildfires become much more common during times of drought.

Vocabulary

- **drought**: A long period of lower than normal rainfall for a particular region.
- **heat wave**: A period of prolonged excessively hot weather for a particular region.

Summary

- It's hard to define a heat wave or a drought because these phenomena depend are deviations from normal conditions in a region.
- A heat wave is caused when a warm high-pressure cell sits over a region.
- Drought may have extremely severe consequences depending on its duration and intensity.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=6rdLu7wiZOE

MEDIA

Click image to the left for more content.

1. What will happen if the world's temperature increases by 3 degrees?
2. What will happen in Europe and the Mediterranean?
3. What will become the norm?
4. What happened in the summer of 2003?
5. How many people died in Europe that summer?

http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/droughts/

6. What are the signs of a drought?
7. What causes a drought occur?
8. What type of pressure system is associated with a drought?
9. What adds to the problem?
10. What can long-term droughts lead to?
11. How long did the drought last in the 1930s?

Review

1. How is a heat wave defined?
2. How is a drought defined?
3. How does the position of the jet stream cause a heat wave?

9.29 Collecting Weather Data

- Describe how scientists collect information about weather.

Can you forecast your health?

You can use a thermometer to better understand your health just like a meteorologist uses one to better understand the weather. A thermometer will help you forecast your health just as it will help to forecast the weather. Other tools, like barometers, also help with weather forecasting.

Collecting Weather Data

To make a weather forecast, the conditions of the atmosphere must be known for that location and for the surrounding area. Temperature, air pressure, and other characteristics of the atmosphere must be measured and the data collected.

Thermometer

Thermometers measure temperature. In an old-style mercury thermometer, mercury is placed in a long, very narrow tube with a bulb. Because mercury is temperature sensitive, it expands when temperatures are high and contracts when they are low. A scale on the outside of the thermometer matches up with the air temperature.

Some modern thermometers use a coiled strip composed of two kinds of metal, each of which conducts heat differently. As the temperature rises and falls, the coil unfolds or curls up tighter. Other modern thermometers measure infrared radiation or electrical resistance. Modern thermometers usually produce digital data that can be fed directly into a computer.

Barometer

Meteorologists use **barometers** to measure air pressure. A barometer may contain water, air, or mercury, but like thermometers, barometers are now mostly digital.

A change in barometric pressure indicates that a change in weather is coming. If air pressure rises, a high pressure cell is on the way and clear skies can be expected. If pressure falls, a low pressure cell is coming and will likely bring storm clouds. Barometric pressure data over a larger area can be used to identify pressure systems, fronts, and other weather systems.

Weather Stations

Weather stations contain some type of thermometer and barometer. Other instruments measure different characteristics of the atmosphere, such as wind speed, wind direction, humidity, and amount of precipitation. These instruments are placed in various locations so that they can check the atmospheric characteristics of that location (**Figure** 9.60). Weather stations are located on land, the surface of the sea, and in orbit all around the world.

FIGURE 9.60

A land-based weather station.

According to the World Meteorological Organization, weather information is collected from 15 satellites, 100 stationary buoys, 600 drifting buoys, 3,000 aircraft, 7,300 ships, and some 10,000 land-based stations.

Radiosondes

Radiosondes measure atmospheric characteristics, such as temperature, pressure, and humidity as they move through the air. Radiosondes in flight can be tracked to obtain wind speed and direction. Radiosondes use a radio to communicate the data they collect to a computer. Radiosondes are launched from about 800 sites around the globe twice daily to provide a profile of the atmosphere. Radiosondes can be dropped from a balloon or airplane to make measurements as they fall. This is done to monitor storms, for example, since they are dangerous places for airplanes to fly.

Radar

Radar stands for Radio Detection and Ranging (**Figure** 9.61). A transmitter sends out radio waves that bounce off the nearest object and then return to a receiver. Weather radar can sense many characteristics of precipitation: its location, motion, intensity, and the likelihood of future precipitation. Doppler radar can also track how fast the precipitation falls. Radar can outline the structure of a storm and can be used to estimate its possible effects.

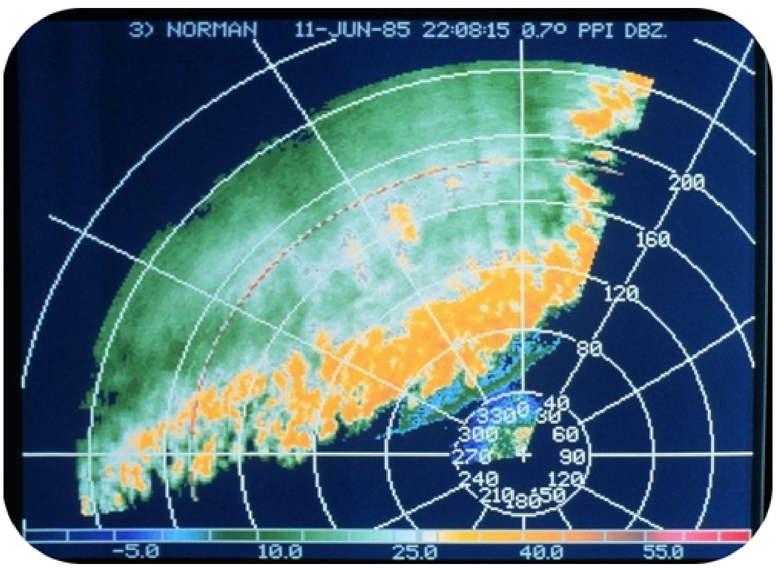


FIGURE 9.61
Radar view of a line of thunderstorms.

Satellites

Weather satellites have been increasingly important sources of weather data since the first one was launched in 1952. Weather satellites are the best way to monitor large-scale systems, such as storms. Satellites are able to record long-term changes, such as the amount of ice cover over the Arctic Ocean in September each year.

Weather satellites may observe all energy from all wavelengths in the electromagnetic spectrum. Visible light images record storms, clouds, fires, and smog. Infrared images record clouds, water and land temperatures, and features of the ocean, such as ocean currents (**Figure** 9.62).

An online guide to weather forecasting from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fcst/home.rxml.

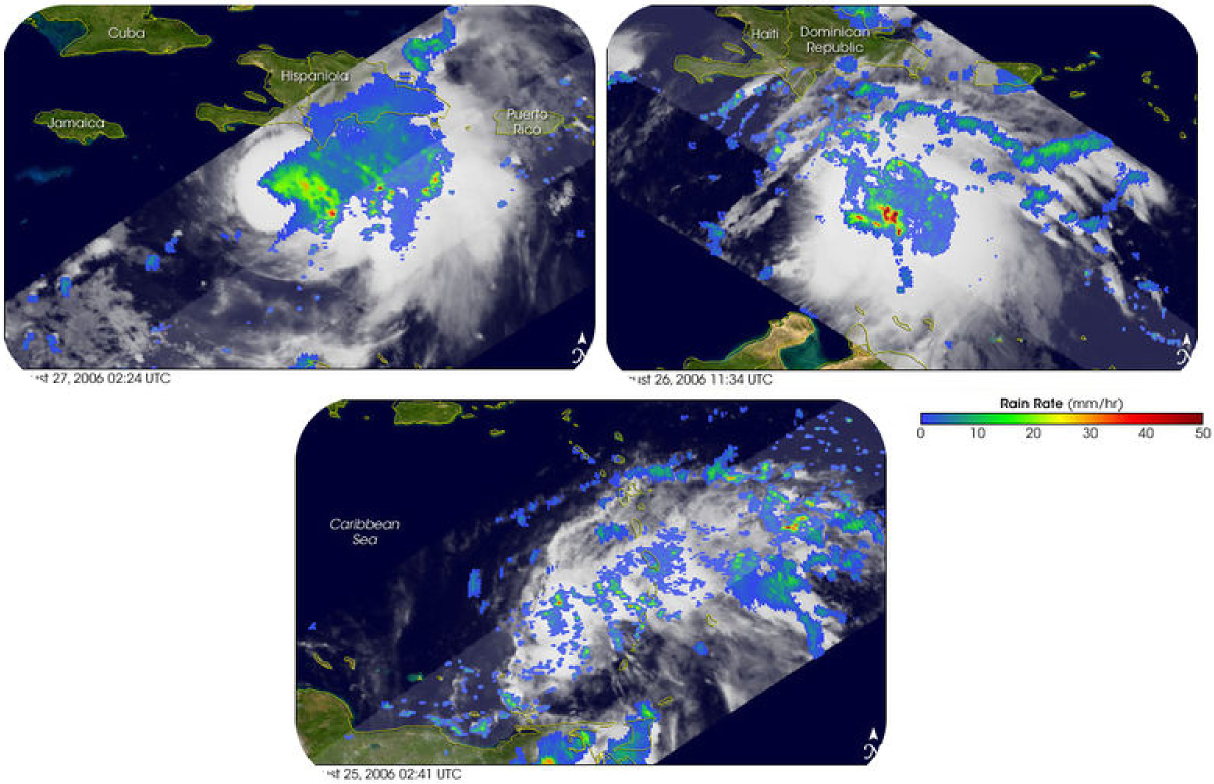


FIGURE 9.62

Infrared data superimposed on a satellite image shows rainfall patterns in Hurricane Ernesto in 2006.

Vocabulary

- **barometer**: An instrument for measuring atmospheric pressure.
- **radar**: Radio detection and ranging device that emits radio waves and receives them after they bounce on the nearest surface. This creates an image of storms and other nearby objects.
- **radiosonde**: A group of instruments that measure the characteristics of the atmosphere — temperature, pressure, humidity, etc. — as they move through the air.
- **thermometer**: A device that measures temperature.

Summary

- Various instruments measure weather conditions: thermometers measure air temperature, and barometers measure air pressure.
- Satellites monitor weather and also help with understanding long-term changes in climate.
- Radar is used to monitor precipitation.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=RTkPlhc3k-0

MEDIA

Click image to the left for more content.

1. What is contemporary weather forecasting based upon?
2. What gathers the data?
3. What do radisonde balloons do?
4. What data do satellites collect?
5. What data is collected by radar?
6. List other ways weather data is collected.

Review

1. What can a barometer tell you about the coming weather?
2. Weather prediction is now much better than it was 30 years ago. Can you figure out why?
3. Since there are weather satellites, why do you think weather forecasters still use radiosondes?

9.30 Predicting Weather

- Explain how meteorologists forecast the weather.

Does a picnic bring rain?

Weather forecasts are better than they ever have been. According to the World Meteorological Organization (WMO), a 5-day weather forecast today is as reliable as a 2-day forecast was 20 years ago. Now there's no excuse to be rained out on a picnic!

Numerical Weather Prediction

The most accurate weather forecasts are made by advanced computers, with analysis and interpretation added by experienced meteorologists. These computers have up-to-date mathematical models that can use much more data and make many more calculations than would ever be possible by scientists working with just maps and calculators. Meteorologists can use these results to give much more accurate weather forecasts and climate predictions.

In Numerical Weather Prediction (NWP), atmospheric data from many sources are plugged into supercomputers running complex mathematical models (**Figure** 9.63). The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects weather further into the future. It then uses these results to project the weather still further into the future, as far as the meteorologists want to go. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right.

Weather prediction is extremely valuable for reducing property damage and even fatalities. If the proposed track of a hurricane can be predicted, people can try to secure their property and then evacuate (**Figure** 9.64).

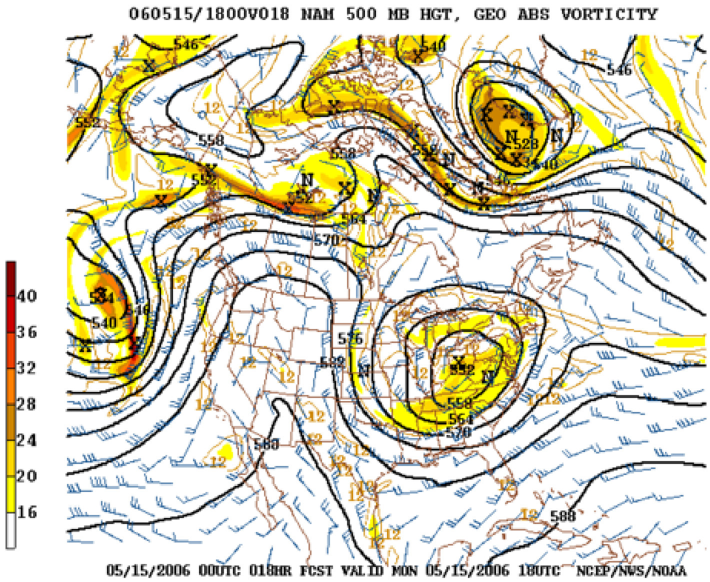


FIGURE 9.63
A weather forecast using numerical weather prediction.

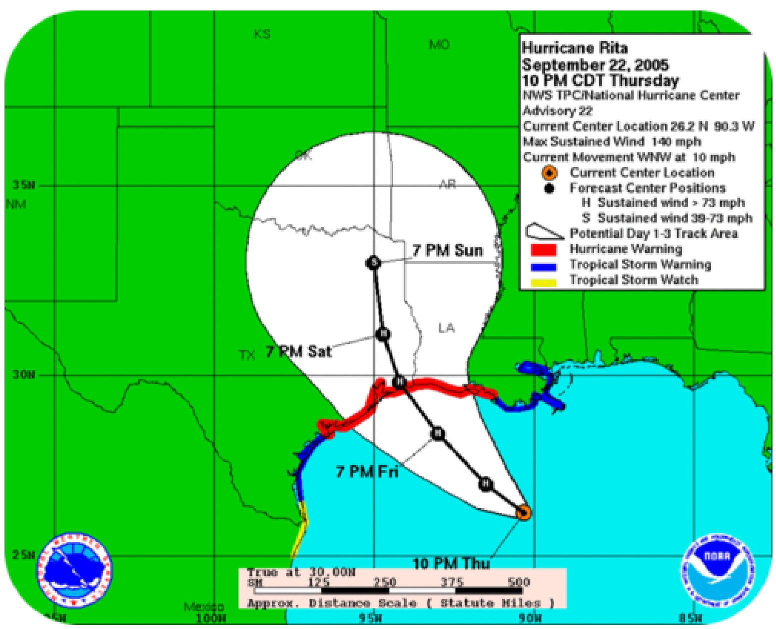


FIGURE 9.64
By predicting Hurricane Rita's path, it is likely that lives were saved.

Summary

- Meteorologists use computers to crank data through mathematical models to forecast the weather.
- Numerical weather prediction calculates what will happen to conditions horizontally and vertically over an area.
- Weather forecasts can go further into the future than ever.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=dqpFU5SRPgY

MEDIA

Click image to the left for more content.

1. Why is weather difficult to predict?
2. What is the afternoon constellation? What does it do?
3. What are the basic shapes of clouds?
4. What is fog?
5. Why is it important to study clouds?
6. What will Cloudsat do? Why is this an improvement?

Review

1. What is numerical weather prediction?
2. Even with numerical weather prediction, meteorologists have a difficult time predicting the path of a hurricane more than a day or two into the future. Why?
3. One popular online weather prediction site goes 10 days out and another goes 15 days out. Why the discrepancy?

9.31 Weather Maps

- Describe the information depicted on weather maps.
- Analyze weather maps.

What can a weather map tell you about the weather?

A lot! A weather map indicates all sorts of things to let you know the forecast. It also may have some cute graphics associated with it.

Weather Maps

Weather maps simply and graphically depict meteorological conditions in the atmosphere. Weather maps may display only one feature of the atmosphere or multiple features. They can depict information from computer models or from human observations.

On a weather map, important meteorological conditions are plotted for each weather station. Meteorologists use many different symbols as a quick and easy way to display information on the map (**Figure** 9.65).

Once conditions have been plotted, points of equal value can be connected by isolines. Weather maps can have many types of connecting lines. For example:

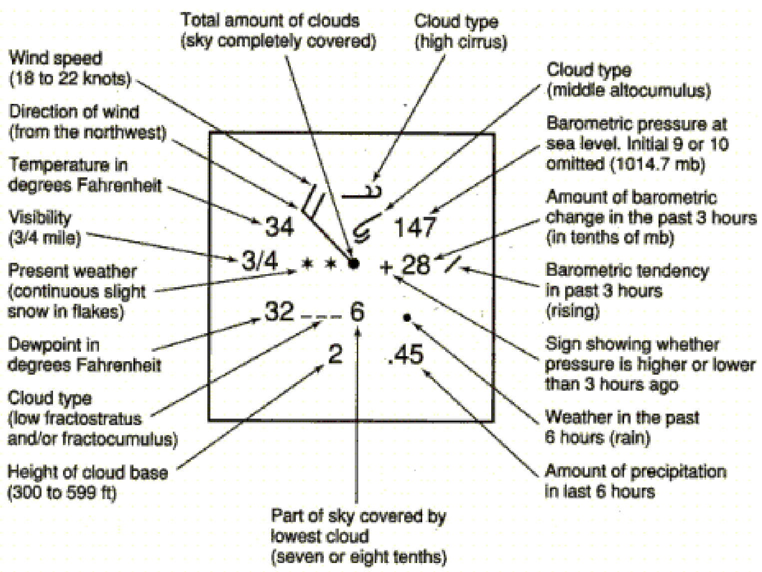


FIGURE 9.65

Explanation of some symbols that may appear on a weather map.

- Lines of equal temperature are called **isotherms**. Isotherms show temperature gradients and can indicate the location of a front. In terms of precipitation, what does the 0^oC (32^oF) isotherm show?

An animation on how to contour isotherms is seen here: Contouring isotherms https://courseware.e-education.psu.edu/public/meteo/meteo101demo/Examples/Shockwave/contouring0203.dcr.

- **Isobars** are lines of equal average air pressure at sea level (**Figure** 9.66). Closed isobars represent the locations of high and low pressure cells.

- **Isotachs** are lines of constant wind speed. Where the minimum values occur high in the atmosphere, tropical cyclones may develop. The highest wind speeds can be used to locate the jet stream.

Surface weather analysis maps are weather maps that only show conditions on the ground (**Figure** 9.67).

An online guide about to how to read weather maps from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/maps/home.rxml.

More about remote sensing of weather is discussed in this online guide: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/rs/home.rxml.

Vocabulary

- **isobars**: Lines connecting locations that have equal air pressure.
- **isotachs**: Lines connecting locations that have equal wind speed.
- **isotherms**: Lines connecting locations that have equal temperatures.
- **weather map**: A map showing weather conditions over a wide area at a given time.

Summary

- Weather maps graphically depict weather conditions.

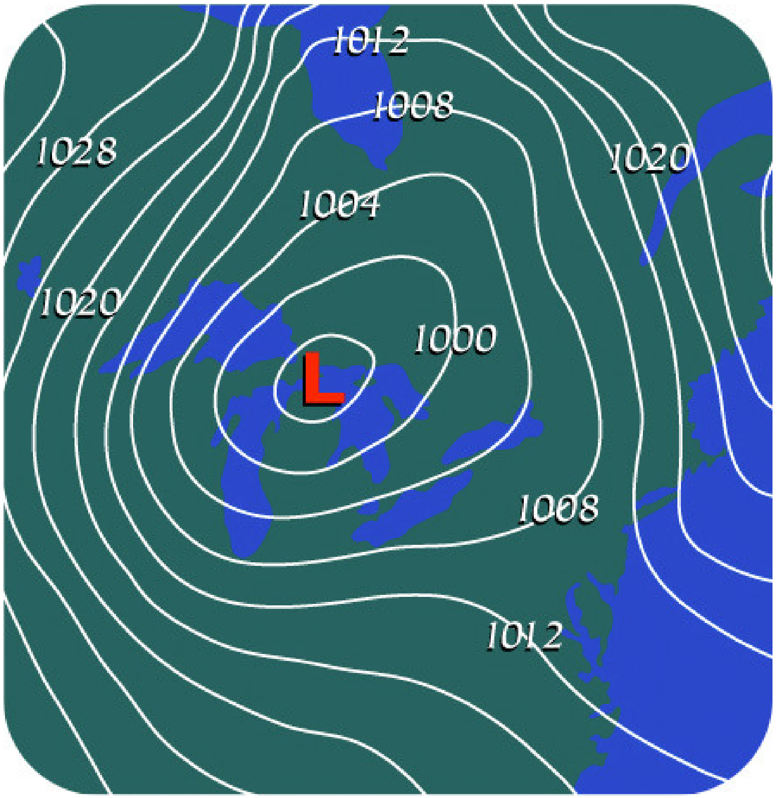


FIGURE 9.66
Isobars can be used to visualize high pressure (H) and low pressure (L) cells.

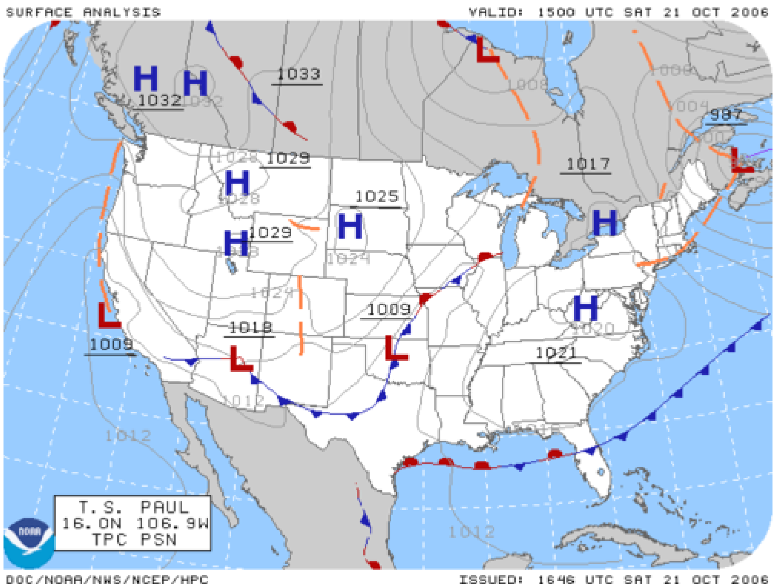


FIGURE 9.67
Surface analysis maps may show sea level mean pressure, temperature, and amount of cloud cover.

- Isotherms are lines of constant temperature; isobars are lines of constant pressure; isotachs are lines of constant wind speed.
- Isobars indicate pressure cells.

Practice

Use these resources to answer the questions that follow.

http://www.ehow.com/video_4435916_read-surface-analysis-weather-map.html

MEDIA

Click image to the left for more content.

1. What do weather maps on television usually tell you?
2. Where should you begin when analyzing weather maps?

How to read weather plots on a weather map

http://www.ehow.com/video_4435917_read-weather-plots-weather-map.html

MEDIA

Click image to the left for more content.

3. What website is an excellent source of weather information?
4. What is a weather station plot?
5. List the various items recorded on a weather station model plot.

Review

1. What is the purpose of isolines on a weather map?
2. Define isobar, isotach, and isotherm.
3. How are high and low pressure cells indicated on a weather map?

9.32 Effect of Latitude on Climate

- Describe how latitude influences a region's climate, particularly its average temperature.

Where do you want to go on vacation?

If you live in a frigid climate you may want to go to lower latitudes for your mid-winter vacation. If you live in the desert, you may like to spend part of your summer at higher latitudes. Different climates are found at different latitudes.

Latitude

Many factors influence the climate of a region. The most important factor is latitude because different latitudes receive different amounts of solar radiation.

- The equator receives the most solar radiation. Days are equally long year-round and the sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the sun's light.

Temperature with Latitude

It's easy to see the difference in temperature at different latitudes on the map above. But temperature is not completely correlated with latitude. There are many exceptions. For example, notice that the western portion of South America has relatively low temperatures due to the Andes Mountains. The Rocky Mountains in the United

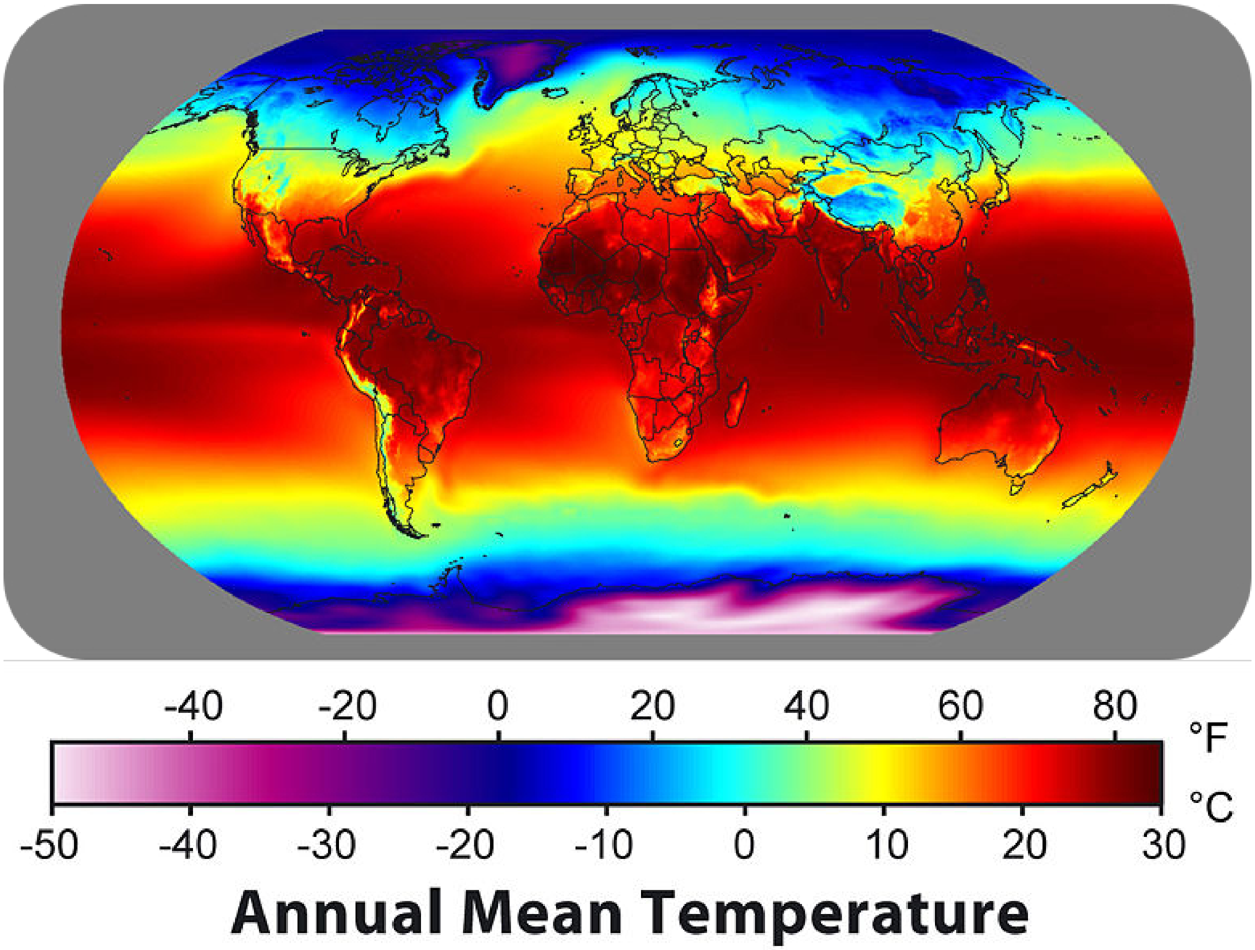


FIGURE 9.68
The average annual temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

States also have lower temperatures due to high altitudes. Western Europe is warmer than it should be due to the Gulf Stream.

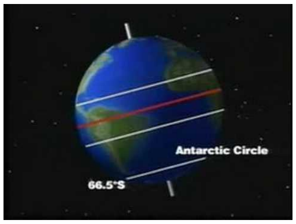
Summary

- The amount of solar radiation received by the planet is greatest at the equator and lessens toward the poles.
- At the poles the sun never rises very high in the sky and sunlight filters through a thick wedge of atmosphere.
- Latitude is not the only factor that determines the temperature of a region, as can be seen in the striped map above.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=95TtXYjOEv4



MEDIA
Click image to the left for more content.

1. What is climate?
2. What influences a regions climate?
3. What is latitude?
4. What is the climate at the equator?
5. What is the tropic of Cancer and the tropic of Capricorn?
6. What is the area between the tropic of Cancer and tropic of Capricorn climate?
7. What are the middle latitudes?
8. Describe the polar regions.
9. What is elevation?
10. How does elevation affect climate?

Review

1. Why do the poles receive so much less solar radiation than the equator considering that it's light for six months at the poles?
2. Why is latitude considered the most important factor in determining temperature?
3. Look at a map of geological features and look at the temperature map to try to determine why some of the exceptions exist. What's the big blue blob north of India?

9.33 Effect of Atmospheric Circulation on Climate

- Explain how major climate traits correlate with the positions of the atmospheric circulation cells.

Does it really never rain in California like the song says?

In California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. The winds do bring rain, quite a bit in northern California, but in San Diego there are only 10 inches a year on average.

Atmospheric Circulation Cells

The position of a region relative to the circulation cells and wind belts has a great affect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (**Figure** 9.70). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail due to the lack of steady winds.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5^o north of the equator, while in the winter it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (**Figure** 9.71).

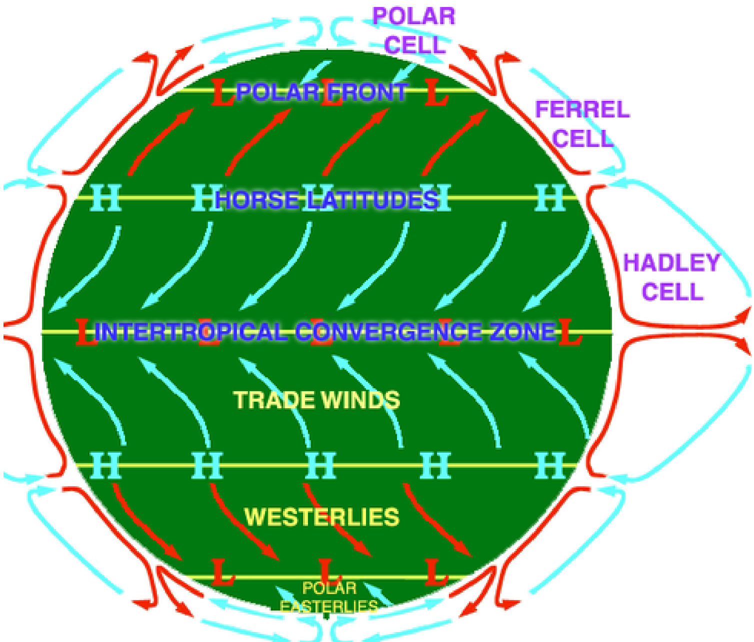


FIGURE 9.69
The atmospheric circulation cells and their relationships to air movement on the ground.

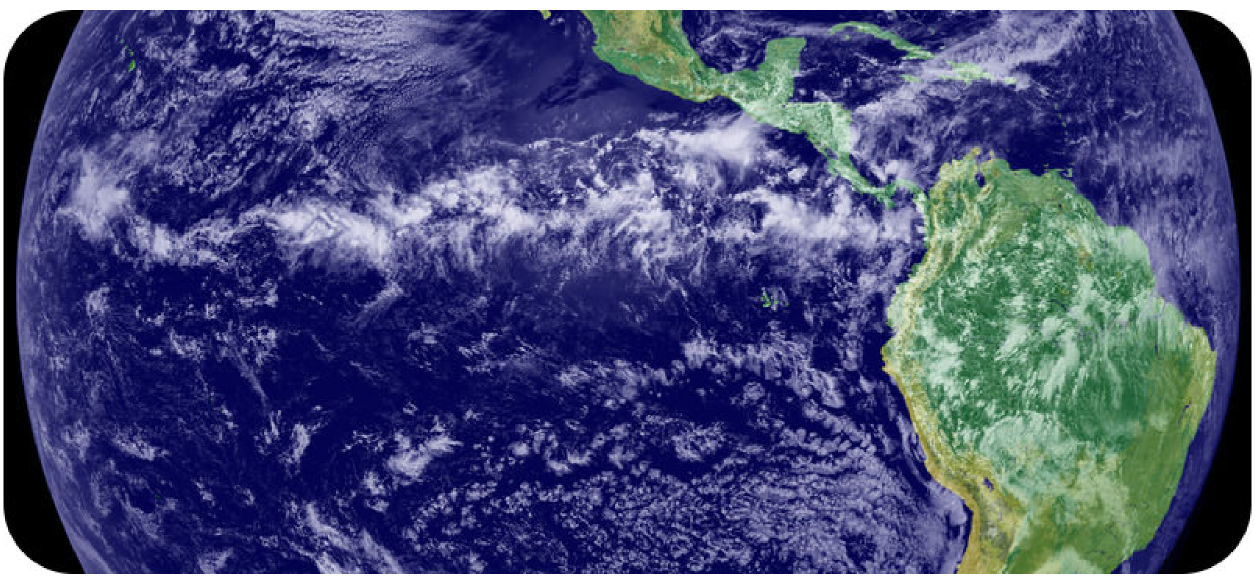


FIGURE 9.70
The ITCZ can easily be seen where thunderstorms are lined up north of the equator.

Hadley Cell and Ferrell Cell Boundary

At about 30^{o}N and 30^{o}S, the air is fairly warm and dry because much of it came from the equator, where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation.

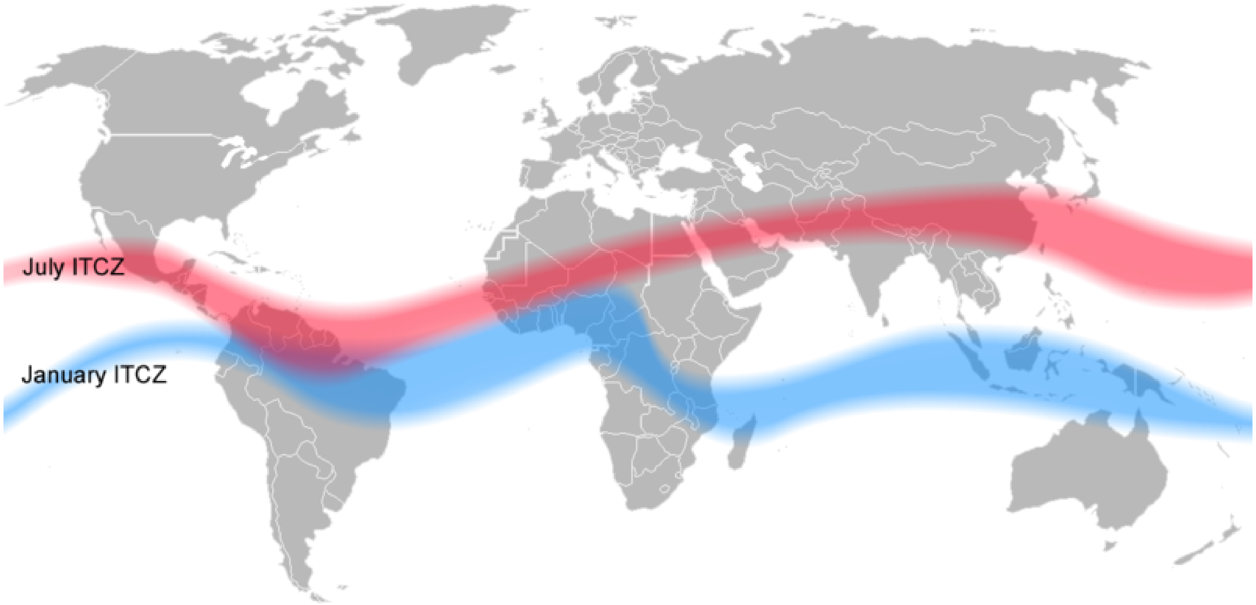


FIGURE 9.71
Seasonal differences in the location of the ITCZ are shown on this map.

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the side after they died. Sailors sometimes didn't make it either.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50^o to 60^o, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and polar cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

Vocabulary

- **Intertropical Convergence Zone (ITCZ)**: A low pressure zone where the Hadley Cells at the equator meet

Summary

- High and low pressure zones related to the atmospheric circulation cells are important in determining a region's climate.
- Prevailing winds influence the climate of a region because they bring in weather from the upwind area.
- Boundaries between cells are often known for winds and stormy weather due to the contact of different air masses.

Practice

Use this resource to answer the questions that follow.

http://earthguide.ucsd.edu/eoc/middle_school_t/teachers/earth/sp_atmosphere/p_atmo_circulation_composite.html

1. What is the atmosphere?
2. How are winds named?
3. What happens when surface winds converge?
4. What occurs when surface winds diverge?
5. What is the ITCZ? How does it change with the seasons?
6. What is air pressure? How does it vary by latitude?

Review

1. What are prevailing winds and how do they affect climate?
2. What is the ITCZ? How does its location affect weather?
3. Where is there not much wind?

9.34 Effect of Continental Position on Climate

- Define marine and continental climates, and explain how continental position and ocean currents affect climate.

What causes San Francisco's famous fog?

The California Current travels from the north and brings cold water to the region just offshore. The warm Mediterranean climate of coastal California contrasts with the cold water offshore and forms advection fog, which blows off the shore and up to a few miles inland. Fog under the Golden Gate Bridge is a common sight in the City by the Bay.

Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.

- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37^{o}N latitude, within the westerly winds (**Figure** 9.72).

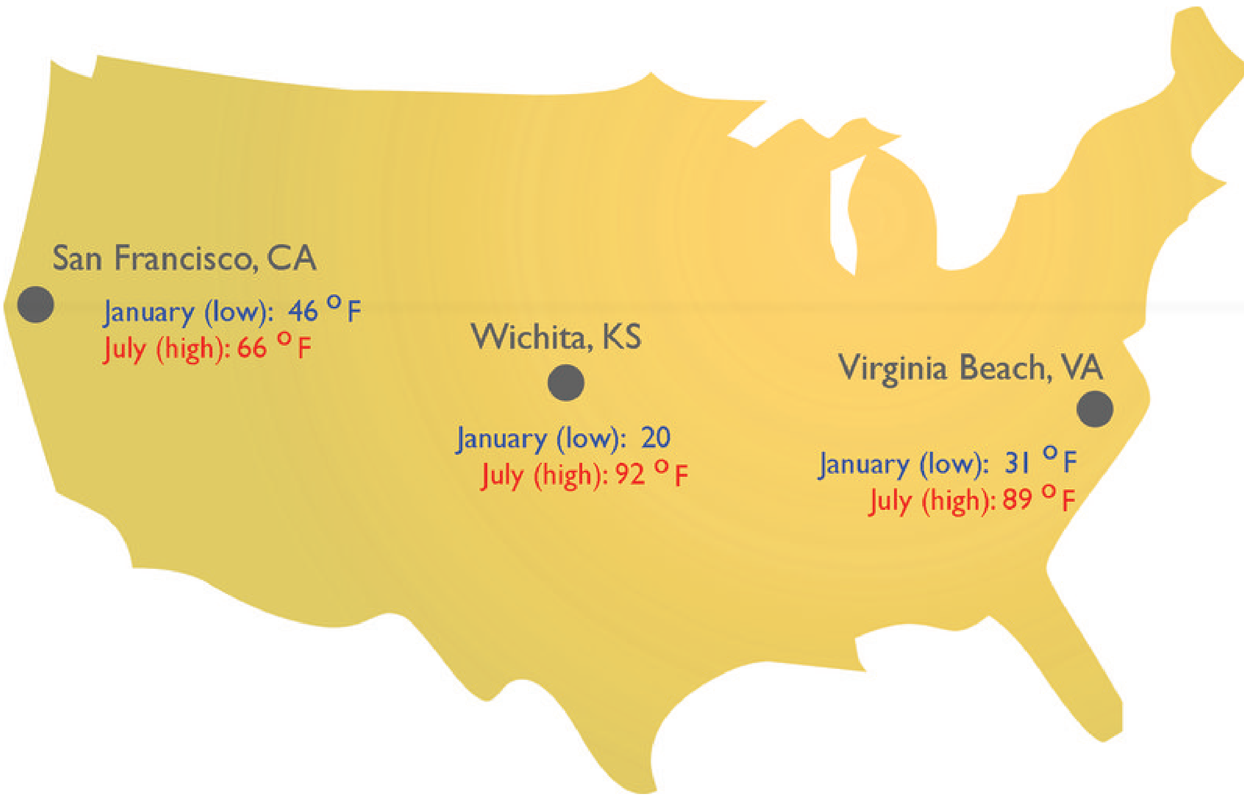


FIGURE 9.72
How does the ocean influence the climate of these three cities?

The climate of San Francisco is influenced by the cool California current and offshore upwelling. Wichita has a more extreme continental climate. Virginia Beach, though, is near the Atlantic Ocean. Why is the climate there less influenced by the ocean than is the climate in San Francisco? Hint: Think about the direction the winds are going at that latitude. The weather in San Francisco comes from over the Pacific Ocean while much of the weather in Virginia comes from the continent.

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in "Concept Water on Earth."

Vocabulary

- **continental climate**: A more variable climate dominated by a vast expanse of land.
- **maritime climate**: A moderate climate dominated by a nearby ocean.

Summary

- A maritime climate is influenced by a nearby ocean. A continental climate is influenced by nearby land.
- The temperature of offshore currents affect nearby land areas.
- A maritime climate is less extreme than a continental climate because the ocean moderates temperatures.

Practice

Use this resource to answer the questions that follow.

http://www.watchmojo.com/index.php?id=6521

MEDIA
Click image to the left for more content.

1. What does the temperature depend on?
2. What influences the weather in California?
3. What is the temperature variation between the coast and inland in the summer?
4. What is the temperature variation between the coast and inland in the winter?
5. How much rainfall does the redwood forest receive?

Review

1. If upwelling stopped off of California, how would climate be affected?
2. From which direction would weather come to a city at 65-degrees north?
3. Why is the climate of San Francisco so different from the climate of Virginia Beach when both are near an ocean?

9.35 Effect of Altitude and Mountains on Climate

- Explain how altitude and mountain ranges affect climate.
- Define rainshadow effect.

Are they worms crawling across the landscape?

This image shows the difference in climate between mountain ranges and the surrounding lands.

Altitude and Mountain Ranges

Air pressure and air temperature decrease with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood's (5,640 feet) average annual temperature is 62^{o}F (17^{o}C), while Climax Lake's (11,300 feet) is 42^{o}F (5.4^{o}C).

Mountain ranges have two effects on the climate of the surrounding region:

- rainshadow effect, which brings warm, dry climate to the leeward size of a mountain range (**Figure** 9.73).
- separation in the coastal region from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

FIGURE 9.73
The Bonneville Salt Flats are part of the very dry Great Basin of the Sierra Nevada of California. The region receives little rainfall.

Five factors that Affect Climate takes a very thorough look at what creates the climate zones. The climate of a region allows certain plants to grow, creating an ecological biome **(5f, 6a, 6b)**: http://www.youtube.com/watch?v=E7DLLxrrBV8 (5:23).

MEDIA
Click image to the left for more content.

Summary

- Collisions between molecules increase temperature: where air is denser, the air temperature is higher.
- Rainshadow effect occurs on the leeward side of a mountain range.
- Maritime air may become stuck on the windward side of a mountain range and so is unable to bring cooler air further inland.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=yuvy4nLtWk4

MEDIA
Click image to the left for more content.

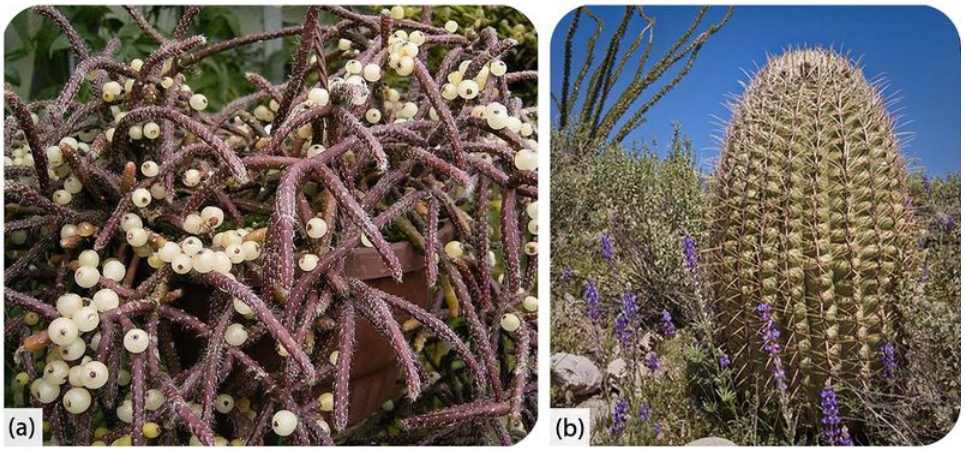
1. What two factors cab affect climate on mountains?
2. What occurs on the windward side of a mountain?
3. Describe the climate on the windward side of the mountain.
4. Describe the climate on the leeward side of the mountain.
5. What are rain shadow deserts?
6. Describe the characteristics seen on the windward side of the Sierra Nevada Mountains.
7. Describe the characteristics see on the leeward side of the Sierra Nevada Mountains.

Review

1. Why does an increase in altitude cause a change in temperature?
2. What is rainshadow effect?
3. Besides rainshadow effect, how else do mountains affect weather downwind?

9.36 Climate Zones and Biomes

- Define biome and microclimate.
- Describe the major climate zones and explain how they relate to biomes.



How do plants that evolved without any genetic interaction end up being so similar?

Organisms evolve to fit the conditions they are in. There are only so many ways to minimize the use of water, so plants in arid climates evolve very similar structures for that purpose. There are many instances of parallel evolution in widely separated organisms.

Climate Zones and Biomes

The major factors that influence climate determine the different climate zones. In general, the same type of climate zone will be found at similar latitudes and in similar positions on nearly all continents, both in the Northern and Southern Hemispheres. The exceptions to this pattern are the climate zones called the continental climates, which are not found at higher latitudes in the Southern Hemisphere. This is because the Southern Hemisphere land masses are not wide enough to produce a continental climate.

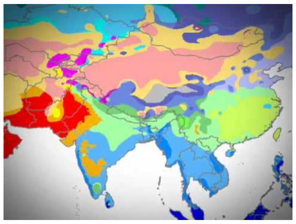
Classification

Climate zones are classified by the Köppen classification system. This system is based on the temperature, the amount of precipitation, and the times of year when precipitation occurs. Since climate determines the type of vegetation that grows in an area, vegetation is used as an indicator of climate type.

Biomes

A climate type and its plants and animals make up a **biome**. The organisms of a biome share certain characteristics around the world, because their environment has similar advantages and challenges. The organisms have adapted to that environment in similar ways over time. For example, different species of cactus live on different continents, but they have adapted to the harsh desert in similar ways.

The similarities between climate zones and biome types are displayed in this video: http://www.youtube.com/watch?v=Z_THTbynoRA (1:01).



MEDIA

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Major Climate Groups

The Köppen classification system recognizes five major climate groups. Each group is divided into subcategories. Some of these subcategories are forest, monsoon, and wet/dry types, based on the amount of precipitation and season when that precipitation occurs (**Figure** 9.74).

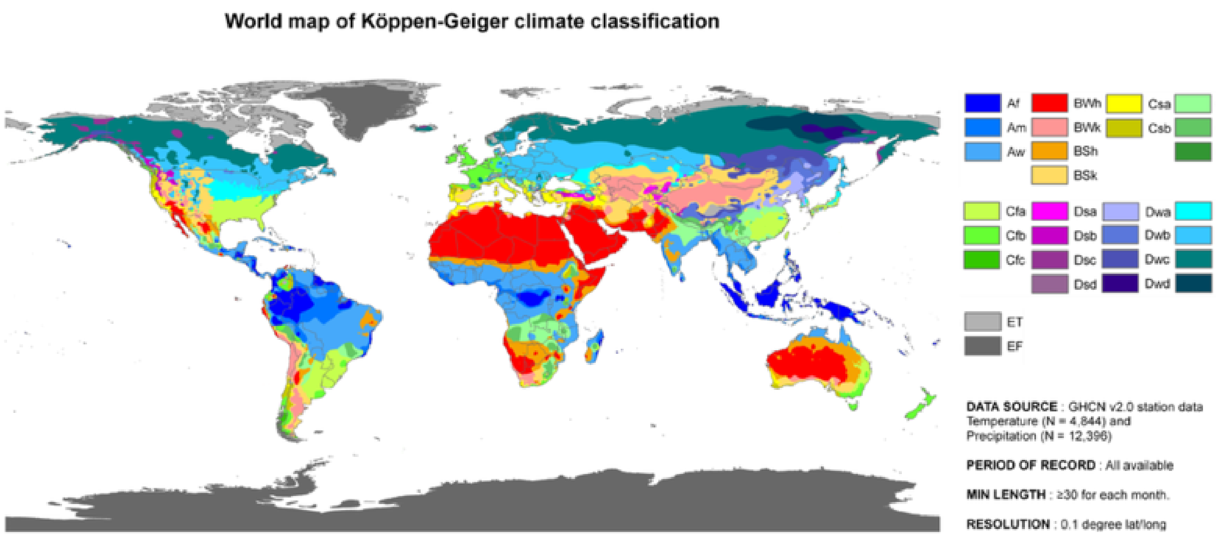


FIGURE 9.74

This world map of the Köppen classification system indicates where the climate zones and major biomes are located.

Tropical Moist Climates

Tropical moist climates are found in a band about 15^o to 25^o N and S of the equator (**Figure** 9.74).

- Temperature: Intense sunshine. Each month has an average temperature of at least 18^oC (64^oF).
- Rainfall: Abundant, at least 150 cm (59 inches) per year.

The main vegetation for this climate is the tropical rainforest.

Dry Climates

Dry climates have less precipitation than evaporation.

- Temperature: Abundant sunshine. Summer temperatures are high; winters are cooler and longer than in tropical moist climates.
- Rainfall: Irregular; several years of drought are often followed by a single year of abundant rainfall. Dry climates cover about 26% of the world's land area.

Low latitude deserts are found at the Ferrell cell high pressure zone. Higher latitude deserts occur within continents or in rainshadows. Vegetation is sparse but well adapted to the dry conditions.

Moist Subtropical Mid-latitude

Moist subtropical mid-latitude climates are found along the coastal areas in the United States.

- Temperature: The coldest month ranges from just below freezing to almost balmy, between -3^{o}C and 18^{o}C (27^o to 64^{o}F). Summers are mild, with average temperatures above 10^{o}C (50^{o}F). Seasons are distinct.
- Rainfall: There is plentiful annual rainfall.

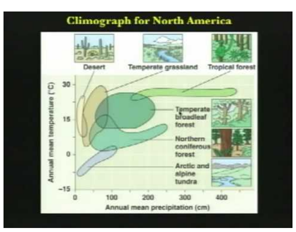
Continental Climates

Continental climates are found in most of the North American interior from about 40°N to 70°N.

- Temperature: The average temperature of the warmest month is higher than 10°C (50°F) and the coldest month is below -3°C (27°F).
- Precipitation: Winters are cold and stormy (look at the latitude of this zone and see if you can figure out why). Snowfall is common and snow stays on the ground for long periods of time.

Trees grow in continental climates, even though winters are extremely cold, because the average annual temperature is fairly mild. Continental climates are not found in the Southern Hemisphere because of the absence of a continent large enough to generate this effect.

This "Ecosystem Ecology" video lecture at U.C. Berkley outlines the factors that create climate zones and consequently the biomes: http://www.youtube.com/watch?v=3tY3aXgX4AM (46:46).



MEDIA

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Polar Climates

Polar climates are found across the continents that border the Arctic Ocean, Greenland, and Antarctica.

- Temperature: Winters are entirely dark and bitterly cold. Summer days are long, but the sun is low on the horizon so summers are cool. The average temperature of the warmest month is less than 10^{o}C (50^{o}F). The annual temperature range is large.
- Precipitation: The region is dry, with less than 25 cm (10 inches) of precipitation annually; most precipitation occurs during the summer.

Microclimates

When climate conditions in a small area are different from those of the surroundings, the climate of the small area is called a **microclimate**. The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it, because rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope, so each side supports different amounts and types of vegetation.

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found in other areas of the world at high altitudes.

Vocabulary

- **biome**: The living organisms that are found within a climate zone that make that zone distinct.
- **microclimate**: A local climate that is different from the regional climate.

Summary

- A biome is a climate zone and the plants and animals that live in it.
- The Koppen classification system divides climates into five major types and many subtypes based on temperature and humidity characteristics.
- A microclimate has different climate conditions from the surrounding regions.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ZouWWVyz9v8

MEDIA

Click image to the left for more content.

1. What determines the characteristics of the Moab desert?
2. Where are deserts often found?
3. Why are the poles cold?
4. How can the ocean heat the land?
5. What is the mean temperature at Reykjavik?
6. What brings the warm temperatures to Iceland?
7. How do greenhouse gases effect climate?
8. What are the principal factors in determining climate?

Review

1. How does a biome relate to a climate zone?
2. How does a region develop its own microclimate?
3. Where do you think dry climates are located? Where are subtropical climates located?

Summary

The layers of the atmosphere are divided by their temperature gradients. The lowest layer is the troposphere, where all weather takes place. The next layer is the stratosphere, which contains the protective ozone layer. The density of the gases decreases with altitude and generally so does temperature. More solar energy strikes at the equator and this is what drives the global winds. Warm air rises, moves poleward, and then sinks when it meets with air moving toward the equator. The result is six atmospheric circulation cells, three in each hemisphere. Local differences in temperature also create winds. Where the air is stable for at least a few days, the conditions of the land or water beneath the air alter the air and so creates an air mass. Interactions between air masses bring about a lot of weather; for example, the thunderstorms and tornadoes that form along a front. Weather prediction is much better than it was in past years, due in part to the information gleaned from satellites. Climate is the long-term average of weather. The climate of a location depends on its latitude, position relative to the atmospheric circulation cells, position on a continent, altitude, and position relative to mountains. Where climate is roughly the same, there is a climate zone. The organisms that live within a climate zone create a unique biome.

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CHAPTER 10 Life on Earth

Chapter Outline

Introduction

The only known life in the universe. So far.

It's possible, maybe even likely, that there is life elsewhere in the universe, but if there is life we haven't found it yet. What makes Earth unique in the solar system is not only that it has life but that it has such an incredible diversity of life forms. The origin of life, the evolution of a variety of life forms, and the evolution of life that can read this sentence is certainly unique in the universe.

10.1 Biological Communities

- Identify and define the component parts of biological communities and ecosystems.

How is a community of people like a community of organisms?

Different species have different jobs within their community. Some are the farmers, some are traders, some are the janitors, and others have different roles.

Biological Communities

A **population** consists of all individuals of a single **species** that exist together at a given place and time. A species is a single type of organism that can interbreed and produce fertile offspring. All of the populations living together in the same area make up a **community**.

Ecosystems

An **ecosystem** is made up of the living organisms in a community and the nonliving things, the physical and chemical factors, that they interact with. The living organisms within an ecosystem are its **biotic** factors (**Figure** 10.1). Living things include bacteria, algae, fungi, plants, and animals, including invertebrates, animals without backbones, and vertebrates, animals with backbones.

FIGURE 10.1
(a) The horsetail Equisetum is a primitive plant. (b) Insects are among the many different types of invertebrates. (c) A giraffe is an example of a vertebrate.

Physical and chemical features are **abiotic** factors. Abiotic factors include resources living organisms need, such as light, oxygen, water, carbon dioxide, good soil, and nitrogen, phosphorous, and other nutrients. Nutrients cycle through different parts of the ecosystem and can enter or leave the ecosystem at many points. Abiotic factors also include environmental features that are not materials or living things, such as living space and the right temperature range. Energy moves through an ecosystem in one direction.

Niches

Organisms must make a living, just like a lawyer or a ballet dancer. This means that each individual organism must acquire enough food energy to live and reproduce. A species' way of making a living is called its **niche**. An example of a niche is making a living as a top carnivore, an animal that eats other animals, but is not eaten by any other animals (**Figure** 10.2). Every species fills a niche, and niches are almost always filled in an ecosystem.

Habitat

An organism's **habitat** is where it lives (**Figure** 10.3). The important characteristics of a habitat include climate, the availability of food, water, and other resources, and other factors, such as weather.

Vocabulary

- **abiotic**: Non-living features of an ecosystem include space, nutrients, air, and water.
- **biotic**: Living features of an ecosystem include viruses, plants, animals, and bacteria.
- **community**: All of the populations of organisms in an ecosystem.
- **ecosystem**: All of the living things in a region and the physical and chemical factors that they need.
- **habitat**: Where an organism lives, with distinctive features such as climate or resource availability.
- **niche**: An organism's "job" within its community.

FIGURE 10.2
The top carnivore niche is filled by lions on the savanna, wolves in the tundra, and tuna in the oceans.

FIGURE 10.3
Birds living in a saguaro cactus. A habitat may be a hole in a cactus or the underside of a fern in a rainforest. It may be rocks and the nearby sea.

- **population**: All the individuals of a species that occur together in a given place and time.
- **species**: A classification of organisms that can or do interbreed and produce fertile offspring.

Summary

- All of the individuals of a species that exist together at a given place and time make up a population. A community is made up of all of the populations in an area.

- The living and nonliving factors that living organisms need plus the communities of organisms themselves make up an ecosystem.
- A habitat is where an organism lives and a niche is what it does to make a living.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=O3CZFfyed3M

MEDIA
Click image to the left for more content.

1. What are the biotic components of an ecosystem?
2. What is a species?
3. What is a population?
4. List two examples of populations.
5. What is a community?
6. How can a natural community vary in size?

- http://www.hippocampus.org/Biology → Biology for AP* → Search: **Abiotic Factors Affecting Living Systems**

7. What does abiotic mean?
8. What effects do the abiotic tractors have on the populations that live there?
9. How does the Earth's tilt effect life?

Review

1. Define species, population, community, niche, habitat, biotic factor, and abiotic factor.
2. Diagram how the words listed above relate to each other.
3. Choose a type of wild organism that you're familiar with and list the biotic and abiotic factors that it needs to live.

10.2 Roles in an Ecosystem

- Define and describe the common roles and relationships of organisms in an ecosystem.

What roles do coral reef organisms have?

Corals are not rocks or plants, but little animals that live in a carbonate shell they create. They have a symbiotic relationship with zooxanthellae, tiny photosynthesizing organisms. The zooxanthellae provide food for the coral and the coral provides a safe home for the zooxanthellae. Together they form the base of a complex ecosystem.

Roles in Ecosystems

There are many different types of ecosystems. Climate conditions determine which ecosystems are found in a particular location. A biome encompasses all of the ecosystems that have similar climate and organisms.

Different organisms live in different types of ecosystems because they are adapted to different conditions. Lizards thrive in deserts, but no reptiles are found in any polar ecosystems. Amphibians can't live too far from the water. Large animals generally do better in cold climates than in hot climates.

Despite this, every ecosystem has the same general roles that living creatures fill. It's just the organisms that fill those niches that are different. For example, every ecosystem must have some organisms that produce food in the form of chemical energy. These organisms are primarily algae in the oceans, plants on land, and bacteria at hydrothermal vents.

Producers and Consumers

The organisms that produce food are extremely important in every ecosystem. Organisms that produce their own food are called **producers**. There are two ways of producing food energy:

- Photosynthesis: plants on land, phytoplankton in the surface ocean, and some other organisms.
- Chemosynthesis: bacteria at hydrothermal vents.

Organisms that use the food energy that was created by producers are named **consumers**. There are many types of consumers:

- **Herbivores** eat producers directly. These animals break down the plant structures to get the materials and energy they need.
- **Carnivores** eat animals; they can eat herbivores or other carnivores.
- **Omnivores** eat plants and animals as well as fungi, bacteria, and organisms from the other kingdoms.

Feeding Relationships

There are many types of feeding relationships (**Figure** 10.5) between organisms. A **predator** is an animal that kills and eats another animal, known as its **prey**. **Scavengers** are animals, such as vultures and hyenas, that eat organisms that are already dead. **Decomposers** break apart dead organisms or the waste material of living organisms, returning the nutrients to the ecosystem.

Relationships Between Species

Species have different types of relationships with each other. **Competition** occurs between species that try to use the same resources. When there is too much competition, one species may move or adapt so that it uses slightly different resources. It may live at the tops of trees and eat leaves that are somewhat higher on bushes, for example. If the competition does not end, one species will die out. Each niche can only be inhabited by one species.

Some relationships between species are beneficial to at least one of the two interacting species. These relationships are known as **symbiosis** and there are three types:

- In **mutualism**, the relationship benefits both species. Most plant-pollinator relationships are mutually beneficial. What does each get from the relationship?
- In **commensalism**, one organism benefits and the other is not harmed.

FIGURE 10.4
A llama grazes on a terrace near Machu Picchu, Peru

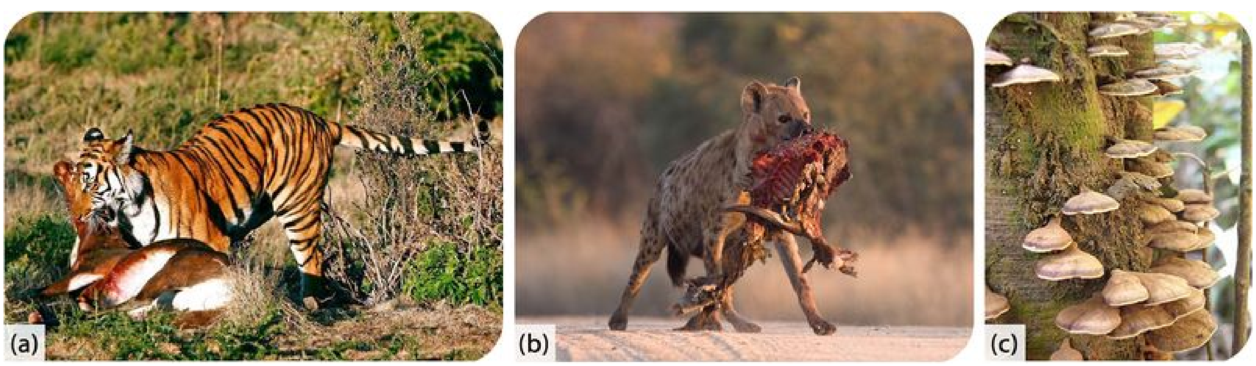


FIGURE 10.5
(a) Predator and prey; (b) Scavengers; (c) Bacteria and fungi, acting as decomposers.

- In **parasitism**, the parasite species benefits and the host is harmed. Parasites do not usually kill their hosts because a dead host is no longer useful to the parasite. Humans host parasites, such as the flatworms that cause schistosomiasis.

Choose which type of relationship is described by each of the images and captions below (**Figure** 10.6).

FIGURE 10.6
(a) The pollinator gets food; the plant's pollen gets caught in the bird's feathers so it is spread to far away flowers. (b) The barnacles receive protection and get to move to new locations; the whale is not harmed. (c) These tiny mites are parasitic and consume the insect called a harvestman.

Vocabulary

- **carnivore**: Animals that only eat other animals for food.
- **commensalism**: A relationship in which one species benefits and the other species is not harmed.
- **competition**: A rivalry between two species, or individuals of the same species, for the same resources.
- **consumer**: An organism that uses other organisms for food energy.
- **decomposer**: An organism that breaks down the tissues of a dead organism into its various components, including nutrients, that can be used by other organisms.
- **herbivore**: An animal that only eats producers.
- **mutualism**: A symbiotic relationship between two species in which both species benefit.
- **omnivore**: An organism that consumes both producers and other consumers for food.
- **parasitism**: A symbiotic relationship between two species in which one species benefits and one species is harmed.
- **predator**: A symbiotic relationship between two species in which one species benefits and one species is harmed.
- **prey**: An animal that could be killed and eaten by a predator.
- **producer**: An organism that converts energy into chemical energy that it can use for food. Most producers use photosynthesis but a very small number use chemosynthesis.
- **scavenger**: Animals that eat animals that are already dead.
- **symbiosis**: Relationships between two species in which at least one species benefits.

Summary

- Herbivores eat plants, carnivores eat meat, and omnivores eat both.
- Predators are animals that eat a prey animal. Scavengers eat organisms that are already dead. Decomposers break down dead plants and animals into component parts, including nutrients.
- Relationships between species can be one of competition or one of symbiosis, in which one or both species benefits. Mutualism, commensalism, and parasitism are the three types of symbiotic relationships.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=D1aRSeT-mQE

MEDIA

Click image to the left for more content.

1. What is competition?
2. What is predation?
3. What is symbiosis?
4. How do stable communities develop?
5. What is succession?
6. What is a niche?
7. What does a niche include?
8. What causes competition?

Review

1. Compare and contrast the two different ways of producing food energy, photosynthesis and chemosynthesis.
2. After a producer produces food energy, follow its path until it ends up being used by another producer.
3. What kind of symbiotic relationship do zooxanthellae and corals have?

10.3 Flow of Energy in Ecosystems

- Define trophic levels.
- Compare and contrast food chains and webs.
- Explain how energy flows through ecosystems.

What is the source of energy for almost all ecosystems?

The Sun supports most of Earth's ecosystems. Plants create chemical energy from abiotic factors that include solar energy. Chemosynthesizing bacteria create usable chemical energy from unusable chemical energy. The food energy created by producers is passed to consumers, scavengers, and decomposers.

Trophic Levels

Energy flows through an ecosystem in only one direction. Energy is passed from organisms at one **trophic level** or energy level to organisms in the next trophic level. Which organisms do you think are at the first trophic level (**Figure** 10.7)?

Most of the energy at a trophic level – about 90% – is used at that trophic level. Organisms need it for locomotion, heating themselves, and reproduction. So animals at the second trophic level have only about 10% as much energy available to them as do organisms at the first trophic level. Animals at the third level have only 10% as much available to them as those at the second level.

Food Chains

The set of organisms that pass energy from one trophic level to the next is described as the **food chain** (**Figure** 10.8). In this simple depiction, all organisms eat at only one trophic level (**Figure** 10.9).

What are the consequences of the loss of energy at each trophic level? Each trophic level can support fewer organisms.

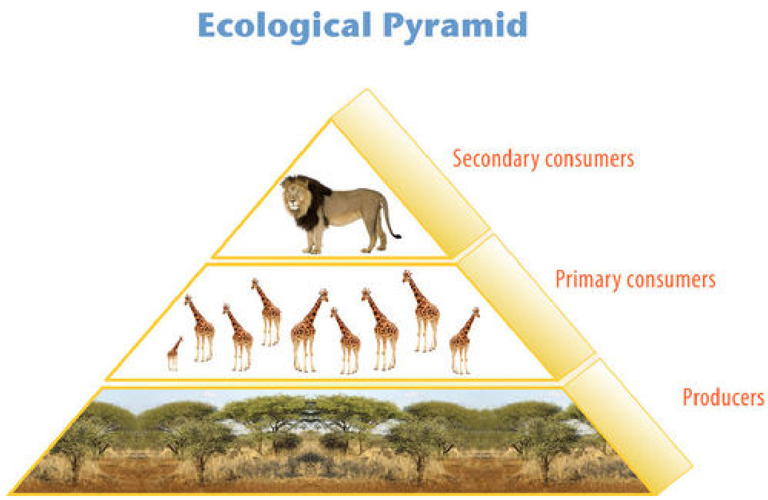


FIGURE 10.7
Producers are always the first trophic level, herbivores the second, the carnivores that eat herbivores the third, and so on.

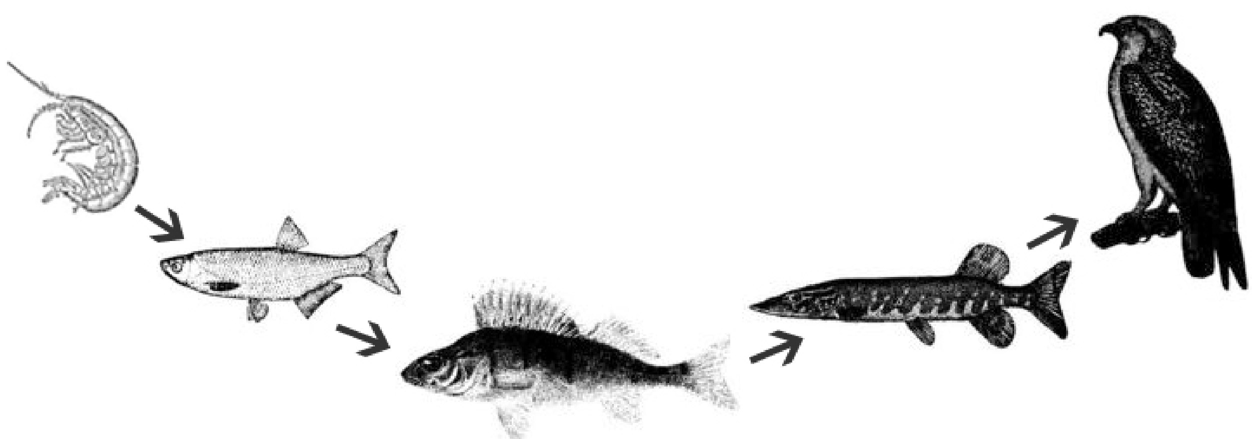


FIGURE 10.8
A simple food chain in a lake. The producers, algae, are not shown. For the predatory bird at the top, how much of the original energy is left?

What does this mean for the range of the osprey (or lion, or other top predator)? A top predator must have a very large range in which to hunt so that it can get enough energy to live.

Why do most food chains have only four or five trophic levels? There is not enough energy to support organisms in a sixth trophic level. Food chains of ocean animals are longer than those of land-based animals because ocean conditions are more stable.

Why do organisms at higher trophic levels tend to be larger than those at lower levels? The reason for this is simple: a large fish must be able to eat a small fish, but the small fish does not have to be able to eat the large fish (**Figure** 10.10).

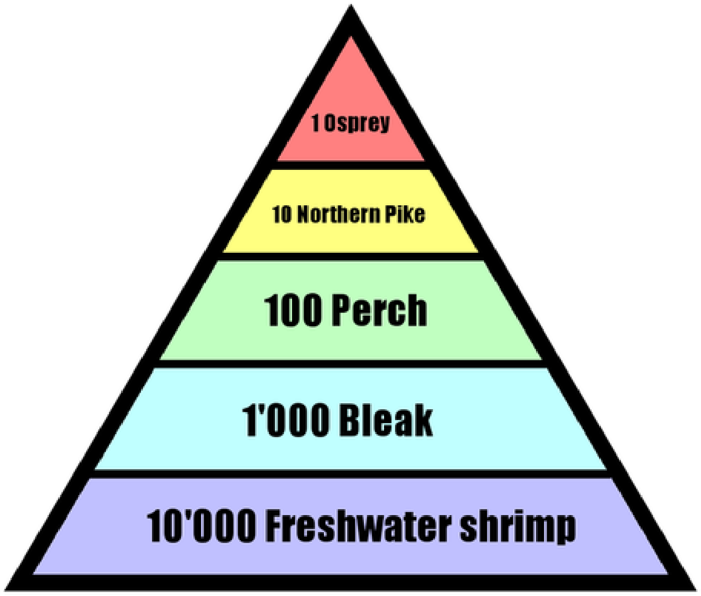


FIGURE 10.9
How many osprey are there relative to the number of shrimp?

FIGURE 10.10
In this image the predators (wolves) are smaller than the prey (bison), which goes against the rule placed above. How does this relationship work? Many wolves are acting together to take down the bison.

Food Webs

What is a more accurate way to depict the passage of energy in an ecosystem? A **food web** (**Figure** 10.11) recognizes that many organisms eat at multiple trophic levels.

Even food webs are interconnected. All organisms depend on two global food webs. The base of one is phytoplankton and the other is land plants. How are these two webs interconnected? Birds or bears that live on land may eat fish, which connects the two food webs.

Humans are an important part of both of these food webs; we are at the top of a food web, since nothing eats us.

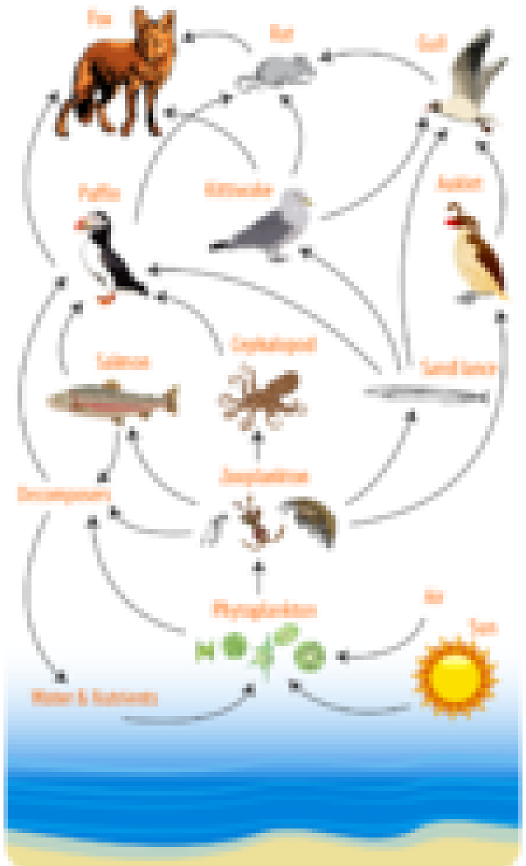


FIGURE 10.11
A food web includes the relationships between producers, consumers, and decomposers.

That means that we are top predators.

Vocabulary

- **food chain**: An energy pathway that includes all organisms that are linked as they pass along food energy, beginning with a producer and moving on to consumers.
- **food web**: Interwoven food chains that show each organism eating from different trophic levels.
- **trophic level**: Energy levels within a food chain or food web.

Summary

- A food chain describes the passage of energy between trophic levels.
- A food web is a set of interconnected and overlapping food chains.
- Food webs are interconnected, such as nearby land and a marine food webs.

Practice

Use this resource to answer the questions that follow.

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

MEDIA
Click image to the left for more content.

1. What do all organisms require?
2. What provides the energy required by the ecosystem?
3. How is energy transferred from one organism to another?
4. How is some of the energy lost?
5. How do nutrients move through and ecosystem?

Review

1. What does a food chain depict? Why do scientists usually use a food web instead of a food chain?
2. Start with the Sun and describe what happens to energy through the trophic levels. Why does this not go on forever (with many more trophic levels)?
3. What trophic level do you inhabit? Do all humans inhabit the same trophic level?

10.4 Flow of Matter in Ecosystems

- Describe how matter flows through ecosystems.
- Compare and contrast the flow of matter with the flow of energy in ecosystems.

What killed millions of sailors in the 15th through 18th centuries?

Sailors at sea or explorers in polar regions, even Crusaders, who went without fresh food developed scurvy due to the lack of vitamin C in their diets. Without the right nutrients in the right amounts, you can't live — and humans need vitamin C. It wasn't until 1932 that the link between scurvy and a nutrient was made.

Flow of Matter in Ecosystems

The flow of matter in an ecosystem is not like energy flow. Matter enters an ecosystem at any level and leaves at any level. Matter cycles freely between trophic levels and between the ecosystem and the physical environment (**Figure** 10.12).

Nutrients

Nutrients are ions that are crucial to the growth of living organisms. Nutrients such as nitrogen and phosphorous are important for plant cell growth. Animals use silica and calcium to build shells and skeletons. Cells need nitrates and phosphates to create proteins and other biochemicals. From nutrients, organisms make tissues and complex molecules such as carbohydrates, lipids, proteins, and nucleic acids.

What are the sources of nutrients in an ecosystem? Rocks and minerals break down to release nutrients. Some enter the soil and are taken up by plants. Nutrients can be brought in from other regions, carried by wind or water. When one organism eats another organism, it receives all of its nutrients. Nutrients can also cycle out of an ecosystem.

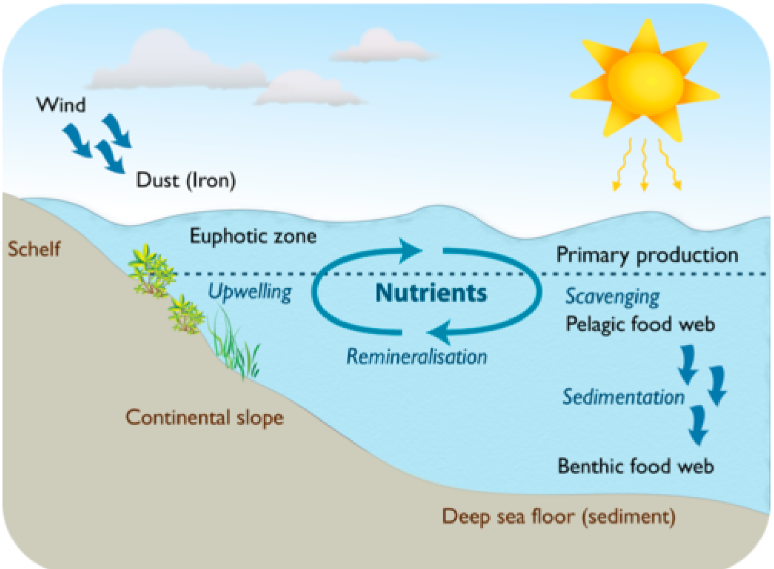


FIGURE 10.12
Nutrients cycle through ocean food webs.

Decaying leaves may be transported out of an ecosystem by a stream. Wind or water carries nutrients out of an ecosystem.

Decomposers play a key role in making nutrients available to organisms. Decomposers break down dead organisms into nutrients and carbon dioxide, which they respire into the air. If dead tissue would remain as it is, eventually nutrients would run out. Without decomposers, life on Earth would have died out long ago.

Vocabulary

- **decomposer**: An organism that breaks down the tissues of a dead organism into its various components, including nutrients, that can be used by other organisms.
- **nutrients**: Ions that organisms need to live and grow.

Summary

- Ions that are crucial to the growth of organisms are known as nutrients.
- Decomposers break down dead organisms into nutrients and gases so that they can be used by other organisms.
- Nutrients can enter or exit an ecosystem at any point and can cycle around the planet.

Practice

Use this resource to answer the questions that follow.

http://www.powerhouseanimation.com/gallery/projectArchive/publishers-resource-group/prg_flowOfEnergy.swf

1. What is carbon dioxide in the air a reservoir for?

2. What do producers do with carbon?

3. What do herbivores do with carbon?

4. Why is the biomass of carnivores less than herbivores?

5. What do decomposers do?

6. How is carbon returned to the atmosphere?

Review

1. How does the flow of matter differ from the flow of energy through an ecosystem?
2. How do nutrients enter and exit and ecosystem?
3. What would happen to life on Earth if there were no decomposers?

10.5 Nitrogen Cycle in Ecosystems

- Describe nitrogen's roles as a nutrient.
- Define nitrogen fixation and explain how it occurs.

Lentils, anyone?

Why are legumes important to biological cycles? Nitrogen gas, as found in the atmosphere, is not useful to organisms. Legumes have bacteria in their root nodules that fix nitrogen. Putting legumes into a crop rotation reduces fertilizer costs and makes the soil and the crops healthier.

Nitrogen as a Nutrient

Nitrogen (N_2) is vital for life on Earth as an essential component of organic materials, such as amino acids, chlorophyll, and nucleic acids such as DNA and RNA. (**Figure** 10.13). Chlorophyll molecules, essential for photosynthesis, contain nitrogen.

Nitrogen Fixing

Although nitrogen is the most abundant gas in the atmosphere, it is not in a form that plants can use. To be useful, nitrogen must be "fixed," or converted into a more useful form. Although some nitrogen is fixed by lightning or blue-green algae, much is modified by bacteria in the soil. These bacteria combine the nitrogen with oxygen or hydrogen to create nitrates or ammonia (**Figure** 10.14).

Nitrogen-fixing bacteria either live free or in a symbiotic relationship with leguminous plants (peas, beans, peanuts). The symbiotic bacteria use carbohydrates from the plant to produce ammonia that is useful to the plant. Plants use

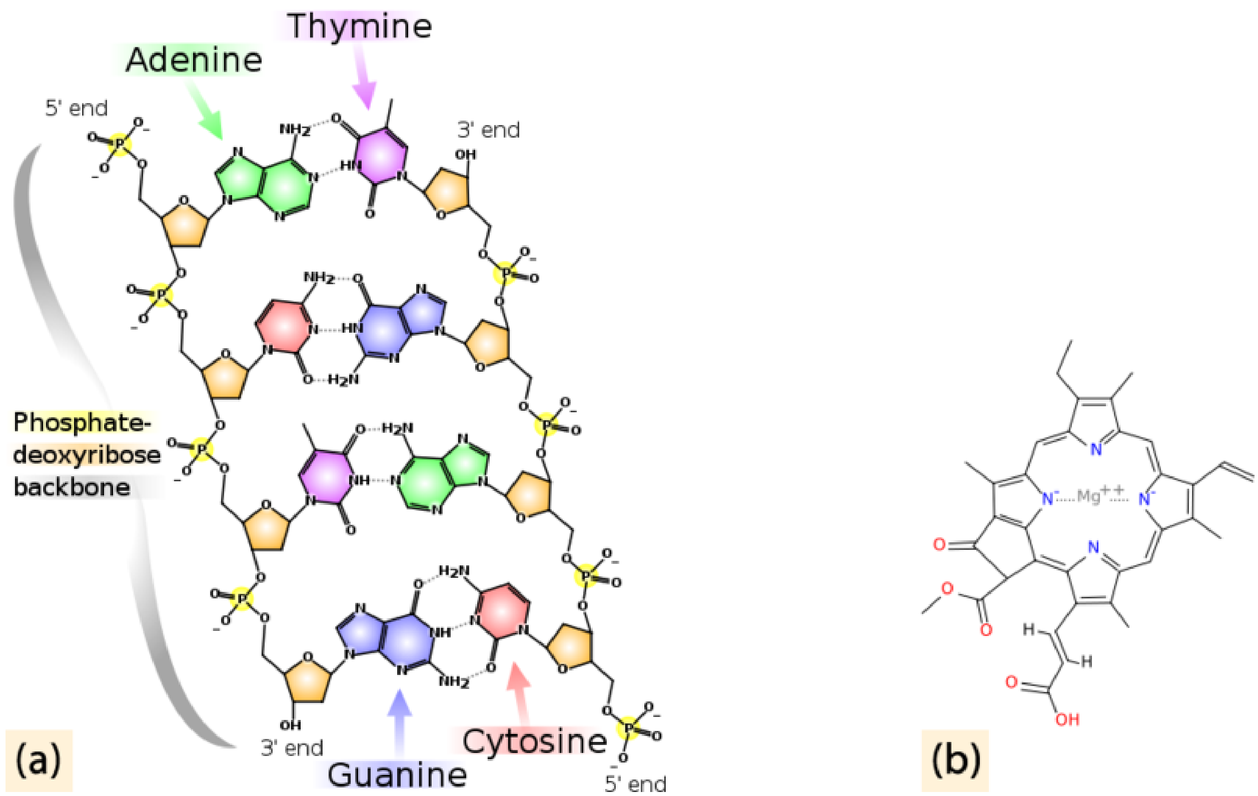


FIGURE 10.13
(a) Nucleic acids contain nitrogen (b) Chlorophyll molecules contain nitrogen

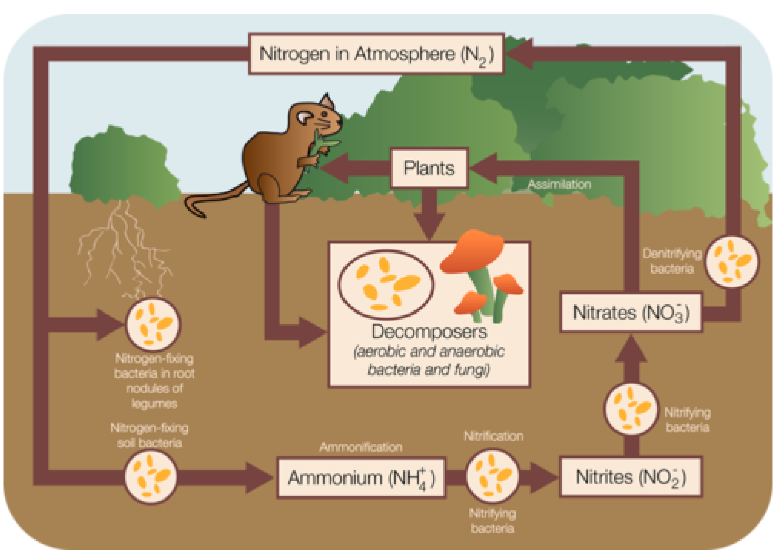


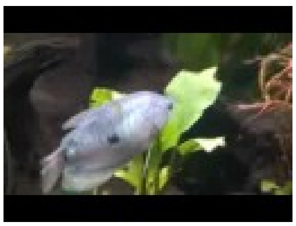
FIGURE 10.14
The nitrogen cycle.

this fixed nitrogen to build amino acids, nucleic acids (DNA, RNA), and chlorophyll. When these legumes die, the fixed nitrogen they contain fertilizes the soil.

Up the Food Chain

Animals eat plant tissue and create animal tissue. After a plant or animal dies or an animal excretes waste, bacteria and some fungi in the soil fix the organic nitrogen and return it to the soil as ammonia. Nitrifying bacteria oxidize the ammonia to nitrites, while other bacteria oxidize the nitrites to nitrates, which can be used by the next generation of plants. In this way, nitrogen does not need to return to a gas. Under conditions when there is no oxygen, some bacteria can reduce nitrates to molecular nitrogen.

This very thorough video on the nitrogen cycle with an aquatic perspective was created by high school students: http://www.youtube.com/watch?v=pdY4I-EaqJA#38;feature=related (5:08).



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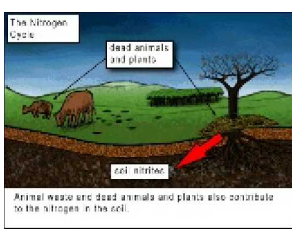
Summary

- Nitrogen is an essential component of many organic molecules.
- Nitrogen is fixed when it is changed into a form that organisms can use.
- Bacteria and some fungi fix organic nitrogen into ammonia and nitrifying bacteria oxidize it to nitrates.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=ZCogeBk92NA



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1. What percentage of the air is nitrogen?
2. How is nitrogen removed from the air?
3. What contributes nitrogen to the soil?
4. What happens to soil nitrates?
5. How is nitrogen released from the soil?

Review

1. Describe how nitrogen is fixed.
2. Why are legumes important as nitrogen fixers?
3. How is nitrogen fixed in an aquatic environment?

10.6 Fresh Water Ecosystems

- Describe the various types of freshwater ecosystems.

Why did people used to rush to fill in swamps?

People didn't know the value of wetlands. Many are in locations that might be desirable for people to live, like near a shoreline. Mosquitoes, which no one seems to like, breed there. But wetlands serve a number of valuable purposes. They are breeding grounds for many organisms and they protect inland areas from storms. Now wetlands are protected.

Freshwater Ecosystems

Organisms that live in lakes, ponds, streams, springs or wetlands are part of freshwater ecosystems. These ecosystems vary by temperature, pressure (in lakes), the amount of light that penetrates and the type of vegetation that lives there.

Lake Ecosystems

Limnology is the study of bodies of fresh water and the organisms that live there. A lake has zones just like the ocean. The ecosystem of a lake is divided into three distinct zones (**Figure** 10.15):

1. The surface (littoral) zone is the sloped area closest to the edge of the water.
2. The open-water zone (also called the photic or limnetic zone) has abundant sunlight.
3. The deep-water zone (also called the aphotic or profundal zone) has little or no sunlight.

There are several life zones found within a lake:

- In the littoral zone, sunlight promotes plant growth, which provides food and shelter to animals such as snails, insects, and fish.
- In the open-water zone, other plants and fish, such as bass and trout, live.
- The deep-water zone does not have photosynthesis since there is no sunlight. Most deep-water organisms are scavengers, such as crabs and catfish that feed on dead organisms that fall to the bottom of the lake. Fungi and bacteria aid in the decomposition in the deep zone.

Though different creatures live in the oceans, ocean waters also have these same divisions based on sunlight with similar types of creatures that live in each of the zones.

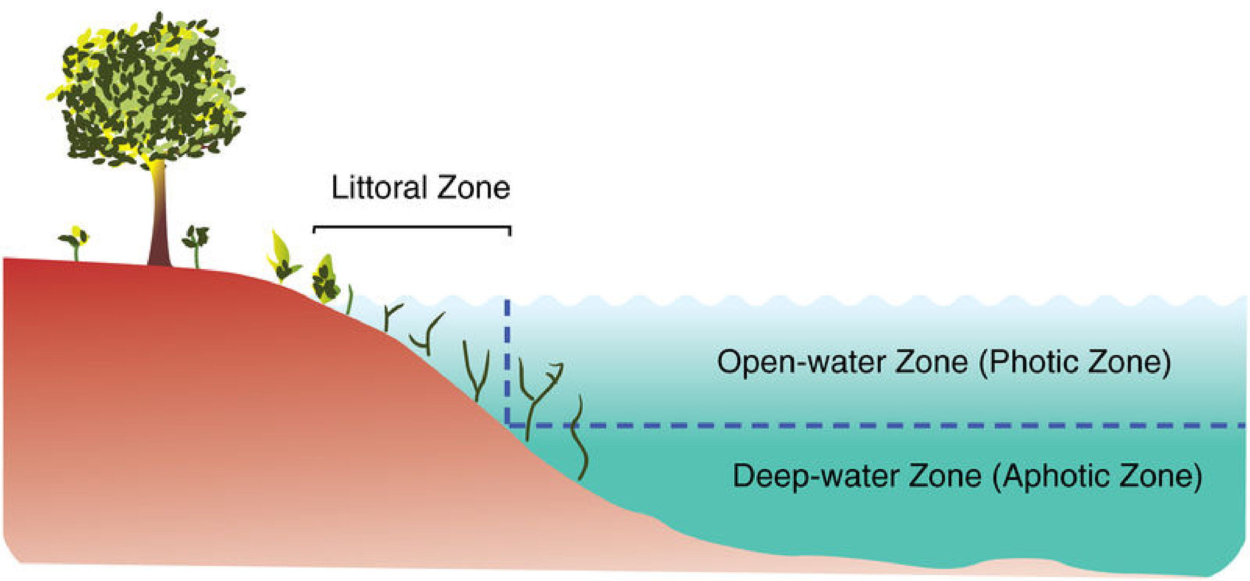


FIGURE 10.15
The three primary zones of a lake are the littoral, open-water, and deep-water zones.

Wetlands

Wetlands are lands that are wet for significant periods of time. They are common where water and land meet. Wetlands can be large flat areas or relatively small and steep areas.

Wetlands are rich and unique ecosystems with many species that rely on both the land and the water for survival. Only specialized plants are able to grow in these conditions. Wetlands tend have a great deal of biological diversity. Wetland ecosystems can also be fragile systems that are sensitive to the amount and quality of water present within them.

Marshes

Marshes are shallow wetlands around lakes, streams, or the ocean where grasses and reeds are common, but trees are not (**Figure** 10.16). Frogs, turtles, muskrats, and many varieties of birds are at home in marshes.

FIGURE 10.16
A salt marsh on Cape Cod in Massachusetts.

Swamps

A **swamp** is a wetland with lush trees and vines found in low-lying areas beside slow-moving rivers (**Figure** 10.17). Like marshes, they are frequently or always inundated with water. Since the water in a swamp moves slowly, oxygen in the water is often scarce. Swamp plants and animals must be adapted for these low-oxygen conditions. Like marshes, swamps can be fresh water, salt water, or a mixture of both.

FIGURE 10.17
A swamp is characterized by trees in still water.

Ecological Role of Wetlands

As mentioned above, wetlands are home to many different species of organisms. Although they make up only 5% of the area of the United States, wetlands contain more than 30% of the plant types. Many endangered species live in wetlands, so wetlands are protected from human use.

Wetlands also play a key biological role by removing pollutants from water. For example, they can trap and use fertilizer that has washed off a farmer's field, and therefore they prevent that fertilizer from contaminating another body of water. Since wetlands naturally purify water, preserving wetlands also helps to maintain clean supplies of water.

Vocabulary

- **limnology**: The study of freshwater bodies and the organisms that live in them.
- **marsh**: A shallow wetland with grasses and reeds, but there no trees. Water may be fresh, saline, or brackish.
- **swamp**: A low-lying wetland where water moves very slowly and oxygen levels are low.
- **wetlands**: Lands that are wet a large amount of the time.

Summary

- The conditions that affect lake ecosystems are similar to those that affect marine ecosystems, such as light penetration, temperature and water depth.
- Wetlands are lands that are wet for a significant portion of the year.
- Wetlands are extremely important as an ecosystem and as a filter for pollutants.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Freshwater Biomes**

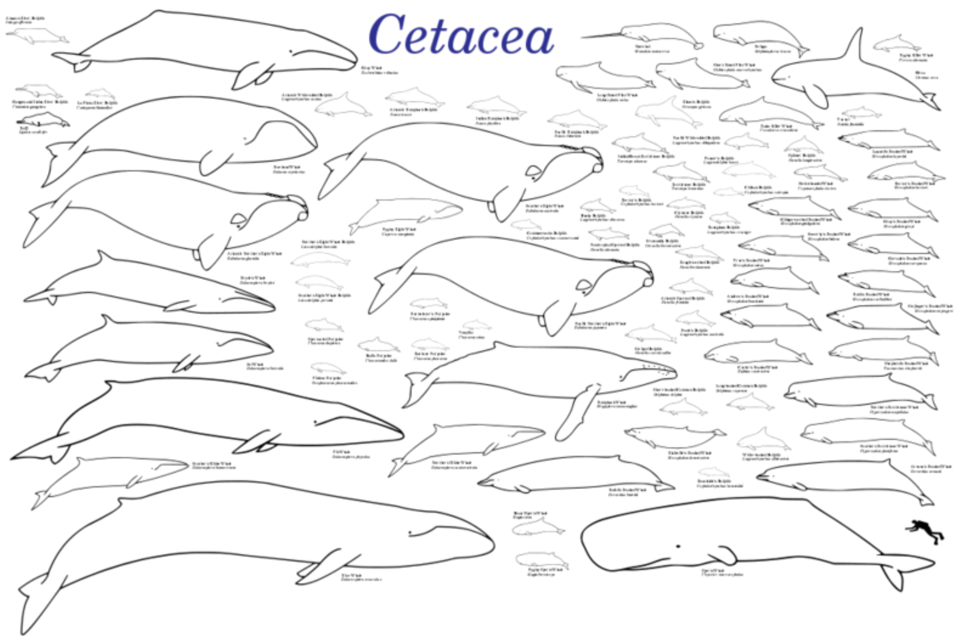
1. What determines if a body of water is freshwater?
2. What percentage of the Earth's water is freshwater?
3. What are wetlands?
4. List the different types of wetlands.
5. What are ponds and lakes?
6. List and explain the three zones of lakes and ponds.
7. What are streams and rivers?

Review

1. Describe how ecological zones in lakes are similar to ecological zones in oceans.
2. For many decades, people drained wetlands. Was this a good idea or a bad idea? Why?
3. How are marshes different from swamps? How are they the same?

10.7 Types of Marine Organisms

- Describe types of marine organisms.



How does the ocean seem all the same, yet have so much biodiversity?

Although it may seem like the ocean is all the same, there are many different habitats based on temperature, salinity, pressure, light, currents, and other factors. Organisms have adapted to these conditions in many interesting and effective ways. Covering 70% of Earth's surface, the oceans are home to a large portion of all life on Earth.

Types of Ocean Organisms

The smallest and largest animals on Earth live in the oceans. Why do you think the oceans can support large animals?

Marine animals breathe air or extract oxygen from the water. Some float on the surface and others dive into the ocean's depths. There are animals that eat other animals, and plants generate food from sunlight. A few bizarre creatures break down chemicals to make food! The following section divides ocean life into seven basic groups.

Plankton

Plankton are organisms that cannot swim but that float along with the current. The word "plankton" comes from the Greek for wanderer. Most plankton are microscopic, but some are visible to the naked eye (**Figure** 10.18).

Phytoplankton are tiny plants that make food by photosynthesis. Because they need sunlight, phytoplankton live in the photic zone. Phytoplankton are responsible for about half of the total **primary productivity** (food energy) on Earth. Like other plants, phytoplankton release oxygen as a waste product.

A video of a research vessel sampling plankton is seen here: http://www.youtube.com/watch?v=mQG4zAoh6xc#38;feature=channel.

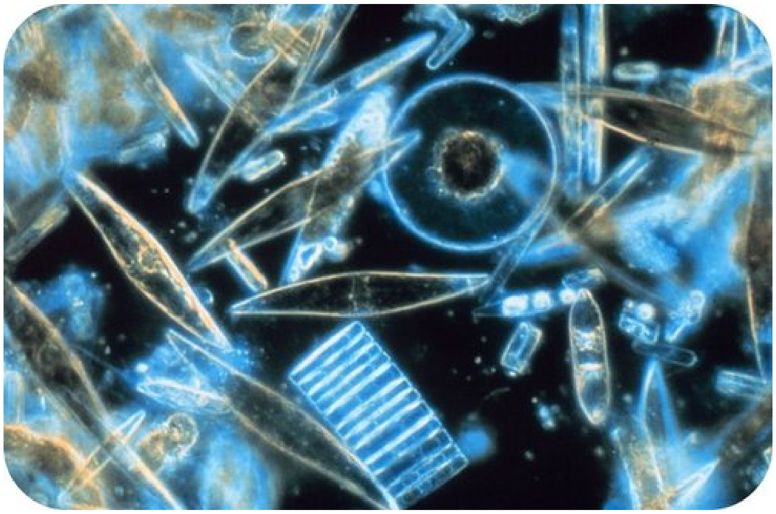


FIGURE 10.18
Microscopic diatoms are a type of phytoplankton.

Zooplankton, or animal plankton, eat phytoplankton as their source of food (**Figure** 10.19). Some zooplankton live as plankton all their lives and others are juvenile forms of animals that will attach to the bottom as adults. Some small invertebrates live as zooplankton.

FIGURE 10.19
Copepods are abundant and so are an important food source for larger animals.

Plants and Algae

The few true plants found in the oceans include salt marsh grasses and mangrove trees. Although they are not true plants, large algae, which are called seaweed, also use photosynthesis to make food. Plants and seaweeds are found in the neritic zone, where the light they need penetrates so that they can photosynthesize (**Figure** 10.20).

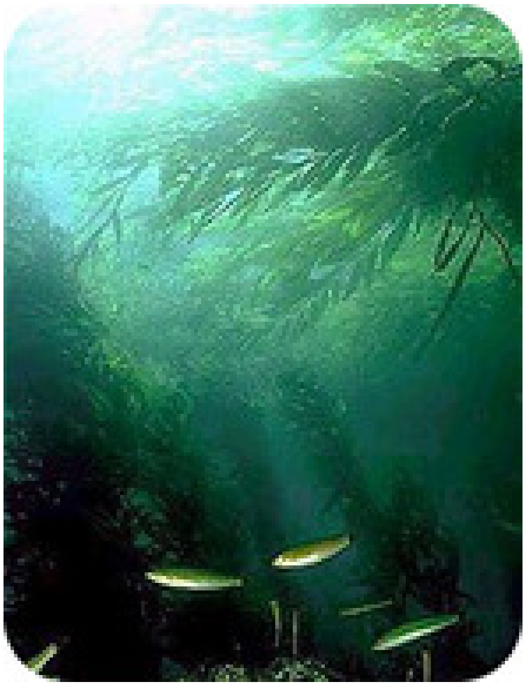


FIGURE 10.20

Kelp grows in forests in the neritic zone. Otters and other organisms depend on the kelp-forest ecosystem.

Marine Invertebrates

The variety and number of **invertebrates**, animals without a backbone, is truly remarkable (**Figure** 10.21). Marine invertebrates include sea slugs, sea anemones, starfish, octopuses, clams, sponges, sea worms, crabs, and lobsters. Most of these animals are found close to the shore, but they can be found throughout the ocean.

FIGURE 10.21

(a) Mussels; (b) Crown of thorns sea star; (c) Moon jelly; (d) A squid.

Jellies are otherworldly creatures that glow in the dark, without brains or bones, some more than 100 feet long. Along with many other ocean areas, they live just off California's coast.

Learn more about jellies by watching http://science.kqed.org/quest/video/amazing-jellies/.

MEDIA

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Fish

Fish are **vertebrates**; they have a backbone. What are some of the features fish have that allows them to live in the oceans? All fish have most or all of these traits:

- Fins with which to move and steer.
- Scales for protection.
- Gills for extracting oxygen from the water.
- A swim bladder that lets them rise and sink to different depths.
- Ectothermy (cold-bloodedness), so that their bodies are the same temperature as the surrounding water.
- Bioluminescence, or light created from a chemical reaction that can attract prey or mates in the dark ocean.

Included among the fish are sardines, salmon, and eels, as well as the sharks and rays (which lack swim bladders) (**Figure** 10.22).

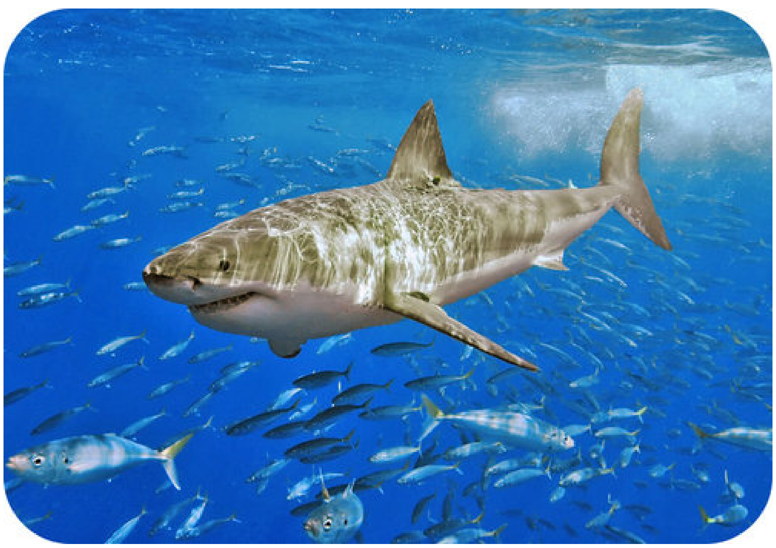


FIGURE 10.22

The Great White Shark is a fish that preys on other fish and marine mammals.

Reptiles

Only a few types of reptiles live in the oceans and they live in warm water. Why are reptiles so restricted in their ability to live in the sea? Sea turtles, sea snakes, saltwater crocodiles, and marine iguana that are found only at the Galapagos Islands sum up the marine reptile groups (**Figure** 10.23). Sea snakes bear live young in the ocean, but turtles, crocodiles, and marine iguanas all lay their eggs on land.

Seabirds

Many types of birds are adapted to living in the sea or on the shore. With their long legs for wading and long bills for digging in sand for food, shorebirds are well adapted for the intertidal zone. Many seabirds live on land but go to

FIGURE 10.23
Sea turtles are found all over the oceans, but their numbers are diminishing.

sea to fish, such as gulls, pelicans, and frigate birds. Some birds, like albatross, spend months at sea and only come on shore to raise chicks (**Figure** 10.24).

FIGURE 10.24
(a) Shorebirds; (b) Seabirds; (c) Albatross.

Marine Mammals

What are the common traits of mammals? Mammals are endothermic (warm-blooded) vertebrates that give birth to live young, feed them with milk, and have hair, ears, and a jaw bone with teeth.

What traits might mammals have to be adapted to life in the ocean?

- For swimming: streamlined bodies, slippery skin or hair, fins.
- For warmth: fur, fat, high metabolic rate, small surface area to volume, specialized blood system.

- For salinity: kidneys that excrete salt, impervious skin.

The five types of marine mammals are pictured here: (**Figure** 10.25).

FIGURE 10.25

(a) Cetaceans: whales, dolphins, and porpoises. (b) Sirenians: manatee and the dugong. (c) Mustelids: Sea otters (terrestrial members are skunks, badgers and weasels). (d) Pinnipeds: Seals, sea lions, and walruses. (e) Polar bear.

Vocabulary

- **invertebrate**: Animal with no backbone.
- **phytoplankton**: Tiny plants that photosynthesize and create food energy and oxygen.
- **plankton**: A diverse group of tiny animals and plants that freely drift in the water.
- **primary productivity**: The creation of food energy.
- **vertebrate**: Animal with a backbone.
- **zooplankton**: Tiny animals that float at the surface their whole lives or only part of their lives.

Summary

- Plankton are tiny organisms that are swept along on currents. Phytoplankton are tiny photosynthesizers and zooplankton are tiny animals.
- Fish have gills for breathing, swim bladders for rising and sinking, and other adaptations for life in the oceans.
- Shorebirds live at the interface of land and sea; some birds live on land but fish at sea, and some birds spend most of their time at sea and only come to shore to nest.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/news/animals-news/coml-complete-census-vin/

1. When did the census begin?

2. How many expeditions occurred during this census?

3. What was the purpose of this census?

4. What did the researchers find in Australia?

5. What did they discover about the tuna off of Northern Europe?

6. What did this census create?

Additional videos and information can be found at: http://www.coml.org/video-gallery.

Review

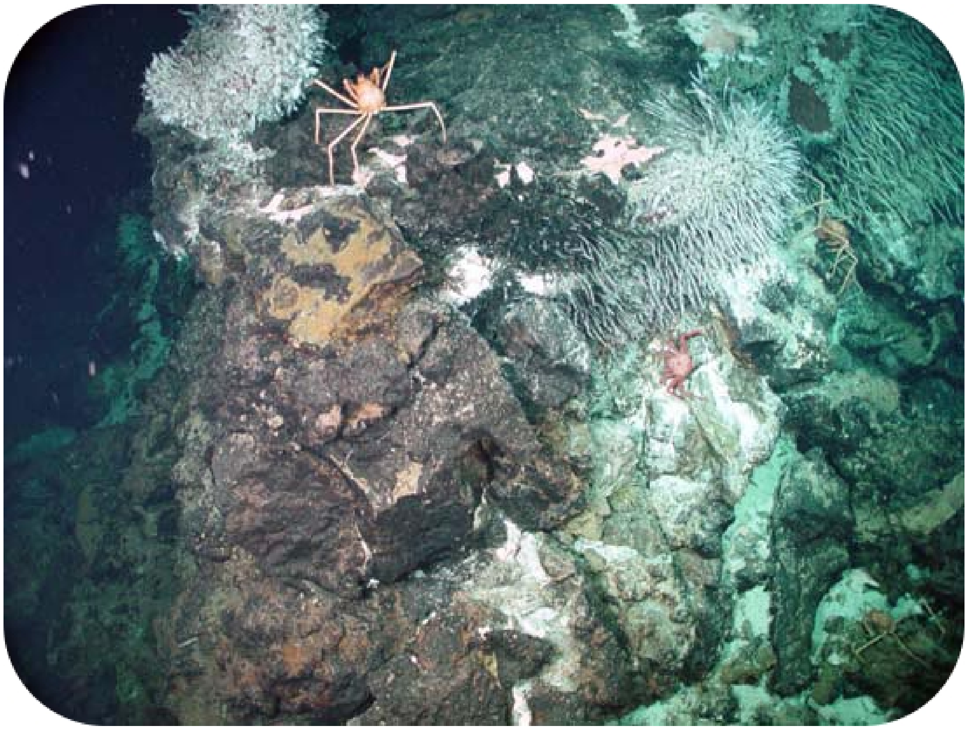
1. How are phytoplankton different from plants?

2. Describe how fish are adapted to life in the oceans.

3. Describe how marine mammals are adapted to life in the oceans. How are these adaptations different from those of fish?

10.8 Ocean Ecosystems

- Describe the various types of ocean ecosystems.



Which ecosystem doesn't depend on photosynthesis?

When scientists first dove in Alvin and witnessed hydrothermal vents, they were not surprised by the eruptions of hot water. But they never anticipated finding life there. Without sunlight, they knew that photosynthesis could not be the basis of this community. Eventually they discovered a different way of producing food, chemosynthesis. Many more hydrothermal vents were discovered and many more types of vent organisms.

The Intertidal

Conditions in the intertidal zone change rapidly as water covers and uncovers the region and waves pound on the rocks. A great abundance of life is found in the intertidal zone (**Figure** 10.26). High energy waves hit the organisms that live in this zone, so they must be adapted to pounding waves and exposure to air during low tides. Hard shells protect from waves and also protect against drying out when the animal is above water. Strong attachments keep the animals anchored to the rock.

In a tide pool, as in the photo, what organisms are found where and what specific adaptations do they have to that zone? The mussels on the top left have hard shells for protection and to prevent drying because they are often not covered by water. The sea anemones in the lower right are more often submerged and have strong attachments but can close during low tides.

Many young organisms get their start in estuaries and so they must be adapted to rapid shifts in salinity.

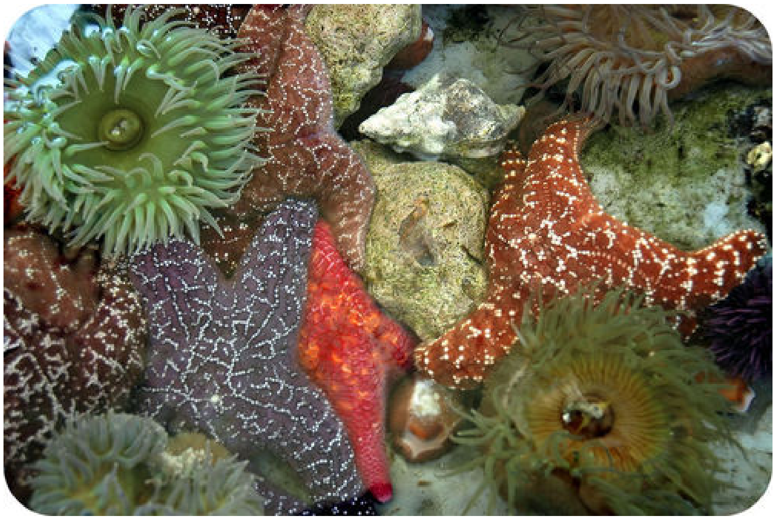


FIGURE 10.26
Organisms in a tide pool include sea stars and sea urchins.

Reefs

Corals and other animals deposit calcium carbonate to create rock **reefs** near the shore. Coral reefs are the "rainforests of the oceans," with a tremendous amount of species diversity (**Figure** 10.27).

FIGURE 10.27
Coral reefs are among the most densely inhabited and diverse areas on the globe.

Reefs can form interesting shapes in the oceans. Remember that hot spots create volcanoes on the seafloor. If these volcanoes rise above sea level to become islands, and if they occur in tropical waters, coral reefs will form on them. Since the volcanoes are cones, the reef forms in a circle around the volcano. As the volcano comes off the hot spot, the crust cools. The volcano subsides and then begins to erode away (**Figure** 10.28).

Eventually, all that is left is a reef island called an atoll. A lagoon is found inside the reef.

FIGURE 10.28
In this image of Maupiti Island in the South Pacific, the remnants of the volcano are surrounded by the circular reef.

Oceanic Zone

The open ocean is a vast area. Food either washes down from the land or is created by photosynthesizing plankton. Zooplankton and larger animals feed on the phytoplankton and on each other. Larger animals such as whales and giant groupers may live their entire lives in the open water.

How do fish survive in the deepest ocean? The few species that live in the greatest depths are very specialized (**Figure** 10.29). Since it's rare to find a meal, the fish use very little energy; they move very little, breathe slowly, have minimal bone structure and a slow metabolism. These fish are very small. To maximize the chance of getting a meal, some species may have jaws that unhinge to accept a larger fish or backward-folding teeth to keep prey from escaping.

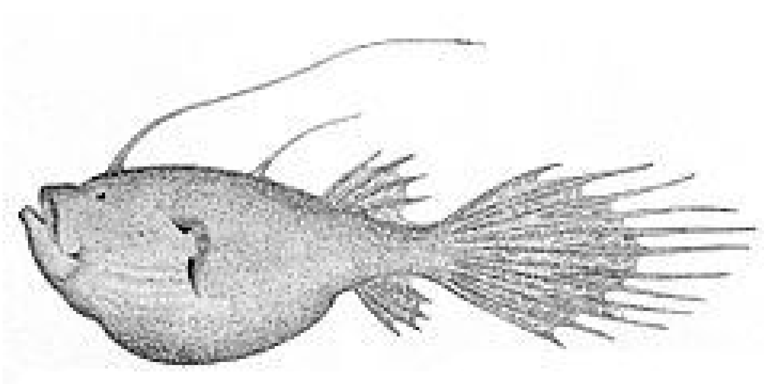


FIGURE 10.29
An 1896 drawing of a deep sea angler fish with a bioluminescent "lure" to attract prey.

Many ocean-related videos are found in National Geographic Videos, Environment Video, Habitat, Ocean section: http://video.nationalgeographic.com/video/player/environment/. Just a few are listed below.

- How we can know what lives in the ocean is in "Deep-Sea Robo Help."
- Some of the results of the Census of Marine Life have been released and are discussed in "Record-Breaking Sea-Creature Surveys Released."
- Bioluminescence is common in the oceans and seen in "Why Deep Sea Creatures Glow."

Hydrothermal Vents

Hydrothermal vents are among the most unusual ecosystems on Earth since they are dependent on chemosynthetic organisms at the base of the food web. At mid-ocean ridges at **hydrothermal vents**, bacteria that use **chemosynthesis** for food energy are the base of a unique ecosystem (**Figure** 10.30). This ecosystem is entirely separate from the photosynthesis at the surface. Shrimp, clams, fish, and giant tube worms have been found in these extreme places.

FIGURE 10.30
Giant tube worms found at hydrothermal vents get food from the chemosynthetic bacteria that live within them. The bacteria provide food; the worms provide shelter.

A video explaining hydrothermal vents with good footage is seen here: http://www.youtube.com/watch?v=rFHtVRKoaUM#38;feature=related.

Vocabulary

- **chemosynthesis**: The breakdown of chemicals to produce food energy.
- **hydrothermal vent**: A stream of heated water that enters into the ocean at a mid-ocean ridge.
- **reef**: A large underwater structure created from the calcium carbonate skeletons of coral.

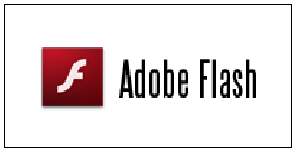
Summary

- In the ocean, phytoplankton photosynthesize as the main food source. They are eaten by zooplankton and other larger animals.
- Organisms that live in the deepest ocean have amazing adaptations to the exceptionally harsh conditions, such as unhinging jaws, backward-folding teeth, or a bioluminescent lure.
- A hydrothermal vent ecosystem has chemosynthesis as its food source. The ecosystem is independent of photosynthesis at the surface.

Practice

Use these resources to answer the questions that follow.

http://www.untamedscience.com/biology/world-biomes/intertidal-biome



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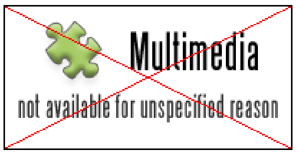
1. What is the intertidal zone?
2. What do organisms in an intertidal zone have to deal with each day?
3. What is zonation?
4. How have some of the organisms in the intertidal zone adapted to life there?

http://www.untamedscience.com/biology/world-biomes/deep-sea-biome



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5. Why is the deep sea not well explored?
6. What organisms live in the epipelagic zone?
7. What organisms live in the mesopelagic zone?
8. What color are most of the animals in this zone?
9. What is bioluminescence?
10. What is found in the deep scattering layer?

Review

1. Why is there so much biodiversity in the intertidal zone?
2. Why is survival in the deep ocean difficult? What adaptations to organisms have to do this?
3. What is bioluminescence and how does it help organisms survive in the ocean?

10.9 Adaptation and Evolution of Populations

- Define adaptation.
- Explain the theory of evolution by natural selection.

Why would an organism match its background? Wouldn't it be better to stand out?

An organism that blends with its background is more likely to avoid predators. If it survives, it is more likely to have offspring. Those offspring are more likely to blend into their backgrounds.

Adaptation

The characteristics of an organism that help it to survive in a given environment are called **adaptations**. Adaptations are traits that an organism inherits from its parents. Within a population of organisms are genes coding for a certain number of traits. For example, a human population may have genes for eyes that are blue, green, hazel, or brown, but as far as we know, not purple or lime green.

Adaptations develop when certain **variations** or differences in a population help some members survive better than others (**Figure** 10.31). The variation may already exist within the population, but often the variation comes from a **mutation**, or a random change in an organism's genes. Some mutations are harmful and the organism dies; in that case, the variation will not remain in the population. Many mutations are neutral and remain in the population. If the environment changes, the mutation may be beneficial and it may help the organism adapt to the environment. The organisms that survive pass this favorable trait on to their offspring.

Biological Evolution

Many changes in the genetic makeup of a species may accumulate over time, especially if the environment is changing. Eventually the descendants will be very different from their ancestors and may become a whole new species. Changes in the genetic makeup of a species over time are known as biological **evolution**.

Natural Selection

The mechanism for evolution is **natural selection**. Traits become more or less common in a population depending on whether they are beneficial or harmful. An example of evolution by natural selection can be found in the deer mouse, species *Peromyscus maniculatus*. In Nebraska this mouse is typically brown, but after glaciers carried lighter sand over the darker soil in the Sand Hills, predators could more easily spot the dark mice. Natural selection favored the light mice, and over time, the population became light colored.

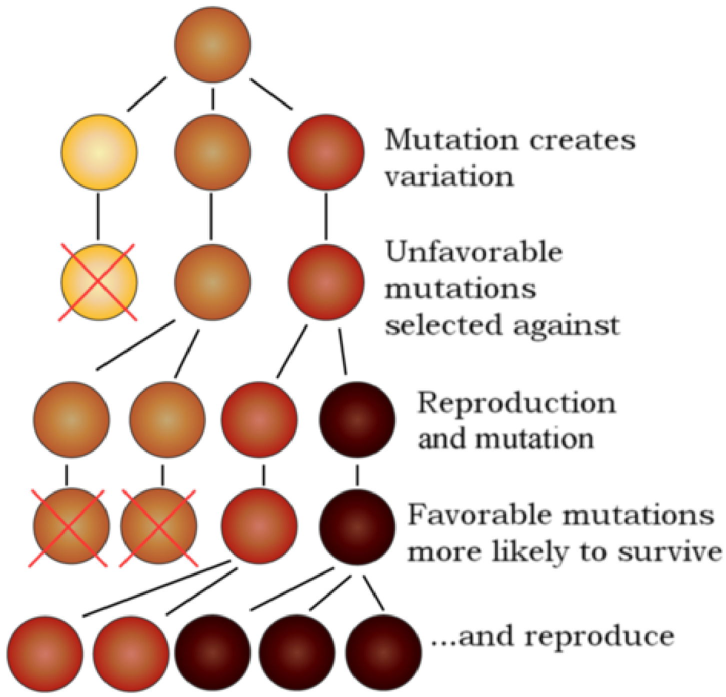


FIGURE 10.31
An explanation of how adaptations develop.

This story is covered in more detail here: http://news.harvard.edu/gazette/story/2009/08/mice-living-in-sand-hills-quickly-evolved-lighter-coloration/.

Vocabulary

- **adaptation**: A trait that an organism inherits that helps it survive in its natural environment.
- **evolution**: Change through time. The change in the genetic makeup of a population of organisms over time such that a new species is often the result.
- **mutation**: A change in the genetic makeup of a population of organisms that can be beneficial, harmful, or neutral.
- **natural selection**: The mechanism for evolution. Natural processes favor some traits over others in a population causing those traits to be more common in subsequent generations. This results in change to a new species or subspecies.
- **variation**: Having many differences.

Summary

- A population has genetic variations, possibly due to mutations. Favorable variations may allow an organism to be better adapted to its environment and survive to reproduce.

- Beneficial traits are favored in a population so that they may become better represented.
- Changes in the genetic makeup of a species may result in a new species; this is biological evolution.

Practice

Use these resources to answer the questions that follow.

http://www.hippocampus.org/Biology → Non-Majors Biology→ Search: **Natural Selection and Evolution**

1. What is natural selection?

2. What are genes?

3. How does natural selection effect the individual?

4. What does natural selection cause in populations?

http://www.youtube.com/watch?v=-mPCqYxB4d4

MEDIA

Click image to the left for more content.

5. How does variety occur in an individual?

6. How are genomes diversified and passed on to offspring?

Review

1. The Grand Canyon was carved, separating what had once been a single population of squirrel into two separate populations. What do you think happened to those populations over time?

2. How does natural selection work?

3. How does biological evolution work?

10.10 Population Size

- Describe the factors that regulate population size.

How many penguins are the right number for this beach?

As many as can survive and have healthy offspring! A population will tend to grow as big as it can for the resources it needs. Once it is too large, some of its members will die off. This keeps the population size at the right number.

Populations

Biotic and abiotic factors determine the population size of a species in an ecosystem. What are some important biotic factors? Biotic factors include the amount of food that is available to that species and the number of organisms that also use that food source. What are some important abiotic factors? Space, water, and climate all help determine a species population.

When does a population grow? A population grows when the number of births is greater than the number of deaths. When does a population shrink? When deaths exceed births.

What causes a population to grow? For a population to grow there must be ample resources and no major problems. What causes a population to shrink? A population can shrink either because of biotic or abiotic limits. An increase in predators, the emergence of a new disease, or the loss of habitat are just three possible problems that will decrease a population. A population may also shrink if it grows too large for the resources required to support it.

Carrying Capacity

When the number of births equals the number of deaths, the population is at its **carrying capacity** for that habitat. In a population at its carrying capacity, there are as many organisms of that species as the habitat can support. The carrying capacity depends on biotic and abiotic factors. If these factors improve, the carrying capacity increases. If the factors become less plentiful, the carrying capacity drops. If resources are being used faster than they are being replenished, then the species has exceeded its carrying capacity. If this occurs, the population will then decrease in size.

Limiting Factors

Every stable population has one or more factors that limit its growth. A **limiting factor** determines the carrying capacity for a species. A limiting factor can be any biotic or abiotic factor: nutrient, space, and water availability are examples (**Figure** 10.32). The size of a population is tied to its limiting factor.

FIGURE 10.32
In a desert such as this, what is the limiting factor on plant populations? What would make the population increase? What would make the population decrease?

What happens if a limiting factor increases a lot? Is it still a limiting factor? If a limiting factor increases a lot, another factor will most likely become the new limiting factor.

This may be a bit confusing, so let's look at an example of limiting factors. Say you want to make as many chocolate chip cookies as you can with the ingredients you have on hand. It turns out that you have plenty of flour and other ingredients, but only two eggs. You can make only one batch of cookies, because eggs are the limiting factor. But then your neighbor comes over with a dozen eggs. Now you have enough eggs for seven batches of cookies, but only two pounds of butter. You can make four batches of cookies, with butter as the limiting factor. If you get more butter, some other ingredient will be limiting.

Species ordinarily produce more offspring than their habitat can support (**Figure** 10.33). If conditions improve, more young survive and the population grows. If conditions worsen, or if too many young are born, there is competition between individuals. As in any competition, there are some winners and some losers. Those individuals that survive to fill the available spots in the niche are those that are the most fit for their habitat.

Vocabulary

- **carrying capacity**: The number of individuals of a given species a particular environment can support.
- **limiting factor**: The one factor that limits the population of a region. The limiting factor can be a nutrient, water, space, or any other biotic or abiotic factor that the species need.

FIGURE 10.33

A frog in frog spawn. An animal produces many more offspring than will survive.

Summary

- Biotic factors that a population needs include food availability. Abiotic factors may include space, water, and climate.
- The carrying capacity of an environment is reached when the number of births equal the number of deaths.
- A limiting factor determines the carrying capacity for a species.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Biology → Non-Majors Biology → Search: **Population Growth**

1. What is population growth?
2. What is the normal pattern of population growth?
3. What internal factors can limit population growth?
4. What external factors can limit population growth?
5. What are limiting factors? List examples.
6. What is carrying capacity?
7. What can cause carrying capacity to change?

Review

1. What happens if a population exceeds its carrying capacity?
2. What happens if a factor that has limited a population's size becomes more available?
3. How might a limiting factor lead to biological evolution?

10.11 Extinction and Radiation of Life

- Define extinction and explain why it occurs.
- Define adaptive radiation, and explain its relationship to extinction.

Should this pterodactyl be concerned? Should you?

When the dinosaurs were wiped out by an asteroid impact, the mammals were waiting to take over their niches. Could this happen again? Are there other ways species could go extinct and leave open niches for new organisms to fill?

Extinction

Most of the species that have lived have also gone extinct. There are two ways to go extinct: besides the obvious way of dying out completely, a species goes extinct if it evolves into a different species. Extinction is a normal part of Earth's history.

But sometimes large numbers of species go extinct in a short amount of time. This is a **mass extinction**. The causes of different mass extinctions are different: collisions with comets or asteroids, massive volcanic eruptions, or rapidly changing climate are all possible causes of some of these disasters (**Figure** 10.34).

Adaptive Radiation

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. With new habitats available, some species will adapt to the new environments. Evolutionary processes act rapidly during

FIGURE 10.34
An extinct *Tyrannosaurus rex*. This fossil resembling a living organism.

these times and many new species evolve to fill those available habitats. The process in which many new species evolve in a short period of time to fill available niches is called **adaptive radiation**. At the end of this period of rapid evolution the life forms do not look much like the ones that were around before the mass extinction. For example, after the extinction of the dinosaurs, mammals underwent adaptive radiation and became the dominant life form.

Vocabulary

- **adaptive radiation**: An explosion in the diversity of species as vacant niches are filled. This often occurs after a mass extinction.
- **mass extinction**: An extinction in which a large percentage of species go extinct.

Summary

- Species go extinct when all of the individuals die out or evolve into a different species.
- Many species go extinct at roughly the same time during a mass extinction.
- New habitats become available and species evolve to fill them so that biodiversity increases during adaptive radiation.

Practice

Use this resource to answer the questions that follow.

http://news.discovery.com/videos/why-tell-me-why-mass-extinction.html

MEDIA
Click image to the left for more content.

1. What percentage of all species are now extinct?
2. What is a mass extinction?
3. Why do extinctions occur?
4. What allows species to survive?
5. What is the cause of the current mass extinction?
6. How may species face extinction in the next 100 years?

Review

1. Why is extinction considered a normal part of Earth's history?
2. What are some of the possible causes of mass extinctions?
3. Why do many new species evolve after a mass extinction?

10.12 Characteristics and Origins of Life

- Describe the characteristics and origins of life on Earth, and explain how scientists study early life.

What is *life*?

How can you tell a blob of organic material from a living creature? What characteristics does something need to be considered alive? Is this material rust or is it bacteria?

The Origin Of Life

No one knows how or when life first began on the turbulent early Earth. There is little hard evidence from so long ago. Scientists think that it is extremely likely that life began and was wiped out more than once; for example, by the impact that created the Moon.

This issue of what's living and what's not becomes important when talking about the origin of life. If we're going to know when a blob of organic material crossed over into being alive, we need to have a definition of life.

Characteristics of Life

To be considered alive a molecule must:

- be organic. The organic molecules needed are amino acids, the building blocks of life.
- have a metabolism.
- be capable of replication (be able to reproduce).

Learning About the Origin of Life

To look for information regarding the origin of life, scientists:

- perform experiments to recreate the environmental conditions found at that time.
- study the living creatures that make their homes in the types of extreme environments that were typical in Earth's early days.
- seek traces of life left by ancient microorganisms, also called **microbes**, such as microscopic features or isotopic ratios indicative of life. Any traces of life from this time period are so ancient it is difficult to be certain whether they originated by biological or non-biological means.

Amino Acids

Amino acids are the building blocks of life because they create proteins. To form proteins, the amino acids are linked together by covalent bonds to form polymers called polypeptide chains (**Figure** 10.35).

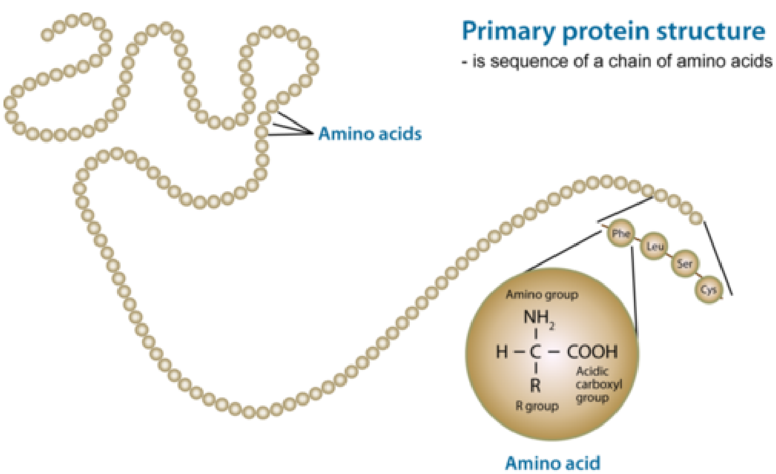


FIGURE 10.35
Amino acids form polypeptide chains.

These chains are arranged in a specific order to form each different type of protein. Proteins are the most abundant class of biological molecules.

An important question facing scientists is where the first amino acids came from: did they originate on Earth or did they fly in from outer space? No matter where they originated, the creation of amino acids requires the right starting materials and some energy.

Miller-Urey Experiment

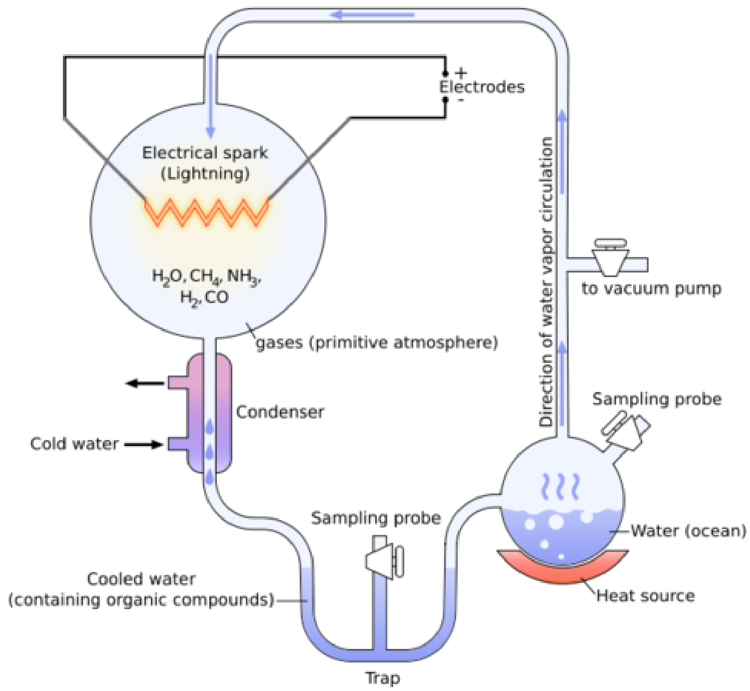


FIGURE 10.36
The setup of the Miller-Urey experiment.

To see if amino acids could originate in the environment thought to be present in the first years of Earth's existence, Stanley Miller and Harold Urey performed a famous experiment in 1953. To simulate the early atmosphere they placed hydrogen, methane, and ammonia in a flask of heated water that created water vapor, which they called the primordial soup. Sparks simulated lightning, which the scientists thought could have been the energy that drove the chemical reactions that created the amino acids. It worked! The gases combined to form water-soluble organic compounds including amino acids.

A dramatic reenactment of this experiment is performed on this video from the 1980 TV show Cosmos: http://www.youtube.com/watch?v=yet1xkAv_HY#38;feature=related. At the end you can learn about the possible role of RNA.

Amino acids might also have originated at hydrothermal vents or deep in the crust where Earth's internal heat is the energy source. Meteorites containing amino acids currently enter the Earth system and so meteorites could have delivered amino acids to the planet from elsewhere in the solar system (where they would have formed by processes similar to those outlined here).

Vocabulary

- **amino acids**: Organic molecules that are the building blocks of life.
- **microbe**: A microorganism.

Summary

- Amino acids are linked by covalent bonds to form peptide chains that are ordered to create specific types of proteins.
- For something to be alive it must be organic, have a metabolism, and be capable of replication.

- Miller and Urey simulated the early atmosphere with hydrogen, methane, ammonia, and water vapor, to which they added sparks and created amino acids.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/100-greatest-discoveries-shorts-origin-of-life.html

MEDIA

Click image to the left for more content.

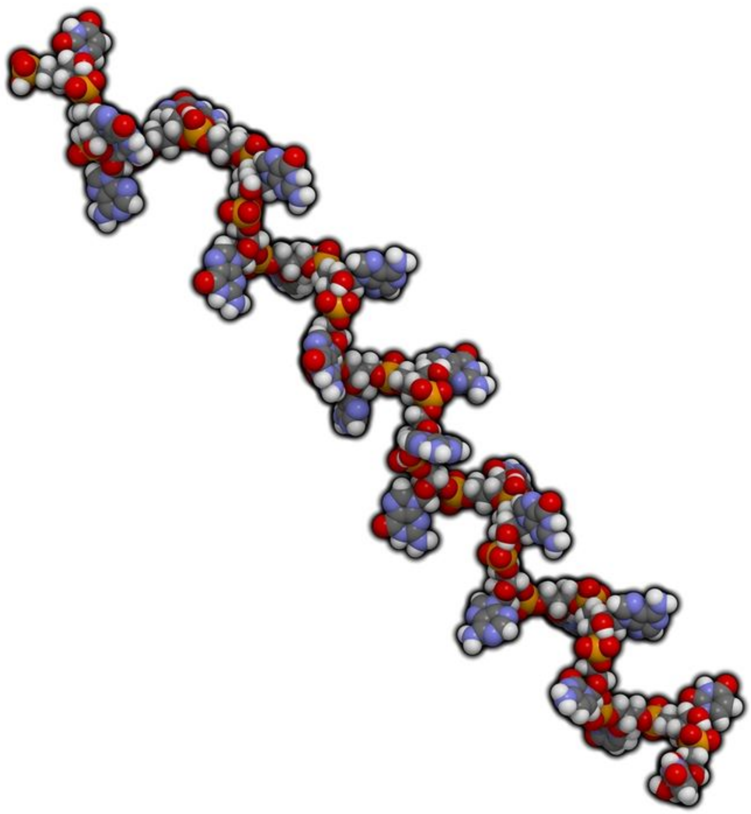
1. Who was Stanley Miller?
2. What was Miller's experiment?
3. What gases did he use in his experiment? Why?
4. What did Miller discover?
5. Explain the importance of this experiment.

Review

1. Why must something that is alive be capable of replication?
2. Why do scientists that are interested in the origin of life study extreme environments?
3. How do scientists learn about the origins of life?

10.13 Metabolism and Replication

- Define metabolism.
- Describe the relationship between nucleic acids and replication.
- Explain the RNA world hypothesis.



What is an RNA world?

Life must self-replicate, a task that is mostly accomplished with DNA today. Some scientists think that the first replicator was not DNA but RNA. They call this the RNA world hypothesis.

Metabolism

Organic molecules must also carry out the chemical work of cells; that is, their **metabolism**. Chemical reactions in a living organism allow that organism to live in its environment, grow, and reproduce. Metabolism gets energy from other sources and creates structures needed in cells. The chemical reactions occur in a sequence of steps known as metabolic pathways. The metabolic pathways are very similar between unicellular bacteria that have been around for billions of years and the most complex life forms on Earth today. This means that they evolved very early in Earth's history.

Replication

Living cells need organic molecules, known as **nucleic acids**, to store genetic information and pass it to the next generation. Deoxyribonucleic acid (DNA) is the nucleic acid that carries information for nearly all living cells today and did for most of Earth's history. Ribonucleic acid (RNA) delivers genetic instructions to the location in a cell where protein is synthesized.

The famous double helix structure of DNA is seen in this animation: http://upload.wikimedia.org/wikipedia/commons/8/81/ADN_animation.gif.

RNA World

Many scientists think that RNA was the first replicator. Since RNA catalyzes protein synthesis, most scientists think that RNA came before proteins. RNA can also encode genetic instructions and carry it to daughter cells, such as DNA.

The idea that RNA is the most primitive organic molecule is called the **RNA world hypothesis**, referring to the possibility that the RNA is more ancient than DNA. RNA can pass along genetic instructions as DNA can, and some RNA can carry out chemical reactions like proteins can.

A video explaining the RNA world hypothesis is seen here: http://www.youtube.com/watch?v=sAkgb3yNgqg.

Pieces of many scenarios can be put together to come up with a plausible suggestion for how life began.

Vocabulary

- **metabolism**: The chemical work of cells; the chemical reactions a living organism needs to live, grow and reproduce.
- **nucleic acid**: Biological molecules necessary for life; includes DNA and RNA
- **RNA world hypothesis**: RNA was the first nucleic acid and the only one at the beginning of life.

Summary

- An organism's metabolism is the chemical reactions that allow it to live, grow, and reproduce.
- Nucleic acids pass genetic information to the next generation: DNA for living cells, and RNA for protein synthesis.
- The RNA world hypothesis suggests that RNA was the first nucleic acid to evolve and DNA came later.

Practice

Use this resource to answer the questions that follow.

http://exploringorigins.org/ribozymes.html

1. What does the Tetrahymena ribozyme do to RNA?

2. What is the RNA World Hypothesis?

3. Who proposed the RNA World Hypothesis?

4. What is the strongest evidence for the RNA World Hypothesis?

5. What is translation?

Review

1. What is the purpose of an organism's metabolism?
2. Why is the fact that metabolic pathways are similar between organisms significant?
3. Explain the RNA world hypothesis. What evidence should scientists look for to support this idea?

10.14 Evolution of Simple Cells

- Identify and describe key developments in the evolution of early life on Earth.

Who was the ancestor to us all (and I really mean us ALL)?

If we trace all the evolutionary lineages (humans, sponges, slime molds, etc.) back, at some point there would be one organism that is the ancestor to all of the others. This organism is referred to as LUCA, which stands for the "Last Universal Common Ancestor." LUCA lived 3.5 to 3.8 billion years ago.

Simple Cells Evolve

Simple organic molecules such as proteins and nucleic acids eventually became complex organic substances. Scientists think that the organic molecules adhered to clay minerals, which provided the structure needed for these substances to organize. The clays, along with their metal cations, catalyzed the chemical reactions that caused the molecules to form polymers. The first RNA fragments could also have come together on ancient clays.

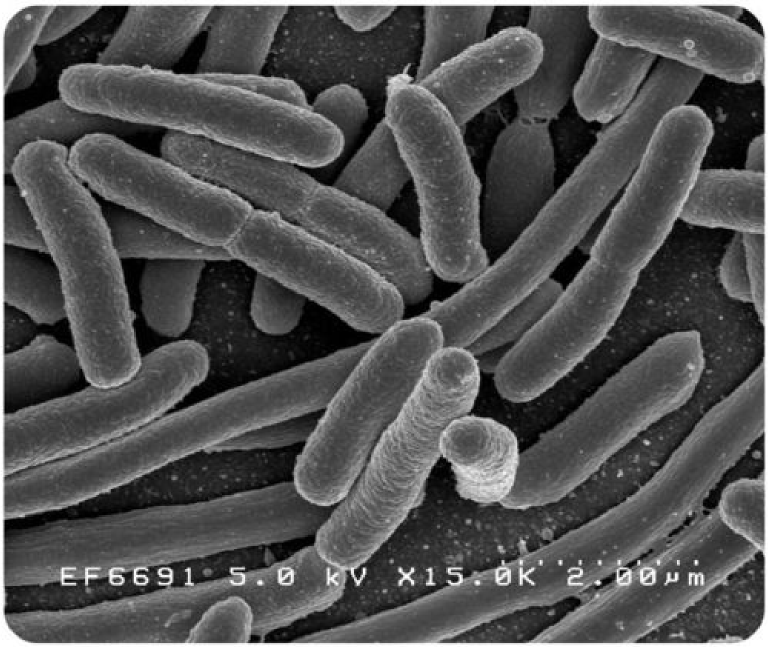


FIGURE 10.37

E. coli (*Escherichia coli*) is a primitive prokaryote that may resemble the earliest cells.

For an organic molecule to become a cell, it must be able to separate itself from its environment. To enclose the molecule, a lipid membrane grew around the organic material. Eventually the molecules could synthesize their own organic material and replicate themselves. These became the first cells.

Prokaryotes

The earliest cells were **prokaryotes** (**Figure** 10.37). Although prokaryotes have a cell membrane, they lack a cell nucleus and other organelles. Without a nucleus, RNA was loose within the cell. Over time the cells became more complex.

LUCA was a prokaryote but differed from the first living cells because its genetic code was based on DNA. The oldest fossils are tiny microbe-like objects that are 3.5 billion years old. Evidence for bacteria, the first single-celled life forms, goes back 3.5 billion years (**Figure** 10.38).

To learn more about LUCA's characteristics, see Wikipedia: http://en.wikipedia.org/wiki/Last_universal_ancestor.

This animation begins with the Big Bang, which will be discussed in Concept Beyond the Solar System, and goes through the history of life on Earth: http://www.johnkyrk.com/evolution.html.

Photosynthesis

The earliest life forms did not have the ability to photosynthesize. Without photosynthesis what did the earliest cells eat? Most likely they absorbed the nutrients that floated around in the organic soup that surrounded them. After hundreds of millions of years, these nutrients would have become less abundant.

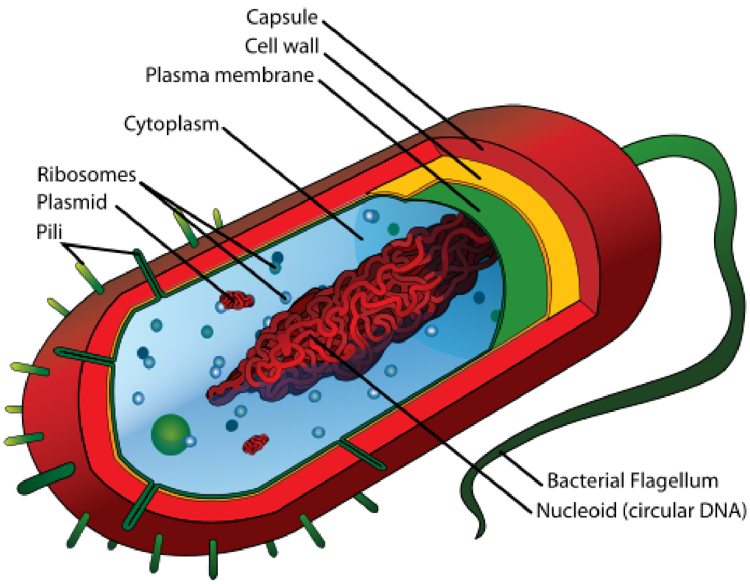


FIGURE 10.38
A diagram of a bacterium.

Sometime around 3 billion years ago (about 1.5 billion years after Earth formed!), photosynthesis began. **Photosynthesis** allowed organisms to use sunlight and inorganic molecules, such as carbon dioxide and water, to create chemical energy that they could use for food. To photosynthesize, a cell needs chloroplasts (**Figure** 10.39).

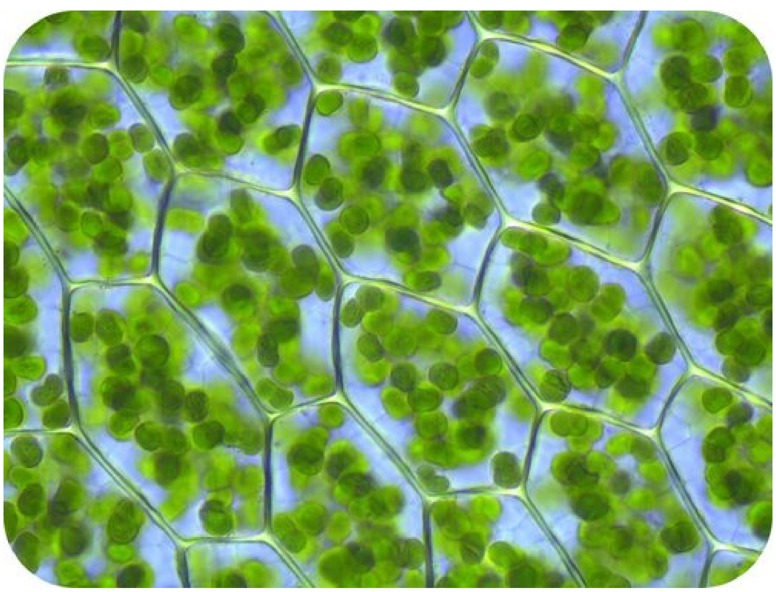


FIGURE 10.39
Chloroplasts are visible in these cells found within a moss.

Importance of Photosynthesis

In what two ways did photosynthesis make the planet much more favorable for life?

1. Photosynthesis allowed organisms to create food energy so that they did not need to rely on nutrients floating around in the environment. Photosynthesizing organisms could also become food for other organisms.

2. A byproduct of photosynthesis is oxygen. When photosynthesis evolved, all of a sudden oxygen was present in large amounts in the atmosphere. For organisms used to an anaerobic environment, the gas was toxic, and many organisms died out.

Cyanobacteria

What were these organisms that completely changed the progression of life on Earth by changing the atmosphere from anaerobic to aerobic? The oldest known fossils that are from organisms known to photosynthesize are **cyanobacteria**. Cyanobacteria were present by 2.8 billion years ago, and some may have been around as far back as 3.5 billion years.

Cyanobacteria were the dominant life forms in the Archean. Why would such a primitive life-form have been dominant in the Precambrian? Many cyanobacteria lived in reef-like structures known as **stromatolites** (**Figure** 10.40). Stromatolites continued on into the Cambrian but their numbers declined.

FIGURE 10.40

These rocks in Glacier National Park, Montana may contain some of the oldest fossil microbes on Earth.

Modern cyanobacteria are also called blue-green algae. These organisms may consist of a single or many cells and they are found in many different environments (**Figure** 10.41). Even now cyanobacteria account for 20% to 30% of photosynthesis on Earth.

Vocabulary

- **cyanobacteria**: Single celled prokaryotes that were extremely abundant in the Precambrian and that changed the atmosphere to one containing oxygen.
- **photosynthesis**: The process in which plants produce simple sugars (food energy) from carbon dioxide, water, and energy from sunlight. Photosynthesis uses carbon dioxide and releases oxygen.
- **prokaryote**: An organism that lacks a cell nucleus or membrane-bound organelles.
- **stromatolite**: Reef like cyanobacteria that still exist today.

Summary

- A prokaryote has a cell membrane but otherwise organelles are loose within the cell.
- Photosynthesis allows organisms to produce food energy with oxygen as a by-product.

FIGURE 10.41
A large bloom of cyanobacteria is harmful to this lake.

- Cyanobacteria, which are still around today, were the earliest known photosynthesizing organisms.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=uU00tg98Jjw

MEDIA
Click image to the left for more content.

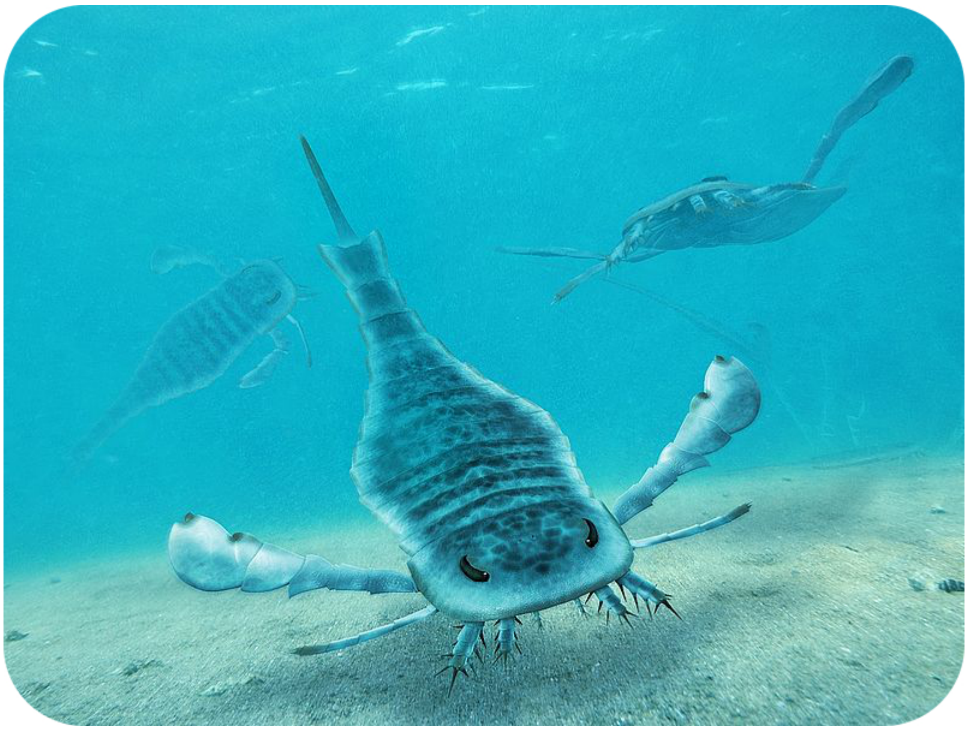
1. What are cyanobacteria?
2. When did cyanobacteria dominate the Earth?
3. How does a prokaryotic cell differ from a eukaryotic cell?
4. What are cyanobacteria responsible for?
5. Where are cyanobacteria found?
6. What are stromatolites?
7. What is a heterocyst? What does it do?
8. What is an akinete? What is its function?

Review

1. Why does there need to be a LUCA and how can scientists learn about it?
2. Why was the development of photosynthesis so important to the evolution of life?
3. What is the role of modern, primitive photosynthesizing organisms?

10.15 Evolution of Eukaryotes to Multicellular Life

- Identify and describe key developments in the evolution of eukaryotes and multicellular organisms.



Is this an ancestor of modern life? How can we tell?

No one knows quite how to categorize these organisms. Some scientists think that they are the ancestors of organisms that came later. Others think that the Ediacara fauna died out and that the organisms that took over during the Cambrian were a different group. It may not be possible to know the solution to this problem.

Evolution of Eukaryotes

About 2 billion years ago, **eukaryotes** evolved. Eukaryotic cells have a nucleus that encloses their DNA and RNA. All complex cells and nearly all multicellular animals are eukaryotic.

The evolution of eukaryotes from prokaryotes is an interesting subject in the study of early life. Scientists think that small prokaryotic cells began to live together in a **symbiotic** relationship; that is, different types of small cells were beneficial to each other and none harmed the others. The small cell types each took on a specialized function and became the organelles within a larger cell. Organelles supplied energy, broke down wastes, or did other jobs that were needed for cells to become more complex.

What is thought to be the oldest eukaryote fossil found so far is 2.1 billion years old. Eukaryotic cells were much better able to live and replicate themselves, so they continued to evolve and became the dominant life form over prokaryotic cells.

Multicellular Life

Prokaryotes and eukaryotes can both be multicellular. The first multicellular organisms were probably prokaryotic cyanobacteria. Multicellularity may have evolved more than once in Earth's history, likely at least once for plants and once for animals.

Early multicellular organisms were soft bodied and did not fossilize well, so little remains of their existence.

Ediacara Fauna

Although the explosion in the number and type of life forms did not come until the beginning of the Cambrian, life at the end of the Precambrian became more complex. Paleontologists find worldwide evidence of a group of extremely diverse multicellular organisms toward the end of the Precambrian (580-542 million years ago). The organism in the introduction is a member of the Ediacara fauna. These organisms have a variety of forms of symmetry, range from soft to rigid, and they take the form of discs, bags, or even "quilted mattresses" (**Figure** 10.42). The organisms seem to have appeared as Earth defrosted from a worldwide glaciation.

FIGURE 10.42
An example of an Ediacara organism.

Why So Long?

Why did it take 4 billion years for organisms as complex as the Ediacara biota to evolve? Scientists do not really know, although there are many possible explanations:

- Evolutionary processes are slow and it took a long time for complexity to evolve.
- There was no evolutionary advantage to being larger and more complex.
- Atmospheric oxygen was limited, so complex organisms could not evolve.
- The planet was too cold for complex life.
- Complex life evolved but was wiped out by the massive global glaciations.

Why Did They Die Out?

Scientists do not know for sure whether the Edicara organisms died out, but most think that they did. If they did die out, the scientists don't know why. Some possibilities include:

- The evolution of predators with skeletons in the Cambrian.
- Competition from more advanced Cambrian organisms.
- Changes in environmental conditions caused by supercontinent breakups, including rising sea level, limited nutrients, or changing atmospheric and oceanic chemistry.

The existence of the Ediacaran fauna does show that a diversity of life forms existed before the Cambrian.

Vocabulary

- **eukaryote**: A cell with a separate nucleus to hold its DNA and RNA.
- **symbiotic**: A relationship between organisms in which each benefits and none is harmed.

Summary

- Eukaryotic cells may have evolved from a symbiotic relationship between specialized prokaryotic cells.
- There are many reasons why complex life may have taken so long to evolve, including the rate of evolutionary processes, the lack of an evolutionary advantage, unfavorable environmental conditions, or mass extinctions.
- Ediacara organisms probably went extinct due to advances in predators, competition, or changes in environmental conditions.

Practice

Use this resource to answer the questions that follow.

The Evolution of Multicellular life

http://www.youtube.com/watch?v=6GDdfB1wbOg

MEDIA

Click image to the left for more content.

1. What has the experiment with yeast shown?
2. How many times has multicellular life developed on Earth?
3. What did scientists use to create multicellular yeast?
4. What did the yeast clusters prove?
5. Why is this study important?
6. What is the next step for scientists?

Review

1. How did eukaryotes evolve from prokaryotes?
2. Why did it take so long for multicellular, complex organisms to evolve?
3. If the Edicara fauna died out, who are the ancestors of life on Earth?

10.16 History of Paleozoic Life

- The describe the diversification and extinction of life during the Paleozoic.

If you woke up and found yourself in the Paleozoic, would you recognize the planet?

Probably not. You'd see things like this bizarre soft-bodied animal. The creature had five eyes, and a long nose like a vacuum cleaner hose. This creature was found as a fossil in the Burgess shale.

Paleozoic Life

The Paleozoic saw the evolution a tremendous diversity of life throughout the seas and onto land.

Cambrian Explosion

The Cambrian began with the most rapid and far-reaching evolution of life forms ever in Earth's history. Evolving to inhabit so many different habitats resulted in a tremendous diversification of life forms. Shallow seas covered the lands, so every major marine organism group, including nearly all invertebrate animal phyla, evolved during this time. With the evolution of hard body parts, fossils are much more abundant and better preserved from this period than from the Precambrian.

The Burgess shale formation in the Rocky Mountains of British Columbia, Canada, contains an amazing diversity of middle Cambrian life forms, from about 505 million years ago. Paleontologists do not agree on whether the Burgess shale fossils can all be classified into modern groups of organisms or whether many represent lines that have gone completely extinct.

Paleozoic Evolution

Throughout the Paleozoic, seas transgressed and regressed. When continental areas were covered with shallow seas, the number and diversity of marine organisms increased. During regressions the number shrank. Arthropods, fish, amphibians and reptiles all originated in the Paleozoic.

FIGURE 10.43
Trilobites were shallow marine animals that flourished during the lower Paleozoic.

Simple plants began to colonize the land during the Ordovician, but land plants really flourished when seeds evolved during the Carboniferous (**Figure** 10.44). The abundant swamps became the coal and petroleum deposits that are the source of much of our fossil fuels today. During the later part of the Paleozoic, land animals and insects greatly increased in numbers and diversity.

FIGURE 10.44
A modern rainforest has many seed-bearing plants that are similar to those that were common during the Carboniferous.

Mass Extinctions

Large extinction events separate the periods of the Paleozoic. After extinctions, new life forms evolved (**Figure**). For example, after the extinction at the end of the Ordovician, fish and the first tetrapod animals appeared. Tetrapods are four legged vertebrates, but the earliest ones did not leave shallow, brackish water.

Permian Extinction

The largest mass extinction in Earth's history occurred at the end of the Permian period, about 250 million years ago. In this catastrophe, it is estimated that more than 95% of marine species on Earth went extinct. Marine species with calcium carbonate shells and skeletons suffered worst. About 70% of terrestrial vertebrate species (land animals) suffered the same fate. This was the only known mass extinction of insects.

This mass extinction appears to have taken place in three pulses, with three separate causes. Gradual environmental change, an asteroid impact, intense volcanism, or changes in the composition of the atmosphere may all have played a role.

Summary

- During the Cambrian explosion many more life forms evolved than at any other time in Earth's history.
- Today's fossil fuels originated in the tremendous number of plants that spread over the land during the Carboniferous.
- The major periods of the Paleozoic are separated by extinction events, the largest of which brought the end of the Paleozoic.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=hDbz2dpebhQ

MEDIA

Click image to the left for more content.

1. What were the first creatures to dominate the land?
2. What happened 250 million years ago?
3. What is a flood basalt eruption?
4. What happened to the Earth's temperature during this extinction?
5. What occurs when the Earth's temperature raises 4-5 degrees?
6. When did the extinction event begin?
7. When did the marine extinction phase begin?
8. What caused the increase of carbon-12?

Review

1. Give three reasons that the Cambrian is significant for the evolution of life.
2. How did extinctions during the Paleozoic lead to changes in life forms?
3. What brought about the Permian extinction?

If you wound up in the Mesozoic would you recognize Earth?

So if you woke up in the Paleozoic, you probably wouldn't recognize Earth. How about if you woke up in the Mesozoic? In some ways, the planet would look a lot more like it does today. Animals would fill the niches you're used to seeing animals fill. But if you looked closely, you'd see that the animals are mostly all reptiles. And some of them may be interested in having you for dinner!

Mesozoic Life

With most niches available after the mass extinction, a great diversity of organisms evolved. Mostly these niches were filled with reptiles.

Climate alternated between cool, warm, and tropical, but overall the planet was much warmer than today. These conditions were good for reptiles. Surprisingly, there was more oxygen in the Mesozoic atmosphere than there is today.

Marine Life

Tiny phytoplankton arose to become the base of the marine food web. At the beginning of the Mesozoic, Pangaea began to break apart, so more beaches and continental shelf areas were available for colonization by new species of marine organisms. Marine reptiles colonized the seas and diversified. Some became huge, filling the niches that are filled by large marine mammals today.

Terrestrial Life

On land, seed plants and trees diversified and spread widely. Lush forests covered much of the land, especially at higher altitudes. Flowering plants evolved during the Cretaceous (**Figure** 10.45).

Dinosaurs

Of course the most famous Mesozoic reptiles were the dinosaurs. Dinosaurs reigned for 160 million years and had tremendous numbers and diversity. Species of dinosaurs filled all the niches that are currently filled by mammals. Dinosaurs were plant eaters, meat eaters, bipedal, quadrupedal, endothermic (warm-blooded), exothermic (cold-blooded), enormous, small, and some could swim or fly.

Scientists now think that some dinosaurs were endotherms (warm-blooded) due to the evidence that has been collected over the decades. There are still some scientists who do not agree, but the amount of evidence makes it likely. Some dinosaurs lived in polar regions where animals that needed sunlight for warmth could not survive in winter. Dinosaurs bones had canals, similar to those of birds, indicating that they grew fast and were very active. Fast growth usually indicates an active metabolism typical of endotherms. Dinosaurs had erect posture and large brains, both correlated with endothermy.

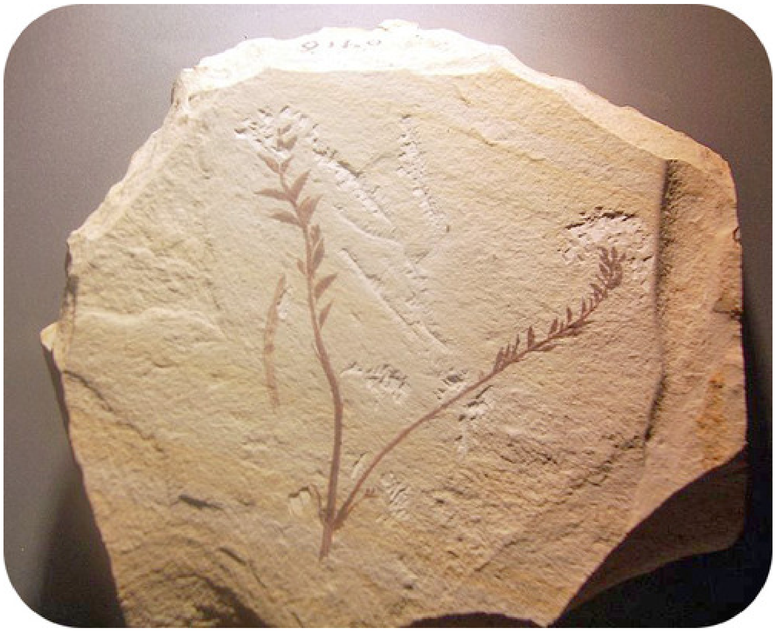


FIGURE 10.45
The earliest known fossil of a flowering plant is this 125 million year old Cretaceous fossil.

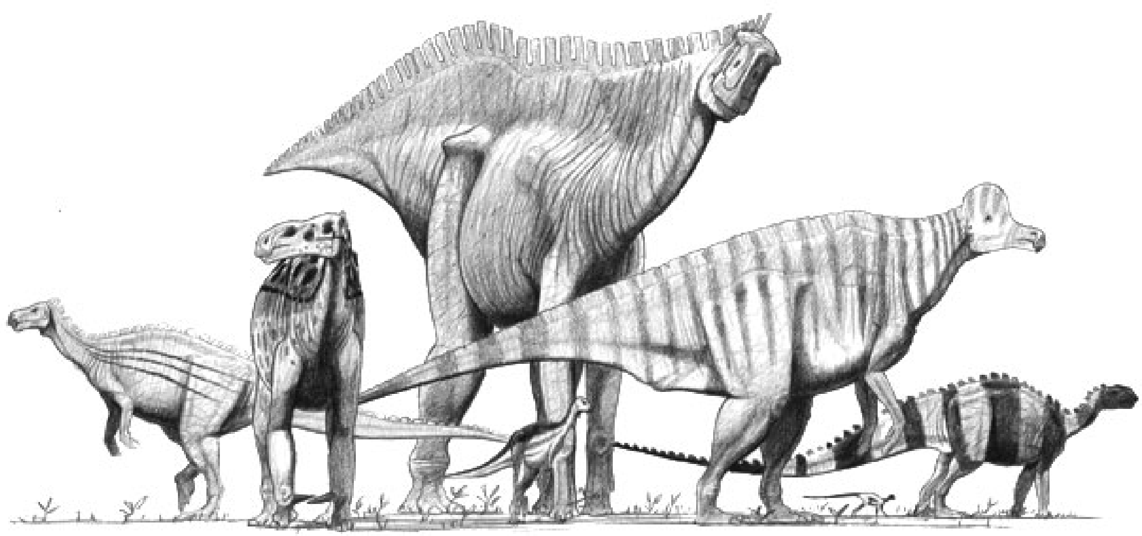


FIGURE 10.46
Some examples of Mesozoic dinosaurs include the Ornithopods. Pictured far left: Camptosaurus, left: Iguanodon, center background: Shantungosaurus, center foreground: Dryosaurus, right: Corythosaurus, far right (small): Heterodontosaurus, far right (large) Tenontosaurus.

An interesting look at the points for dinosaur endothermy is seen here: http://www.ucmp.berkeley.edu/diapsids/endothermy.html.

Rise of the Mammals

Mammals appeared near the end of the Triassic, but the Mesozoic is known as the age of the reptiles. In a great advance over amphibians, which must live near water, reptiles developed adaptations for living away from water. Their thick skin keeps them from drying out, and the evolution of the amniote egg allowed them to lay their eggs on dry land. The **amniote egg** has a shell and contains all the nutrients and water required for the developing embryo.

FIGURE 10.47
Amniotic egg containing a tortoise hatchling.

Cretaceous Mass Extinction

Between the Mesozoic and the Cenozoic, 65 million years ago, about 50% of all animal species, including the dinosaurs, became extinct. Although there are other hypotheses, most scientists think that this mass extinction took place when a giant meteorite struck Earth with the energy of the most powerful nuclear weapon (**Figure** 10.48).

The impact kicked up a massive dust cloud, and when the particles rained back onto the surface they heated the atmosphere until it became as hot as a kitchen oven. Animals roasted. Dust that remained in the atmosphere blocked sunlight for a year or more, causing a deep freeze and temporarily ending photosynthesis. Sulfur from the impact mixed with water in the atmosphere to form acid rain, which dissolved the shells of the tiny marine plankton that form the base of the food chain. With little food being produced by land plants and plankton, animals starved. Carbon dioxide was also released from the impact and eventually caused global warming. Life forms could not survive the dramatic temperature swings.

You may be surprised to know that dinosaurs in one form survived the mass extinctions and live all over the world today. Birds evolved from theropod dinosaurs, and these creatures not only survived the asteroid impact and its

FIGURE 10.48
An artist's painting of the impact that caused the Cretaceous extinctions.

aftermath, but they have also diversified into some of the most fantastic creatures we know (**Figure** 10.49).

FIGURE 10.49
Archeopteryx, the earliest known bird, lived during the late Jurassic.

Vocabulary

- **amniote egg**: An egg that contains all the nutrients needed for the developing embryo and is protected by a shell.

Summary

- Phytoplankton evolved to become the base of the marine food web.
- In the Mesozoic dinosaurs filled the niches that mammals fill today.
- Life of the Mesozoic appears to have ended with a giant asteroid impact.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=y4COsg8o02Q

MEDIA

Click image to the left for more content.

1. When did the asteroid impact the Earth?
2. How large was the impact?
3. Where did it hit?
4. What were the primary killers from this impact?
5. Describe how the Earth looked from space after the impact.
6. How did most of the animals die?
7. Why did the fires burn so hot and intensely?
8. What animal survived the aftermath of the impact?

Review

1. How did life in the Mesozoic resemble life today? How did it differ from life today?
2. What was the importance of the amniote egg for Mesozoic life?
3. Why do scientists say that dinosaurs didn't entirely go extinct? What is their evidence?

10.18 History of Cenozoic Life

- Describe the diversification of life during the Cenozoic and its relationship to modern biodiversity.

Why are Pleistocene animals so large?

A large surface area-to-volume ratio is better for keeping warm, so many ice age mammals were huge. Although the dominant animals were mammals, you might not recognize the Pleistocene Earth any more than the Mesozoic Earth.

Cenozoic Life

The extinction of so many species at the end of the Mesozoic again left many niches available to be filled. Although we call the Cenozoic the age of mammals, birds are more common and more diverse. Early in the era, terrestrial crocodiles lumbered around along with large, primitive mammals and prehistoric birds.

Diversification of the Mammals

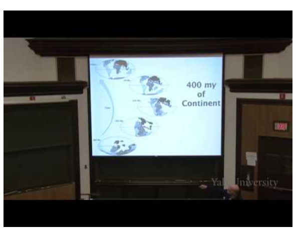
Their adaptations have allowed mammals to spread to even more environments than reptiles. The success of mammals is due to several of their unique traits. Mammals are endothermic and have fur, hair, or blubber for warmth. Mammals can swim, fly, and live in nearly all terrestrial environments. Mammals initially filled the forests that covered many early Cenozoic lands. Over time, the forests gave way to grasslands, which created more niches for mammals to fill.

Pleistocene Megafauna

As climate cooled during the ice ages, large mammals were able to stand the cold weather, so many interesting megafauna developed. These included giant sloths, saber-toothed cats, wooly mammoths, giant condors, and many other animals that are now extinct (**Figure** 10.50).

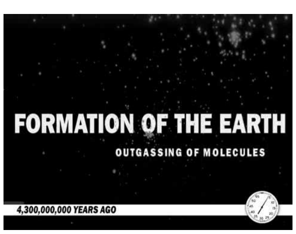
FIGURE 10.50
The saber-toothed cat lived during the Pleistocene.

A lecture from Yale University on the effect of life on Earth and Earth on life during 4.5 billion years. Glaciations appear at minute mark 23:30-26:20 and then the video goes into mass extinctions **(6c)**: http://www.youtube.com/watch?v=K6Dl_Vs-ZkY#38;feature=player_profilepage (47:10).



MEDIA
Click image to the left for more content.

"The Evolution of Life in 60 Seconds" scales all 4.6 billion years of Earth history into one minute. Don't blink at the end **(1i - I&E Stand.)**: http://www.youtube.com/watch?v=YXSEyttblMI#38;feature=related (1:03).



MEDIA
Click image to the left for more content.

Many of the organisms that made up the Pleistocene megafauna went extinct as conditions warmed. Some may have been driven to extinction by human activities.

Imagine a vast grassy plain covered with herds of elephants, bison and camels stretching as far as the eye can see. Lions, tigers, wolves and later, humans, hunt the herds on their summer migration.This was the San Francisco Bay Area at the close of the last Ice Age.

Learn more at http://www.kqed.org/quest/television/ice-age-bay-area2.

MEDIA
Click image to the left for more content.

Summary

- With the extinction of the dinosaurs, mammals diversified and took over the available niches.
- Many of the organisms of the Pleistocene were enormous, probably in have a low surface area to body ratio.
- Many of the Pleistocene megafauna have gone extinct but some remain.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=1DrMxwqdatI

MEDIA
Click image to the left for more content.

1. When were the dinosaurs killed off?
2. What killed off the dinosaurs?
3. How long did it take for mammals to evolve?
4. Where did mammals live?
5. What is the Eocene?
6. What animals ruled the Earth after the dinosaurs?
7. What advantages do mammals have?

Review

1. What are the Pleistocene megafauna and why were they so large?
2. What characteristics do mammals have that allow them to fill so many niches?
3. How does climate affect evolution?

10.19 Human Evolution

- Identify and describe key developments in human evolution.

What is a "cave man"?

What if you were to wake up in the Cenozoic, even in the very recent Cenozoic, but with a group of Neanderthals? They were close relatives, but you might find them to be a bit different from your usual friends.

Human Evolution

Humans evolved during the later Cenozoic. New fossil discoveries alter the details of what we know about the evolution of modern humans, but the major evolutionary path is well understood.

Primate Ancestors

Humans evolved from primates, and apes and humans have a primate common ancestor. About 7 million years ago, chimpanzees (our closest living relatives) and humans shared their last common ancestor.

Hominids

Animals of the genus *Ardipithecus*, living roughly 4 to 6 million years ago, had brains roughly the size of a female chimp. Although they lived in trees, they were bipedal. Standing on two feet allows an organism to see and also to use its hands and arms for hunting. By the time of *Australopithecus afarensis*, between 3.9 and 2.9 million years ago, these human ancestors were completely bipedal and their brains were growing rapidly (**Figure** 10.51).

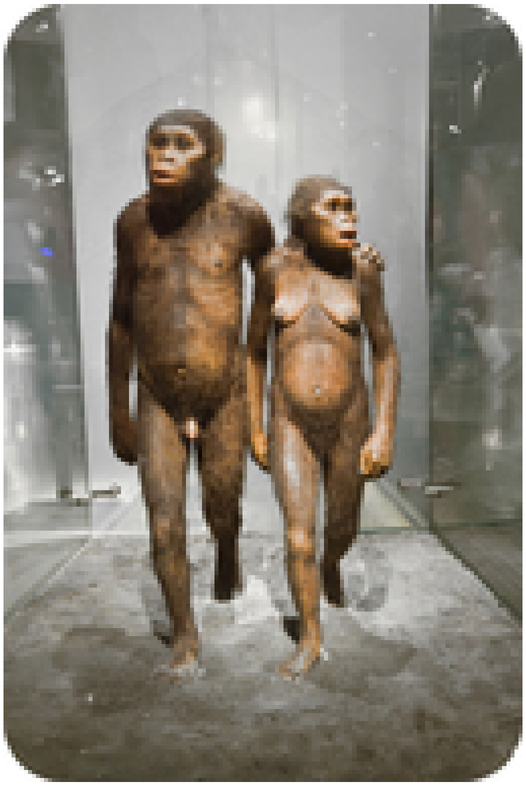


FIGURE 10.51
Australopithecus afarensis is a human ancestor that lived about 3 million years ago.

The genus *Homo* appeared about 2.5 million years ago. Humans developed the first stone tools. *Homo erectus* evolved in Africa about 1.8 million years ago. Fossils of these animals show a much more human-like body structure, which allowed them to travel long distances to hunt. Cultures begin and evolve.

Homo sapiens, our species, originated about 200,000 years ago in Africa. Evidence of a spiritual life appears about 32,000 years ago with stone figurines that probably have religious significance (**Figure** 10.52).

The ice ages allowed humans to migrate. During the ice ages, water was frozen in glaciers and so land bridges such as the Bering Strait allowed humans to walk from the old world to the new world.

Summary

- *Australopithecus afarensis* was completely bipedal and had a growing brain.
- *Homo erectus* evolved 1.8 million years ago and left behind signs of an early culture.
- Our species is *Homo sapiens*, which evolved 200,000 years ago in Africa and continues to today.

Practice

Use this resource to answer the questions that follow.

FIGURE 10.52
Stone figurines likely indicate a spiritual life.

http://www.youtube.com/watch?v=u7Y34zrJjtk

MEDIA
Click image to the left for more content.

1. What was Darwin's little heresy?
2. Who was Huxley?
3. Where was the first Neanderthal found?
4. What was the problem with the fossil evidence from Africa?
5. List the traits that separate humans from apes?
6. What did DNA prove?
7. What does mitochondrial RNA prove?

Review

1. Why did the evolution of bipedalism advance human evolution?
2. Draw a timeline of human ancestors including the name of the ancestor and the time that it lived.
2. What makes *Homo sapiens* different from *Homo erectus*?

10.20 Modern Biodiversity

- Describe modern biodiversity and its relationship to evolutionary adaptations.

How well do you know life on Earth?

It's possible that you could wake up on Earth right now and still not recognize the planet. That's because of the incredible diversity of species. Habitats that you've never encountered would be inhabited by organisms that you've never seen or known about.

Modern Biodiversity

There are more than 1 million species of plants and animals known to be currently alive on Earth (**Figure** 10.53) and many millions more that have not been discovered yet. The tremendous variety of creatures is due to the tremendous numbers of habitats that organisms have evolved to fill.

Adaptations

Many adaptations protect organisms from the external environment (**Figure** 10.54).

Other adaptations help an organism move or gather food. Reindeer have sponge-like hoofs that help them walk on snowy ground without slipping and falling. Hummingbirds have long, thin beaks that help them drink nectar from flowers. Organisms have special features that help them avoid being eaten. When a herd of zebras run away from lions, the zebras' dark stripes confuse the predators so that they have difficulty focusing on just one zebra during the chase. Some plants have poisonous or foul-tasting substances in them that keep animals from eating them. Their brightly colored flowers serve as a warning.

Thousands of northern elephant seals — some weighing up to 4,500 pounds — make an annual migration to breed each winter at Año Nuevo State Reserve in California. Marine biologists are using high-tech tools to explore the secrets of these amazing creatures.

FIGURE 10.53
There is an amazing diversity of organisms on Earth. How do the organisms in this picture each make their living?

FIGURE 10.54
Cacti have thick, water- retaining bodies that help them conserve water.

Find out more at http://science.kqed.org/quest/video/into-the-deep-with-elephant-seals/.

FIGURE 10.55
Poison dart frogs have toxins in their skin. Their bright colors warn potential predators not to take a bite!

Adobe Flash

MEDIA
Click image to the left for more content.

Summary

- There are 1 million known species, but many more have not been discovered.
- The enormous number of species is due to the tremendous variety of habitats.
- Organisms have adaptations that help them to find food or avoid being eaten.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=I7G2rQARCC8

MEDIA
Click image to the left for more content.

1. What is biodiversity?
2. How does biodiversity help people?
3. Why is biodiversity important?
4. How many species are disappearing each day?
5. Why are so many species disappearing?

Review

1. Study the organisms in the photos above. Choose two and list the adaptations that each has for successful living.
2. Now do #1 again.
3. How does adaptation lead to biodiversity?

Summary

Although different ecosystems differ greatly from one another, the structure of an ecosystem is the same. There must be a source of food energy, usually from photosynthesis, and then herbivores, predators, scavengers, and decomposers, among others. Energy flows through the ecosystems in tropic levels and connections between organisms are made in a web, known as the food web. There are many types of ecosystems in fresh water, the oceans, and on land. Organisms must be well adapted to their habitats or they may go extinct. Extinction of a species opens up a niche, which a different species will likely evolve to fill. This has occurred throughout Earth's history as mass extinctions have opened habitats and adaptive radiation has acted on a different set of organisms to fill those habitats. The earliest life was simple cells, possible with RNA as the nucleic acid. Photosynthesis evolved and provided a food source for the food web, plus oxygen to the atmosphere. Multicellular life didn't evolve for 4 billion years. During most of the Paleozoic, life was restricted to the seas. Reptiles ruled in the Mesozoic and even in the Cenozoic life was fairly different from what we see today. The biological processes that govern the evolution of species has resulted in tremendous biodiversity we see today. This includes the evolution of humans, which is better understood as more fossils are discovered.

10.21 References

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Chapter 11 Earth History

Chapter Outline

Introduction

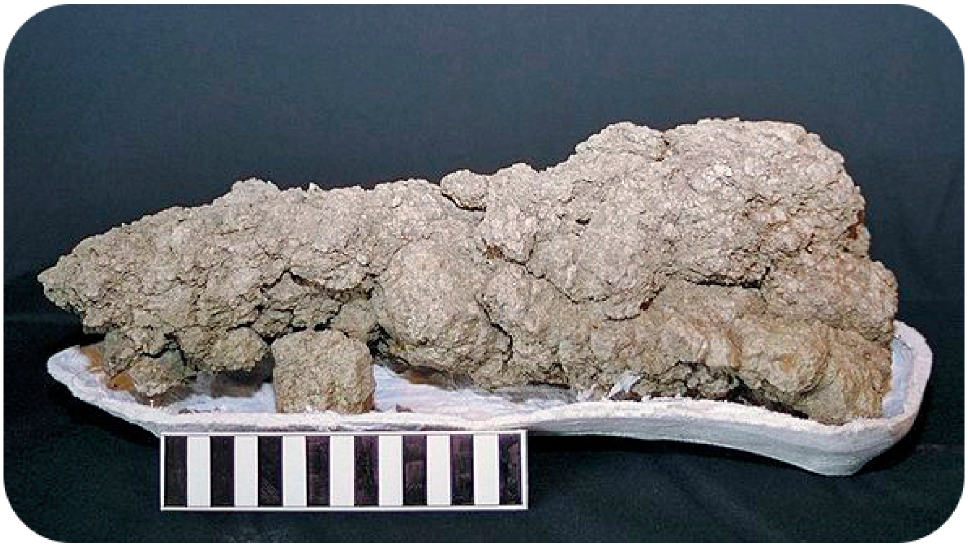
How do you apply what you've learned so far to understanding Earth history?

Something that we hope you have learned from these lessons and from your own life experience is that the laws of nature never change. They are the same today as they were billions of years ago. Water freezes at 0^o C at 1 atmosphere pressure; this is always true.

Knowing that natural laws never change helps scientists understand Earth's past because it allows them to interpret clues about how things happened long ago. Geologists always use present-day processes to interpret the past. If you find a fossil of a fish in a dry terrestrial environment did the fish flop around on land? Did the rock form in water and then move? Since fish do not flop around on land today, the explanation that adheres to the philosophy that natural laws do not change is that the rock moved.

11.1 How Fossilization Creates Fossils

- Describes the conditions necessary for fossilization.



What kind of fossil is this?

As a paleontologist it would be great to find a new species of dinosaur or the best preserved specimen of a species like Tyrannosaurus rex. But lots of important information can be gained from less....um...glamorous finds. One example is this fossil coprolite from a meat-eating dinosaur. Fortunately, fossil poo doesn't stink!

Fossils were Parts of Living Organisms

It wasn't always known that fossils were parts of living organisms. In 1666, a young doctor named Nicholas Steno dissected the head of an enormous great white shark that had been caught by fisherman near Florence, Italy. Steno was struck by the resemblance of the shark's teeth to fossils found in inland mountains and hills (**Figure** 11.1).

Most people at the time did not believe that fossils were once part of living creatures. Authors in that day thought that the fossils of marine animals found in tall mountains, miles from any ocean could be explained in one of two ways:

- The shells were washed up during the Biblical flood. (This explanation could not account for the fact that fossils were not only found on mountains, but also within mountains, in rocks that had been quarried from deep below Earth's surface.)
- The fossils formed within the rocks as a result of mysterious forces.

But for Steno, the close resemblance between fossils and modern organisms was impossible to ignore. Instead of invoking supernatural forces, Steno concluded that fossils were once parts of living creatures.

How Fossils Form

A fossil is any remains or traces of an ancient organism. Fossils include **body fossils**, left behind when the soft parts have decayed away, and **trace fossils**, such as burrows, tracks, or fossilized coprolites (feces) as seen above.

FIGURE 11.1

Fossil Shark Tooth (left) and Modern Shark Tooth (right).

Collections of fossils are known as fossil assemblages.

Fossilization is Rare

Becoming a fossil isn't easy. Only a tiny percentage of the organisms that have ever lived become fossils.

Why do you think only a tiny percentage of living organisms become fossils after death? Think about an antelope that dies on the African plain (**Figure** 11.2).

Most of its body is eaten by hyenas and other scavengers and the remaining flesh is devoured by insects and bacteria. Only bones are left behind. As the years go by, the bones are scattered and fragmented into small pieces, eventually turning into dust. The remaining nutrients return to the soil. This antelope will not be preserved as a fossil.

Is it more likely that a marine organism will become a fossil? When clams, oysters, and other shellfish die, the soft parts quickly decay, and the shells are scattered. In shallow water, wave action grinds them into sand-sized pieces. The shells are also attacked by worms, sponges, and other animals (**Figure** 11.3).

How about a soft bodied organism? Will a creature without hard shells or bones become a fossil? There is virtually no fossil record of soft bodied organisms such as jellyfish, worms, or slugs. Insects, which are by far the most common land animals, are only rarely found as fossils (**Figure** 11.4).

Conditions that Create Fossils

Despite these problems, there is a rich fossil record. How does an organism become fossilized?

FIGURE 11.2

Hyenas eating an antelope. Will the antelope in this photo become a fossil?

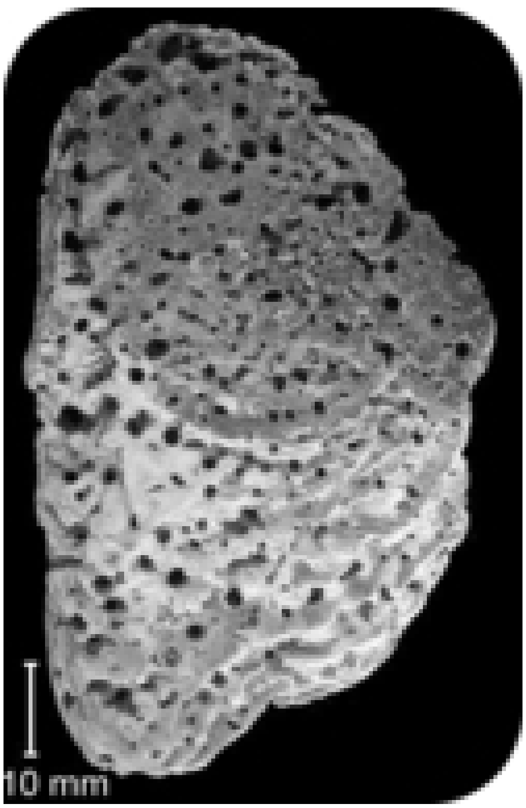


FIGURE 11.3

Fossil shell that has been attacked by a boring sponge.

Hard Parts

Usually it's only the hard parts that are fossilized. The fossil record consists almost entirely of the shells, bones, or other hard parts of animals. Mammal teeth are much more resistant than other bones, so a large portion of the mammal fossil record consists of teeth. The shells of marine creatures are common also.

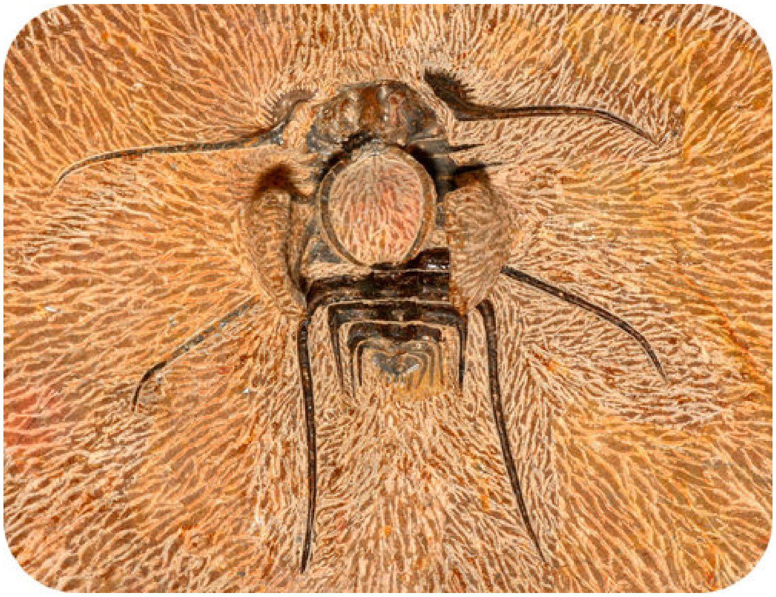


FIGURE 11.4
A rare insect fossil.

Quick Burial

Quick burial is essential because most decay and fragmentation occurs at the surface. Marine animals that die near a river delta may be rapidly buried by river sediments. A storm at sea may shift sediment on the ocean floor, covering a body and helping to preserve its skeletal remains (**Figure** 11.5).

FIGURE 11.5
This fish was quickly buried in sediment to become a fossil.

Quick burial is rare on land, so fossils of land animals and plants are less common than marine fossils. Land organisms can be buried by mudslides, volcanic ash, or covered by sand in a sandstorm (**Figure** 11.6). Skeletons can be covered by mud in lakes, swamps, or bogs.

FIGURE 11.6
People buried by the extremely hot eruption of ash and gases at Mt. Vesuvius in 79 AD.

Unusual Circumstances

Unusual circumstances may lead to the preservation of a variety of fossils, as at the La Brea Tar Pits in Los Angeles, California. Although the animals trapped in the La Brea Tar Pits probably suffered a slow, miserable death, their bones were preserved perfectly by the sticky tar. (**Figure** 11.7).

In spite of the difficulties of preservation, billions of fossils have been discovered, examined, and identified by thousands of scientists. The fossil record is our best clue to the history of life on Earth, and an important indicator of past climates and geological conditions as well.

Exceptional Preservation

Some rock beds contain exceptional fossils or fossil assemblages. Two of the most famous examples of soft organism preservation are from the 505 million-year-old Burgess Shale in Canada (**Figure** 11.8). The 145 million-year-old Solnhofen Limestone in Germany has fossils of soft body parts that are not normally preserved (**Figure** 11.8).

Vocabulary

- **body fossil**: The remains of an ancient organism. Examples include shells, bones, teeth, and leaves.
- **trace fossil**: Evidence of the activity of an ancient organism; e.g. tracks, tubes, and bite marks.

Summary

- Fossils are the remains or traces of living organisms: body fossils are the remains and trace fossils are the traces.

FIGURE 11.7
Artists concept of animals surrounding the La Brea Tar Pits.

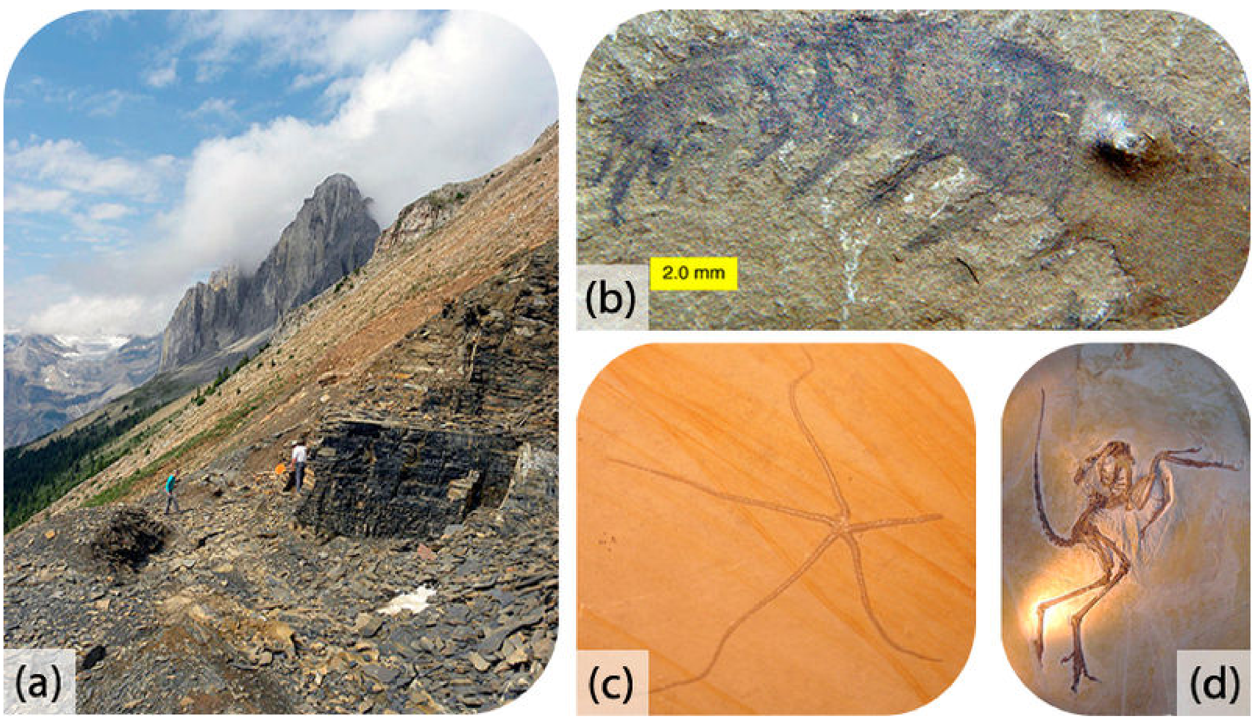


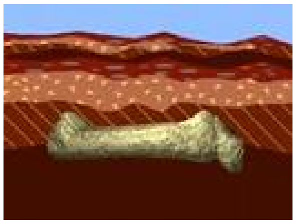
FIGURE 11.8
(a) The Burgess shale contains soft-bodied fossils. (b) Anomalocaris, meaning “abnormal shrimp” is now extinct. The image is of a fossil. (c) A brittle star from the Solnhofen Limestone. (d) The famous Archeopteryx fossil from the Solnhofen Limestone has distinct feathers and was one of the earliest birds.

- Fossils are mostly made of the hard parts of organisms; there are few soft-bodied fossils.
- Some of the best preserved fossils form in extremely unusual circumstances like the La Brea tar pits.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=A5i5Qrp6sJU



MEDIA

Click image to the left for more content.

1. What are fossils?
2. What type of rocks are fossils found in?
3. What are sediments?
4. Explain how a fossil is created.
5. What factors have exposed sedimentary rock?

Review

1. Give three examples of body fossils and trace fossils.
2. Under what conditions do fossils form?
3. Why are more fossils of marine organisms than of land organisms?

11.2 Types of Fossilization

- Learn the five processes that create most of the fossils.

Are all fossils so complete and well-preserved?

Very few circumstances lead to fossils that are as beautiful and complete as this baby mammoth that was frozen in ice. An animal falling into a crevasse or a tar pit does not undergo the scattering and degradation that an animal dying at the surface does and so fossils from these types of rare sites are often fantastic.

Types of Fossilization

Most fossils are preserved by one of five processes outlined below (**Figure** 11.9):

Preserved Remains

Most uncommon is the preservation of soft-tissue original material. Insects have been preserved perfectly in **amber**, which is ancient tree sap. Mammoths and a Neanderthal hunter were frozen in glaciers, allowing scientists the rare opportunity to examine their skin, hair, and organs. Scientists collect DNA from these remains and compare the DNA sequences to those of modern counterparts.

Permineralization

The most common method of fossilization is **permineralization**. After a bone, wood fragment, or shell is buried in sediment, mineral-rich water moves through the sediment. This water deposits minerals into empty spaces and

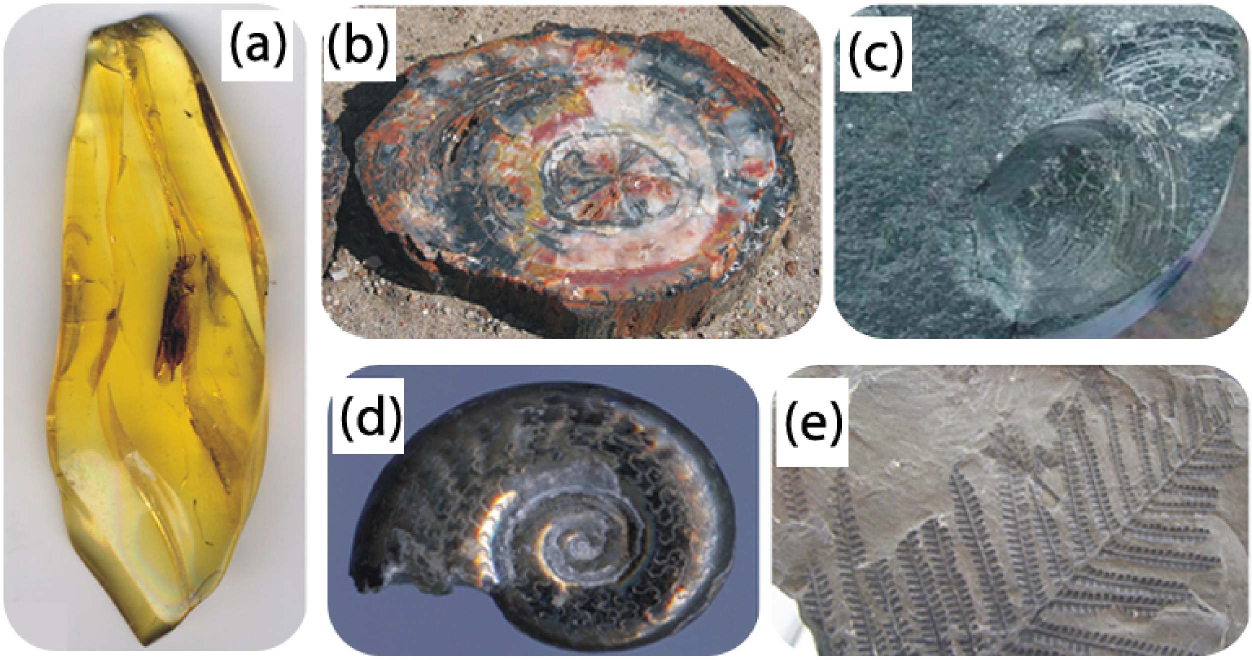


FIGURE 11.9
Five types of fossils: (a) insect preserved in amber, (b) petrified wood (permineralization), (c) cast and mold of a clam shell, (d) pyritized ammonite, and (e) compression fossil of a fern.

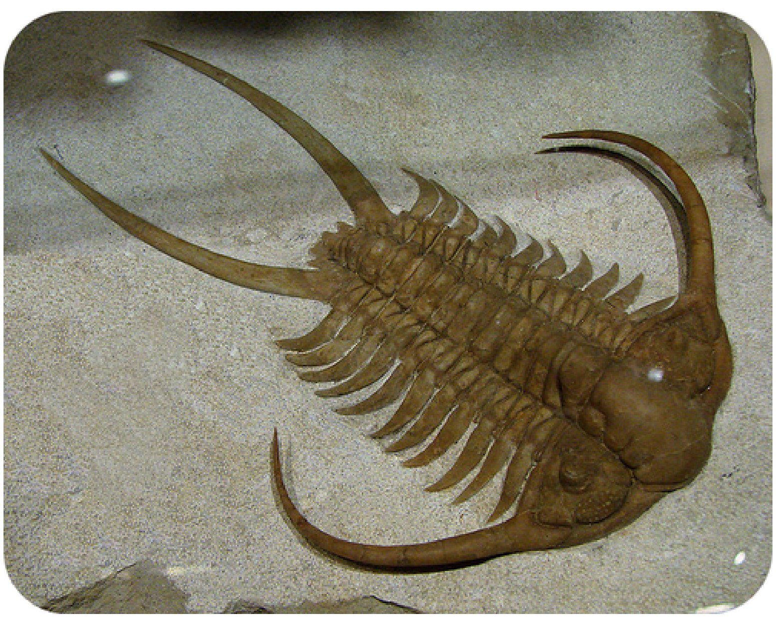


FIGURE 11.10
Trilobite.

produces a fossil. Fossil dinosaur bones, petrified wood, and many marine fossils were formed by permineralization.

Molds and Casts

When the original bone or shell dissolves and leaves behind an empty space in the shape of the material, the depression is called a **mold**. The space is later filled with other sediments to form a matching **cast** within the mold that is the shape of the original organism or part. Many mollusks (clams, snails, octopi, and squid) are found as molds and casts because their shells dissolve easily.

Replacement

The original shell or bone dissolves and is replaced by a different mineral. For example, calcite shells may be replaced by dolomite, quartz, or pyrite. If a fossil that has been replace by quartz is surrounded by a calcite matrix, mildly acidic water may dissolve the calcite and leave behind an exquisitely preserved quartz fossil.

Compression

Some fossils form when their remains are compressed by high pressure, leaving behind a dark imprint. Compression is most common for fossils of leaves and ferns, but can occur with other organisms.

Vocabulary

- **amber**: Fossilized tree sap.
- **cast**: A mold filled with sediment and hardened to create a replica of the original fossil.
- **mold**: An impression made in sediments by the hard parts of an organism.
- **permineralization**: Fossilization in which minerals in water deposit into empty spaces in an organism.

Summary

- Very few fossils preserve soft parts; some insects are preserved in amber and animals may be preserved in ice.
- Some fossils are created when minerals replace the organic material.
- A fossil may be in the form of a mold, which is the depression left in the shape of the material or a cast, which is rocky material that filled the mold.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=TVwPLWOo9TE

MEDIA

Click image to the left for more content.

1. What do paleontologists study?

2. At least how old are most fossils?
3. What are trace fossils?
4. What can be learned from trace fossils?
5. What are mold fossils?
6. What are resin fossils?
7. How are resin fossils formed?
8. What are body fossils?
9. How are body fossils formed?

Review

1. Why are there so few fossils of soft parts?
2. If a snail shell is buried in mud and then infused with mineral rich water what type of fossilization has occurred?
3. What types of fossils are most likely to form by compression and why?

11.3 Earth History and Clues from Fossils

- Fossils are full of information about Earth's past and are essential for unraveling earth history.

Seashells at 20,000 feet!

On his voyage on the Beagle, Charles Darwin noticed many things besides just the Galapagos finches that made him famous. Another important discovery was shell beds high in the Andes Mountains. How did they get there? He determined that they must mean that mountains rise slowly above the ocean, an idea that was being championed at the time by Charles Lyell. If this is the case, Darwin reasoned, the mountains and Earth must be extremely old.

Clues from Fossils

Fossils are our best form of evidence about Earth history, including the history of life. Along with other geological evidence from rocks and structures, fossils even give us clues about past climates, the motions of plates, and other major geological events. Since the present is the key to the past, what we know about a type of organism that lives today can be applied to past environments.

History of Life on Earth

That life on Earth has changed over time is well illustrated by the fossil record. Fossils in relatively young rocks resemble animals and plants that are living today. In general, fossils in older rocks are less similar to modern organisms. We would know very little about the organisms that came before us if there were no fossils. Modern technology has allowed scientists to reconstruct images and learn about the biology of extinct animals like dinosaurs!

MEDIA
Click image to the left for more content.

Environment of Deposition

By knowing something about the type of organism the fossil was, geologists can determine whether the region was terrestrial (on land) or marine (underwater) or even if the water was shallow or deep. The rock may give clues to whether the rate of sedimentation was slow or rapid. The amount of wear and fragmentation of a fossil allows scientists to learn about what happened to the region after the organism died; for example, whether it was exposed to wave action.

Geologic History

The presence of marine organisms in a rock indicates that the region where the rock was deposited was once marine. Sometimes fossils of marine organisms are found on tall mountains indicating that rocks that formed on the seabed were uplifted.

Climate

By knowing something about the climate a type of organism lives in now, geologists can use fossils to decipher the climate at the time the fossil was deposited. For example, coal beds form in tropical environments but ancient coal beds are found in Antarctica. Geologists know that at that time the climate on the Antarctic continent was much warmer. Recall from Concept Plate Tectonics that Wegener used the presence of coal beds in Antarctica as one of the lines of evidence for continental drift.

Index Fossils

An **index fossil** can be used to identify a specific period of time. Organisms that make good index fossils are distinctive, widespread, and lived briefly. Their presence in a rock layer can be used to identify rocks that were deposited at that period of time over a large area.

The fossil of a juvenile mammoth found near downtown San Jose California reveals an enormous amount about these majestic creatures: what they looked like, how they lived, and what the environment of the Bay Area was like so long ago.

Find out more at http://science.kqed.org/quest/video/science-on-the-spot-lupe-the-mammoth-comes-to-life/.

MEDIA
Click image to the left for more content.

Vocabulary

- **index fossil**: A fossil indicates the relative age of the rock in which it is found. Index fossils come from species that were widespread but existed for a relatively brief period of time.

Summary

- Fossils tell a lot about the environment during the time they were deposited.
- Climate is one important thing that can be indicated by fossils since organisms have specific conditions in which they can live.
- An index fossil must be distinctive, widespread and short-lived so that it can identify a specific period of time.

Practice

Use this resource to answer the questions that follow.

Clues to the End - Permian Extinction

http://www.youtube.com/watch?v=eG8XyesAu74

MEDIA

Click image to the left for more content.

1. Why is the paleoecologist collecting samples?
2. What does he want to create from the fossil evidence?
3. How is this similar to forensic science?
4. Why is it important to understand insect feeding?
5. What has been discovered from these fossils?

Review

1. How does a single fossil or set of fossils help geologists to decipher the geological history of an area?
2. How is an index fossil used to identify a time period?
3. Why are the fossils of marine organisms sometimes found in rock units at the tops of high mountains? What evidence would you look for to determine if this reason is plausible?

11.4 Principles of Relative Dating

- Steno's laws are used to determine the order in which geological events took place.

Relative ages.

In most families a person's age fits into his or her generation: Siblings are around the same age as are first cousins. But in some families, multiple marriages, delayed childbearing, extended childbearing or other variations mixes up generations so that Aunt Julia may be five years younger than her nephew. In a family like this it's hard to tell how people are related simply by age. With rock units we use certain principles to tell their ages relative to each other.

Relative Age Dating

Early geologists had no way to determine the absolute age of a geological material. If they didn't see it form, they couldn't know if a rock was one hundred years or 100 million years old. What they could do was determine the ages of materials relative to each other. Using sensible principles they could say whether one rock was older than another and when a process occurred relative to those rocks.

Steno's Laws

Remember Nicholas Steno, who determined that fossils represented parts of once-living organisms? Steno also noticed that fossil seashells could be found in rocks and mountains far from any ocean. He wanted to explain how that could occur. Steno proposed that if a rock contained the fossils of marine animals, the rock formed from sediments that were deposited on the seafloor. These rocks were then uplifted to become mountains.

This scenario led him to develop the principles that are discussed below. They are known as Steno's laws. Steno's laws are illustrated below in (**Figure** 11.11).

- **Original horizontality**: Sediments are deposited in fairly flat, horizontal layers. If a sedimentary rock is found tilted, the layer was tilted after it was formed.
- **Lateral continuity**: Sediments are deposited in continuous sheets that span the body of water that they are deposited in. When a valley cuts through sedimentary layers, it is assumed that the rocks on either side of the valley were originally continuous.
- **Superposition**: Sedimentary rocks are deposited one on top of another. The youngest layers are found at the top of the sequence, and the oldest layers are found at the bottom.

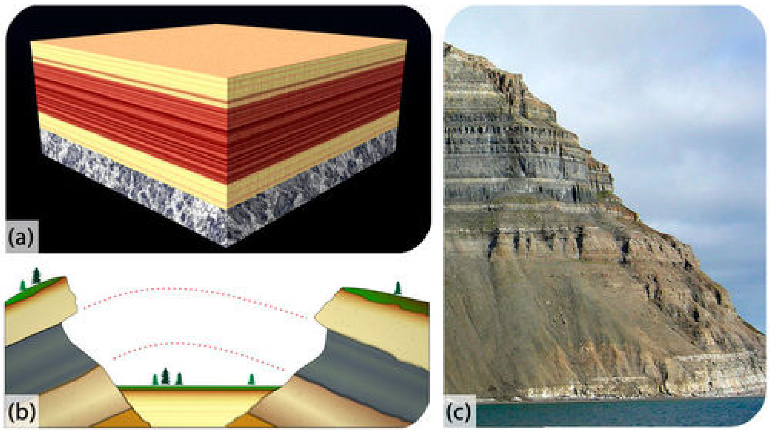


FIGURE 11.11
(a) Original horizontality. (b) Lateral continuity. (c) Superposition.

More Principles of Relative Dating

Other scientists observed rock layers and formulated other principles.

Geologist William Smith (1769-1839) identified the **principle of faunal succession**, which recognizes that:

- Some fossil types are never found with certain other fossil types (e.g. human ancestors are never found with dinosaurs) meaning that fossils in a rock layer represent what lived during the period the rock was deposited.
- Older features are replaced by more modern features in fossil organisms as species change through time; e.g. feathered dinosaurs precede birds in the fossil record.
- Fossil species with features that change distinctly and quickly can be used to determine the age of rock layers quite precisely.

Scottish geologist, James Hutton (1726-1797) recognized the **principle of cross-cutting relationships**. This helps geologists to determine the older and younger of two rock units (**Figure** 11.12).

The Grand Canyon

The Grand Canyon provides an excellent illustration of the principles above. The many horizontal layers of sedimentary rock illustrate the principle of original horizontality (**Figure** 11.13).

- The youngest rock layers are at the top and the oldest are at the bottom, which is described by the law of superposition.
- Distinctive rock layers, such as the Kaibab Limestone, are matched across the broad expanse of the canyon. These rock layers were once connected, as stated by the rule of lateral continuity.
- The Colorado River cuts through all the layers of rock to form the canyon. Based on the principle of cross-cutting relationships, the river must be younger than all of the rock layers that it cuts through.

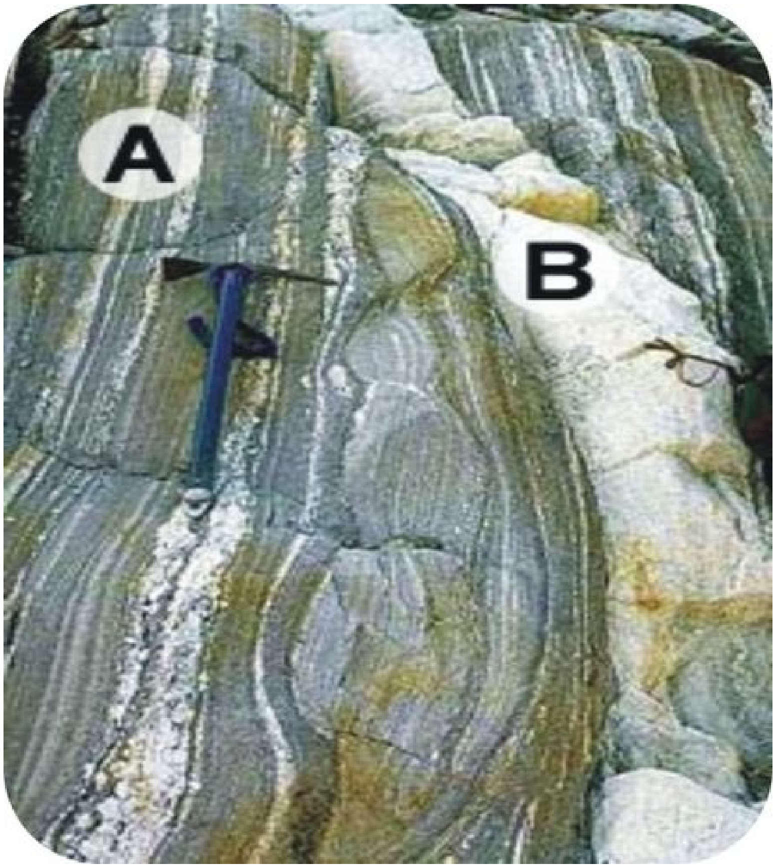


FIGURE 11.12
If an igneous dike (B) cuts a series of metamorphic rocks (A), which is older and which is younger? In this image, A must have existed first for B to cut across it.

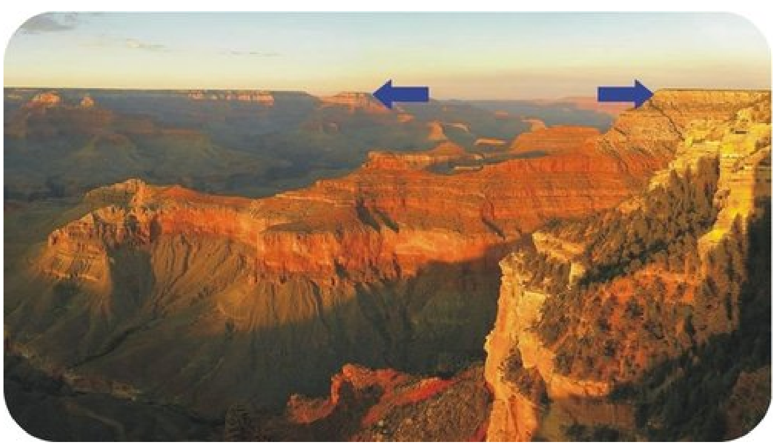


FIGURE 11.13
The Grand Canyon, with the Kaibab Limestone marked with arrows.

Vocabulary

- **lateral continuity**: A sedimentary rock layer that extends sideways as wide as the basin in which it forms.
- **original horizontality**: The idea that sedimentary layers were deposited horizontally.
- **principle of cross-cutting relationships**: One of Steno's principles that states that an intrusion or fault is younger than the rocks that it cuts through.
- **principle of faunal succession**: Fossilized life forms succeed each other in a specific order that can be recognized over large distances.

- **superposition**: In a sequence of sedimentary rock layers, the oldest is at the bottom and the youngest is at the top.

Summary

- Sediments are deposited horizontally with the oldest at the bottom. Any difference in this pattern means that the rock units have been altered.
- The principle of faunal succession recognizes that species evolve and these changes can be seen in the rock record.
- The Grand Canyon exhibits many of the principles of relative dating and is a fantastic location for learning about the geology of the southwestern U.S.

Practice

Use this resource to answer the questions that follow.

Absolute vs. Relative Dating

http://www.youtube.com/watch?v=JNOmpXo2xlU

MEDIA

Click image to the left for more content.

1. What is superposition?
2. How can the age of the layers be determined?
3. How does volcanic ash help with relative dating?
4. What are the radioactive elements?
5. What is the clock for determining relative age?

Review

1. How do Steno's laws help geologists to decipher the geological history of a region?
2. What is the principle of faunal succession?
3. Why does just about every geology textbook use the Grand Canyon as the example in the sections on geological history?

11.5 Determining Relative Ages

- Be able to determine the relative ages of a set of rocks and the processes that have altered them.

Clues can tell you a person's age.

There are ways to tell the ages of people relative to each other. For children we use height, for adults we might use gray hair and wrinkles. There are also ways to tell the relative ages of rocks. We'll practice in this lesson.

Determining the Relative Ages of Rocks

Steno's and Smith's principles are essential for determining the relative ages of rocks and rock layers. In the process of relative dating, scientists do not determine the exact age of a fossil or rock but look at a sequence of rocks to try to decipher the times that an event occurred relative to the other events represented in that sequence. The **relative age** of a rock then is its age in comparison with other rocks. If you know the relative ages of two rock layers, (1) Do you know which is older and which is younger? (2) Do you know how old the layers are in years?

An interactive website on relative ages and geologic time is found here: http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/gtpage1.html.

In some cases, it is very tricky to determine the sequence of events that leads to a certain formation. Can you figure out what happened in what order in (**Figure** 11.14)? Write it down and then check the following paragraphs.

The principle of cross-cutting relationships states that a fault or intrusion is younger than the rocks that it cuts through. The fault cuts through all three sedimentary rock layers (A, B, and C) and also the intrusion (D). So the fault must be the youngest feature. The intrusion (D) cuts through the three sedimentary rock layers, so it must be younger than those layers. By the law of superposition, C is the oldest sedimentary rock, B is younger and A is still younger.

The full sequence of events is:

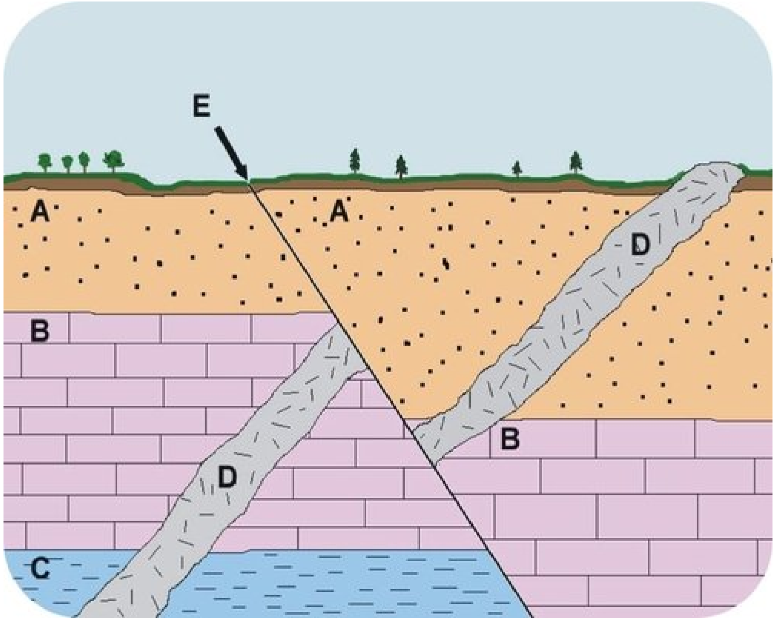


FIGURE 11.14
A geologic cross section: Sedimentary rocks (A-C), igneous intrusion (D), fault (E).

1. Layer C formed.
2. Layer B formed.
3. Layer A formed.
4. After layers A-B-C were present, intrusion D cut across all three.
5. Fault E formed, shifting rocks A through C and intrusion D.
6. Weathering and erosion created a layer of soil on top of layer A.

Vocabulary

- **relative age**: The age of an object in comparison with the age of other objects.

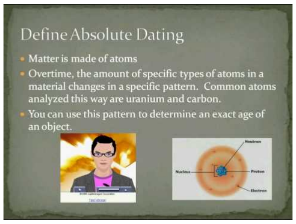
Summary

- The oldest rock units lie beneath the younger ones.
- By the principle of cross-cutting relationships (and common sense) we know that something must exist before something else can cut across it.
- The history of a section of rocks can be deciphered using the principles outlined in this Concept.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=jM7vZ-9bBc0



MEDIA

Click image to the left for more content.

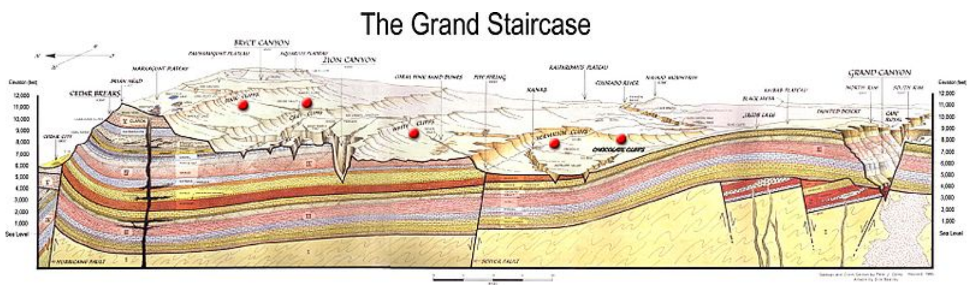
1. What is relative dating?
2. What is the problem with relative dating?
3. Describe the law of supposition.
4. What is absolute dating?
5. Which type of dating gives you an exact date?

Review

1. What is relative age? How does it differ from absolute age?
2. Why do the principles of relative dating not indicate the absolute age of a rock unit?
3. Under what circumstances would a rock unit with an older fossil be above a rock until with a younger fossil?

11.6 Correlation Using Relative Ages

- Rock units can be correlated over vast distances if they are distinctive, or contain index fossils or a key bed.



Rock matching.

If we want to understand the geological history of a location we need to look at the rocks in that location. But if we want to understand a region, we need to correlate the rocks between different locations so that we can meld the individual histories of the different locations into one regional history.

Matching Up Rock Layers

Superposition and cross-cutting are helpful when rocks are touching one another and lateral continuity helps match up rock layers that are nearby. To match up rocks that are further apart we need the process of **correlation**. How do geologists correlate rock layers that are separated by greater distances? There are three kinds of clues:

Distinctive Rock Formations

1. Distinctive rock formations may be recognizable across large regions (**Figure** 11.15).

Index Fossils

2. Two separated rock units with the same index fossil are of very similar age. What traits do you think an index fossil should have? To become an index fossil the organism must have (1) been widespread so that it is useful for identifying rock layers over large areas and (2) existed for a relatively brief period of time so that the approximate age of the rock layer is immediately known.

Many fossils may qualify as index fossils (**Figure** 11.16). Ammonites, trilobites, and graptolites are often used as index fossils.

Microfossils, which are fossils of microscopic organisms, are also useful index fossils. Fossils of animals that drifted in the upper layers of the ocean are particularly useful as index fossils, since they may be distributed over very large areas.

A biostratigraphic unit, or **biozone**, is a geological rock layer that is defined by a single index fossil or a fossil assemblage. A biozone can also be used to identify rock layers across distances.

FIGURE 11.15
The famous White Cliffs of Dover in southwest England can be matched to similar white cliffs in Denmark and Germany.

FIGURE 11.16
Mucrospirifer mucronatus is an index fossil that indicates that a rock was laid down from 416 to 359 million years ago.

Key Beds

3. A **key bed** can be used like an index fossil since a key bed is a distinctive layer of rock that can be recognized across a large area. A volcanic ash unit could be a good key bed. One famous key bed is the clay layer at the boundary between the Cretaceous Period and the Tertiary Period, the time that the dinosaurs went extinct (**Figure** 11.17). This widespread thin clay contains a high concentration of iridium, an element that is rare on Earth but common in asteroids. In 1980, the father-son team of Luis and Walter Alvarez proposed that a huge asteroid struck Earth 66 million years ago and caused the mass extinction.

FIGURE 11.17
The white clay is a key bed that marks the Cretaceous-Tertiary Boundary.

Vocabulary

- **biozone**: A rock unit that is defined by a characteristic index fossil or fossil assemblage.
- **correlation**: Methods for establishing the age relationships of rock units that are not in the same locality.
- **key bed**: A distinctive, widespread rock layer that formed at a single time.
- **microfossil**: A fossil that must be studied with the aid of a microscope.

Summary

- A single rock unit contains the story of the geology of that location. To understand the geology of a region, scientists use correlation.
- To correlate rock units, something distinctive must be present in each. This can include an index fossil, a unique rock type, a key bed, or a unique sequence of rocks.
- A key bed can be global. An example is the iridium layer that was deposited at the time of the Cretaceous-Tertiary extinctions.

Practice

Use this resource to answer the questions that follow.

Leaf fossils in Lapilli tuff

http://www.youtube.com/watch?v=XufnHbL9Wl4

MEDIA

Click image to the left for more content.

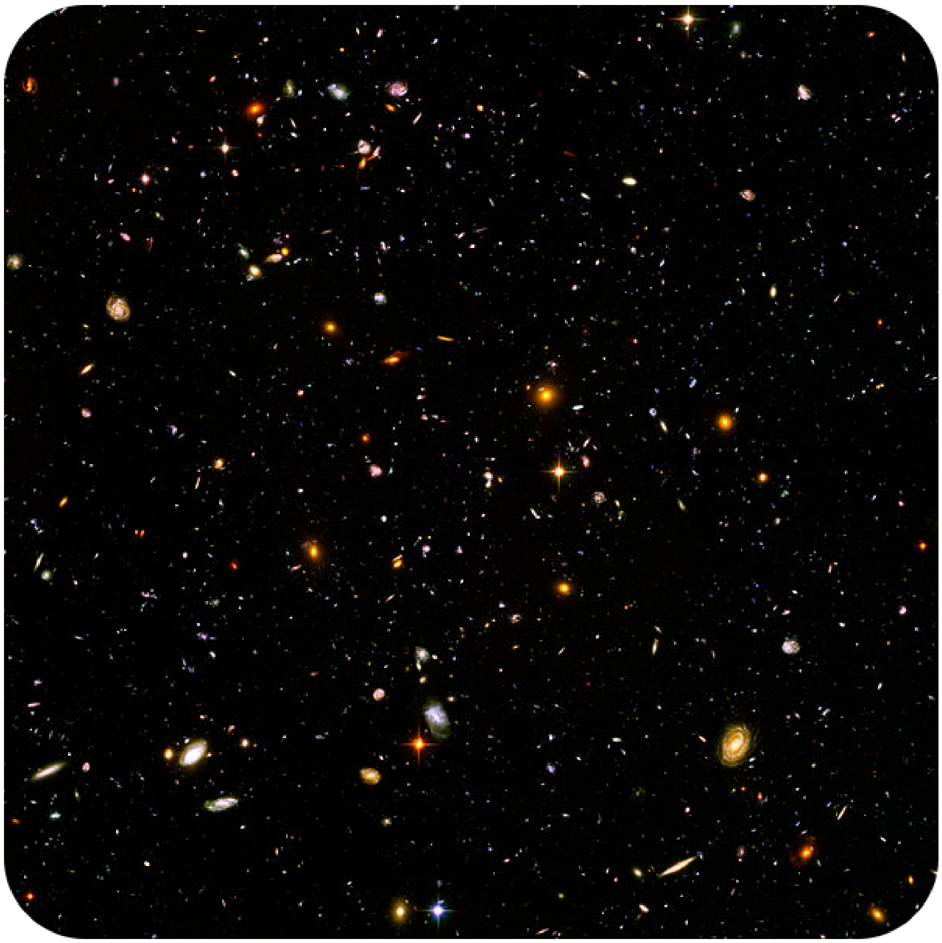
1. Where were these leaf fossils found?
2. Why is this volcanic ash unique?
3. How is the lapilli tuff formed?
4. Why is this lapilli tuff important?
5. What does the lapilli tuff allow scientists to do?

Review

1. What features must the iridium layer that dates to around 66 million years ago have to be a key bed?
2. Why are microfossils especially useful as index fossils?
3. What is the process of correlation?

11.7 Geologic Time Scale

- The geologic time scale allows scientists to refer to events in Earth history in relevant units.



To infinity and beyond!

We can picture deep space, but what does deep time look like? If you divided up the 4.6 billion years of Earth history into one calendar year, as is done at the end of this lesson, you might get an idea.

The Geologic Time Scale

To be able to discuss Earth history, scientists needed some way to refer to the time periods in which events happened and organisms lived. With the information they collected from fossil evidence and using Steno's principles, they created a listing of rock layers from oldest to youngest. Then they divided Earth's history into blocks of time with each block separated by important events, such as the disappearance of a species of fossil from the rock record. Since many of the scientists who first assigned names to times in Earth's history were from Europe, they named the blocks of time from towns or other local places where the rock layers that represented that time were found.

From these blocks of time the scientists created the **geologic time scale** (**Figure** 11.18). In the geologic time scale the youngest ages are on the top and the oldest on the bottom. Why do you think that the more recent time periods are divided more finely? Do you think the divisions in the scale below are proportional to the amount of time each time period represented in Earth history?

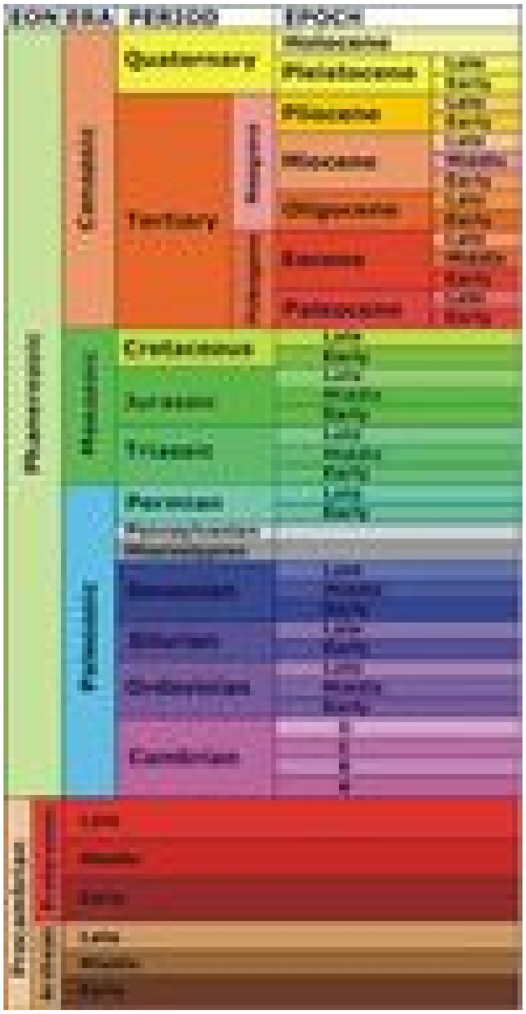


FIGURE 11.18
The geologic time scale is based on relative ages. No actual ages were placed on the original time scale.

In what eon, era, period and epoch do we now live? We live in the Holocene (sometimes called Recent) epoch, Quaternary period, Cenozoic era, and Phanerozoic eon.

Geologic Time Condensed to One Year

It's always fun to think about geologic time in a framework that we can more readily understand. Here are when some major events in Earth history would have occurred if all of earth history was condensed down to one calendar year.

January 1 12 am: Earth forms from the planetary nebula – 4600 million years ago

February 25, 12:30 pm: The origin of life; the first cells – 3900 million years ago

March 4, 3:39 pm: Oldest dated rocks – 3800 million years ago

March 20, 1:33 pm: First stromatolite fossils – 3600 million years ago

July 17, 9:54 pm: first fossil evidence of cells with nuclei – 2100 million years ago

November 18, 5:11 pm: Cambrian Explosion – 544 million years ago

December 1, 8:49 am: first insects – 385 million years ago

December 2, 3:54 am: first land animals, amphibians – 375 million years ago

December 5, 5:50 pm: first reptiles – 330 million years ago

December 12, 12:09 pm: Permo-Triassic Extinction – 245 million years ago

December 13, 8:37 pm: first dinosaurs – 228 million years ago

December 14, 9:59 am: first mammals – 220 million years ago

December 22, 8:24 pm: first flowering plants – 115 million years ago

December 26, 7:52 pm: Cretaceous-Tertiary Extinction – 66 million years ago

December 26, 9:47 pm: first ancestors of dogs – 64 million years ago

December 27, 5:25 am: widespread grasses – 60 million years ago

December 27, 11:09 am: first ancestors of pigs and deer – 57 million years ago

December 28, 9:31 pm: first monkeys – 39 million years ago

December 31, 5:18 pm: oldest hominid – 4 million years ago

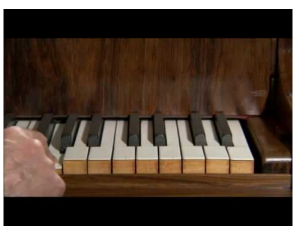
December 31, 11:02 pm: oldest direct human ancestor – 1 million years ago

December 31, 11:48 pm: first modern human – 200,000 years ago

December 31, 11:59 pm: Revolutionary War – 235 years ago

Source: http://www.timetoast.com/timelines/63215

See the video below for another analogy of geologic time:



MEDIA

Click image to the left for more content.

Vocabulary

- **geologic time scale**: A division of Earth's history into blocks of time distinguished by geologic and evolutionary events.

Summary

- The geologic time scale divides earth history into named units that are separated by major events in earth or life history.
- Naming time periods makes it easier to talk about them.
- Humans have been around for a miniscule portion of earth history.

Practice

Use this resource to answer the questions that follow.

Geologic Time - Introduction

http://www.youtube.com/watch?v=NFmdlRMO8II

MEDIA
Click image to the left for more content.

1. How old is the Earth?
2. What is stratigraphy?
3. What is an eon?
4. What do eras and periods represent?
5. What is the lower limit of the Proterozoic era?
6. What are isotopes?
7. Why are isotopes important to geologic time?

Review

1. Why do earth scientists need a geologic time scale?
2. Why are some units of the geologic time scale longer and some shorter?
3. How does the section that condenses all of geologic time into one year make you feel?

11.8 Tree Rings, Ice Cores, and Varves

- Learn three ways that scientists can get an absolute age, tree rings, ice cores and varves.

How can scientists tell the oldest possible age of this painting?

The Netherlandish paintings, which were painted in the low-lying countries of and near the Netherlands, were painted on solid wood panels, usually oak. The wood was split radially so that tree rings are visible and dates for the paintings date, which are from the 15th and 16th centuries, can be determined. Why does this give the oldest possible age?

Tree Ring Dating

In locations where summers are warm and winters are cool, trees have a distinctive growth pattern. Tree trunks display alternating bands of light-colored, low density summer growth and dark, high density winter growth. Each light-dark band represents one year. By counting **tree rings** it is possible to find the number of years the tree lived (**Figure** 11.19).

The width of these growth rings varies with the conditions present that year. A summer drought may make the tree grow more slowly than normal and so its light band will be relatively small. These tree-ring variations appear in all trees in a region. The same distinctive pattern can be found in all the trees in an area for the same time period.

Scientists have created continuous records of tree rings going back over the past 2,000 years. Wood fragments from old buildings and ancient ruins can be age dated by matching up the pattern of tree rings in the wood fragment in question and the scale created by scientists. The outermost ring indicates when the tree stopped growing; that is, when it died. The tree-ring record is extremely useful for finding the age of ancient structures.

FIGURE 11.19
Cross-section showing growth rings.

An example of how tree-ring dating is used to date houses in the United Kingdom is found in this article: http://www.periodproperty.co.uk/ppuk_discovering_article_013.shtml.

Ice Cores

Besides tree rings, other processes create distinct yearly layers that can be used for dating. On a glacier, snow falls in winter but in summer dust accumulates. This leads to a snow-dust annual pattern that goes down into the ice (**Figure** 11.20). Scientists drill deep into ice sheets, producing **ice cores** hundreds of meters long. The information scientists gather allows them to determine how the environment has changed as the glacier has stayed in its position. Analyses of the ice tell how concentrations of atmospheric gases changed, which can yield clues about climate. The longest cores allow scientists to create a record of polar climate stretching back hundreds of thousands of years.

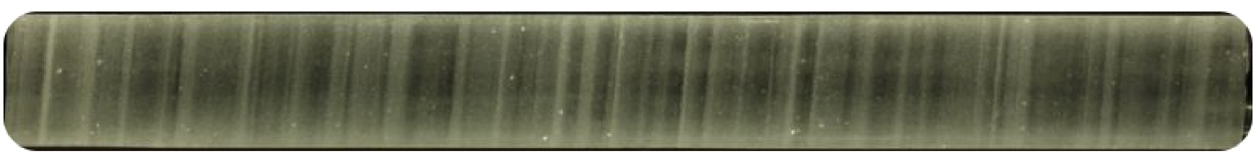


FIGURE 11.20
Ice core section showing annual layers.

Varves

Lake sediments, especially in lakes that are located at the end of glaciers, also have an annual pattern. In the summer, the glacier melts rapidly, producing a thick deposit of sediment. These alternate with thin, clay-rich layers deposited in the winter. The resulting layers, called **varves**, give scientists clues about past climate conditions (**Figure** 11.21). A warm summer might result in a very thick sediment layer while a cooler summer might yield a thinner layer.

FIGURE 11.21
Ancient varve sediments in a rock outcrop.

Vocabulary

- **ice core**: Cylinder of ice extracted from a glacier or ice sheet.
- **tree ring**: Rings of wood equaling one year of tree growth in a tree trunk.
- **varve**: Paired deposit of light-colored, coarser sediments and darker, fine-grained sediments deposited in a glacial lake that represent an annual cycle.

Summary

- Where conditions vary seasonally, trees develop distinctive rings, ice contains more or less dust, and lake sediments show more or less clay.
- Tree rings, ice cores and varves indicate the environmental conditions at the time they were made.
- The distinctive patterns of tree rings, ice cores and varves going back thousands of years can be used to determine the time they were made.

Practice

Use these resources to answer the questions that follow.

Science Nation - Lord of the Tree Rings

http://www.youtube.com/watch?v=FAOYkx8E-Gc

MEDIA
Click image to the left for more content.

1. What do tree rings tell scientists?
2. What can be learned from tree rings?
3. How are tree rings being used to help current climate change?
4. What type of trees do scientists look for? Why?

Science Nation - Ice Cores Secrets Could Reveal Answers to Global Warming

http://www.youtube.com/watch?v=NENZ6TSc1fo

MEDIA

Click image to the left for more content.

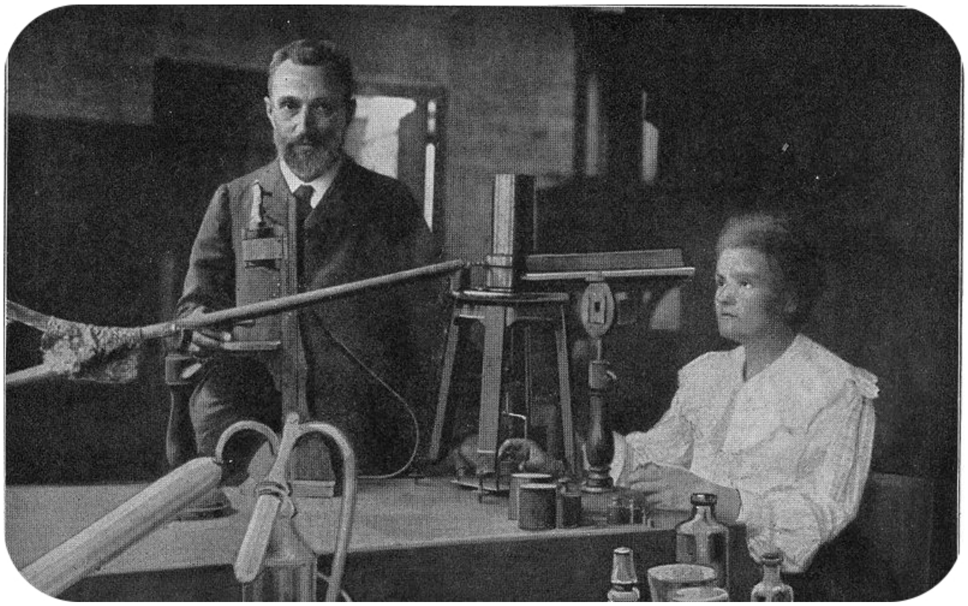
5. What is trapped in the ice cores?
6. How long have ice cores been studied?
7. What can be learned from ice cores?
8. Where are ice cores collected?

Review

1. What is dendrochronology?
2. How do tree rings, ice cores and varves indicate the time at which they were made?
3. How do tree rings, ice cores and varves indicate environmental conditions at the time they formed?

11.9 Radioactive Decay as a Measure of Age

- Radioactive decay gives a way to determine the age of some types of rocks.



Why did this couple win the Nobel Prize?

Pierre and Marie Curie, a husband and wife team of physicists, discovered the spontaneous emission of particles from certain elements. They called this phenomenon "radioactivity." Together they won three Nobel prizes, and the element curium was named in their honor.

Radioactive Decay

Radioactivity is the tendency of certain atoms to decay into lighter atoms, a process that emits energy. Radioactivity also provides a way to find the absolute age of a rock. First, we need to know about radioactive decay.

Radioactive Isotopes

Some isotopes are radioactive; **radioactive isotopes** are unstable and spontaneously change by gaining or losing particles. Two types of radioactive decay are relevant to dating Earth materials (**Table** 11.1):

TABLE 11.1: **Types of Radioactive Decay**

Particle	Composition	Effect on Nucleus
Alpha	2 protons, 2 neutrons	The nucleus contains two fewer protons and two fewer neutrons.
Beta	1 electron	One neutron decays to form a proton and an electron. The electron is emitted.

The radioactive decay of a **parent isotope** (the original element) leads to the formation of stable **daughter product**, also known as daughter isotope. As time passes, the number of parent isotopes decreases and the number of daughter isotopes increases (**Figure** 11.22).

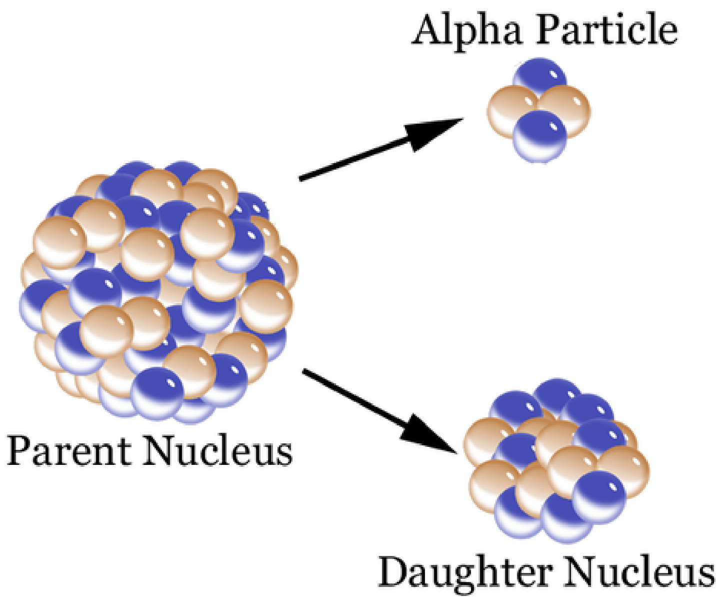


FIGURE 11.22
A parent emits an alpha particle to create a daughter.

An animation of radioactive decay: http://lectureonline.cl.msu.edu/ mmp/applist/decay/decay.htm.

Half-Lives

Radioactive materials decay at known rates, measured as a unit called **half-life**. The half-life of a radioactive substance is the amount of time it takes for half of the parent atoms to decay. This is how the material decays over time (see **Table** 11.2).

TABLE 11.2: Radioactive Decay

No. of half lives passed	Percent parent remaining	Percent daughter produced
0	100	0
1	50	50
2	25	75
3	12.5	87.5
4	6.25	93.75
5	3.125	96.875
6	1.563	98.437
7	0.781	99.219
8	0.391	99.609

Pretend you find a rock with 3.125% parent atoms and 96.875% daughter atoms. How many half lives have passed? If the half-life of the parent isotope is 1 year, then how old is the rock? The decay of radioactive materials can be shown with a graph (**Figure** 11.23).

An animation of half-life: http://einstein.byu.edu/ masong/htmstuff/Radioactive2.html.

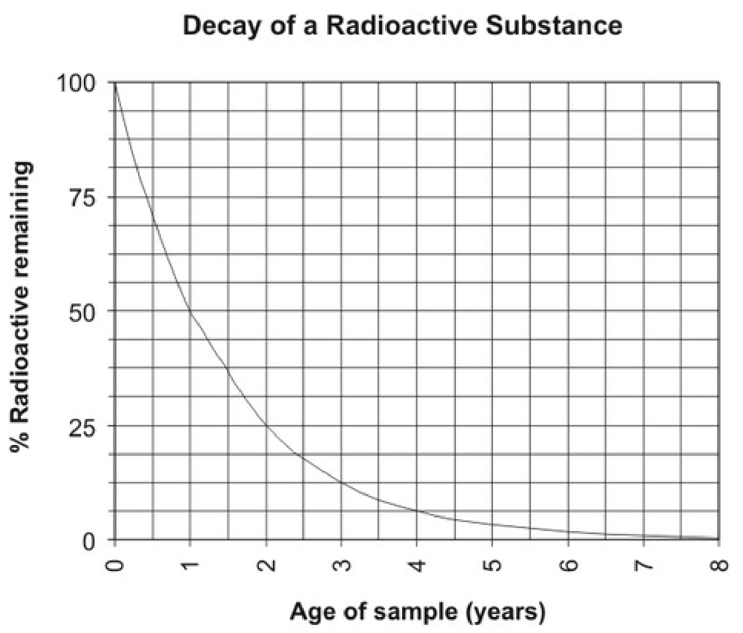
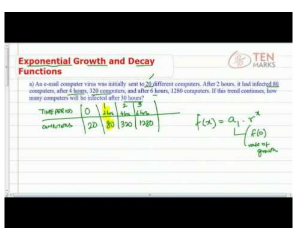


FIGURE 11.23
Decay of an imaginary radioactive substance with a half-life of one year.

Notice how it doesn't take too many half lives before there is very little parent remaining and most of the isotopes are daughter isotopes. This limits how many half lives can pass before a radioactive element is no longer useful for dating materials. Fortunately, different isotopes have very different half lives.

Radiometric decay is exponential. Learn how exponential growth and decay can be described mathematically in this video (**I&E 1e**): http://www.youtube.com/watch?v=UbwMW7Q6F3E (4:46).



MEDIA
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Vocabulary

- **daughter product**: The product of the radioactive decay of a parent isotope.
- **half-life**: The amount of time required for half of the atoms of a radioactive substance to decay to the daughter product.
- **parent isotope**: An unstable isotope that will undergo radioactive decay.
- **radioactive isotope**: Substance that is unstable and likely to decay into another isotope.
- **radioactivity**: Emission of high-energy particles by unstable isotopes.

Summary

- A half life is the time it takes for half of the parent isotopes of an element to change to daughter isotopes.
- With alpha decay, the nucleus loses two protons and two neutrons; with beta decay only one electron is lost.

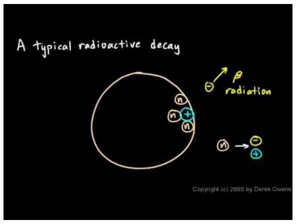
- Radiometric decay is exponential.

Practice

Use this resource to answer the questions that follow.

A Typical Radioactive Decay

http://www.youtube.com/watch?v=r-t01FsUXao



MEDIA

Click image to the left for more content.

1. Why are protons necessary near neutrons?
2. What does a neutron decay into?
3. What does the electron ejection cause?
4. What happens to the element when it gains a proton?
5. What is an alpha particle?
6. What is transmutation?
7. What is produced from transmutation?

Review

1. Describe the two types of radioactive decay that are relevant to dating earth materials.
2. For how many half lives is a set of parent and daughter isotopes useful as a system of dating?
3. What does it mean that radioactive decay is exponential?

11.10 Radiometric Dating

- Radiometric dating uses radioactive isotopes to get the absolute ages of rocks and other materials.

How do you date a rock (and who would want to)?

How you date a rock depends on what type of rock it is and how old it might be. Different radioactive isotopes have different half lives and so they are useful for dating different types and ages of rocks. Who would want to? Why, geologists, of course!

Radiometric Dating of Rocks

Radiometric dating is the process of using the concentrations of radioactive substances and daughter products to estimate the age of a material. Different isotopes are used to date materials of different ages. Using more than one isotope helps scientists to check the accuracy of the ages that they calculate.

Radiocarbon Dating

Radiocarbon dating is used to find the age of once-living materials between 100 and 50,000 years old. This range is especially useful for determining ages of human fossils and habitation sites (**Figure** 11.24).

The atmosphere contains three isotopes of carbon: carbon-12, carbon-13 and carbon-14. Only carbon-14 is radioactive; it has a half-life of 5,730 years. The amount of carbon-14 in the atmosphere is tiny and has been relatively stable through time.

Plants remove all three isotopes of carbon from the atmosphere during photosynthesis. Animals consume this carbon when they eat plants or other animals that have eaten plants. After the organism's death, the carbon-14 decays to stable nitrogen-14 by releasing a beta particle. The nitrogen atoms are lost to the atmosphere, but the amount of carbon-14 that has decayed can be estimated by measuring the proportion of radioactive carbon-14 to stable carbon-12. As time passes, the amount of carbon-14 decreases relative to the amount of carbon-12.

FIGURE 11.24
Carbon isotopes from the black material in these cave paintings places their creating at about 26,000 to 27,000 years BP (before present).

A video of carbon-14 decay is seen here: http://www.youtube.com/watch?v=81dWTeregEA; a longer explanation is here: http://www.youtube.com/watch?v=udkQwW6aLik#38;feature=related.

Potassium-Argon Dating

Potassium-40 decays to argon-40 with a half-life of 1.26 billion years. Argon is a gas so it can escape from molten magma, meaning that any argon that is found in an igneous crystal probably formed as a result of the decay of potassium-40. Measuring the ratio of potassium-40 to argon-40 yields a good estimate of the age of that crystal.

Potassium is common in many minerals, such as feldspar, mica, and amphibole. With its half-life, the technique is used to date rocks from 100,000 years to over a billion years old. The technique has been useful for dating fairly young geological materials and deposits containing the bones of human ancestors.

Uranium-Lead Dating

Two uranium isotopes are used for radiometric dating.

- Uranium-238 decays to lead-206 with a half-life of 4.47 billion years.
- Uranium-235 decays to form lead-207 with a half-life of 704 million years.

Uranium-lead dating is usually performed on zircon crystals (**Figure** 11.25). When zircon forms in an igneous rock, the crystals readily accept atoms of uranium but reject atoms of lead. If any lead is found in a zircon crystal, it can be assumed that it was produced from the decay of uranium.

Uranium-lead dating is useful for dating igneous rocks from 1 million years to around 4.6 billion years old. Zircon crystals from Australia are 4.4 billion years old, among the oldest rocks on the planet.

FIGURE 11.25
Zircon crystal.

Limitations of Radiometric Dating

Radiometric dating is a very useful tool for dating geological materials but it does have limits:

1. The material being dated must have measurable amounts of the parent and/or the daughter isotopes. Ideally, different radiometric techniques are used to date the same sample; if the calculated ages agree, they are thought to be accurate.

2. Radiometric dating is not very useful for determining the age of sedimentary rocks. To estimate the age of a sedimentary rock, geologists find nearby igneous rocks that can be dated and use relative dating to constrain the age of the sedimentary rock.

Using Radiometric Ages to Date Other Materials

As you've learned, radiometric dating can only be done on certain materials. But these important numbers can still be used to get the ages of other materials! How would you do this? One way is to constrain a material that cannot be dated by one or more that can. For example, if sedimentary rock A is below volcanic rock B and the age of volcanic rock B is 2.0 million years, then you know that sedimentary rock A is older than 2.0 million years. If sedimentary rock A is above volcanic rock C and it's age is 2.5 million years then you know that sedimentary rock A is between 2.0 and 2.5 million years. In this way, geologists can figure out the approximate ages of many different rock formations.

Vocabulary

- **radiometric dating**: Process of using the concentrations of radioactive substances and daughter products to estimate the age of a material.

Summary

- Radiocarbon is useful for relatively young, carbon-based materials; other longer-lived isotopes are good for older rocks and minerals.

- Different isotope pairs are useful for certain materials of certain ages.
- Radiometric dating cannot be used if parent or daughter are not measurable or if one or the other has been lost from the system.

Practice

Use this resource to answer the questions that follow.

Radionetric Dating

http://www.youtube.com/watch?v=1920gi3swe4

MEDIA

Click image to the left for more content.

1. What do scientists want to answer with radiometric dating?
2. What is the easiest way to date rocks?
3. How do we get actual dates on rocks?
4. How is the rock crushed?
5. What are scientists looking for in this rock?
6. Who came up with the principle of radiometric dating?
7. What is the mass spectrometer? Who invented it?
8. What is the spectrometer separating in this rock?
9. Why is the dating of rocks important?
10. What is the age of the Earth?

Review

1. How would you determine which isotope pair to use for a particular material?
2. How does radiocarbon dating work and on what materials does it work best on?
3. What types of rocks are best fro radiometric dating and why?

11.11 Age of Earth

- Know how scientists arrived at the conclusion that Earth is 4.6 billion years old.

How old is Earth and how do scientists know?

4.6 billion years old. Arriving at this number wasn't easy but there are many lines of evidence that have allowed scientists to reach that conclusion.

Indirect Estimates

During the 18th and 19th centuries, geologists tried to estimate the age of Earth with indirect techniques. What methods can you think of for doing this? One example is that by measuring how much sediment a stream deposited in a year, a geologist might try to determine how long it took for a stream to deposit an ancient sediment layer. Not surprisingly, these methods resulted in wildly different estimates. A relatively good estimate was produced by the British geologist Charles Lyell, who thought that 240 million years had passed since the appearance of the first animals with shells. Today scientists know that this event occurred about 530 million years ago.

In 1892, William Thomson (later known as Lord Kelvin) calculated that the Earth was 100 million years old. He did this systematically assuming that the planet started off as a molten ball and calculating the time it would take for it to cool to its current temperature. This estimate was a blow to geologists and supporters of Charles Darwin's theory of evolution, which required an older Earth to provide time for geological and evolutionary processes to take place.

Thomson's calculations were soon shown to be flawed when radioactivity was discovered in 1896. What Thomson didn't know is that radioactive decay of elements inside Earth's interior provides a steady source of heat. Thomson had grossly underestimated Earth's age.

More Quantitatively

Radioactivity turned out to be useful for dating Earth materials and for coming up with a quantitative age for Earth. Scientists not only date ancient rocks from Earth's crust, they also date meteorites that formed at the same time Earth and the rest of the solar system were forming. Moon rocks also have been radiometrically dated.

Using a combination of radiometric dating, index fossils, and superposition, geologists have constructed a well-defined timeline of Earth history. With information gathered from all over the world, estimates of rock and fossil ages have become increasingly accurate. This is the modern geologic time scale with all of the ages.

All of this evidence comes together to pinpoint the age of Earth at 4.6 billion years. A video discussing the evidence for this is found here: http://www.youtube.com/watch?v=w5369-OobM4

The age of Earth is also discussed in this video: http://www.youtube.com/watch?v=lplcRdNDcps#38;feature=channel.

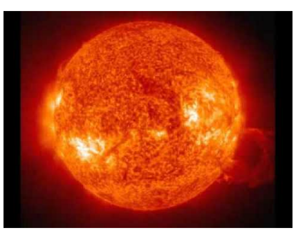
Summary

- Early geologists estimated Earth's age in a variety of inaccurate ways like the amount of time it might take for a sediment layer to be deposited.
- Estimates of how long it would take for a molten Earth to cool were also too young since scientists didn't know about radioactivity.
- Radiometric dating of meteorites and Moon rocks indicate that Earth is 4.6 billion years old.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=w5369-OobM4



MEDIA

Click image to the left for more content.

1. What is comparative dating?
2. How is absolute dating determined?
3. What is carbon dating?
4. What is paleomagnetic dating?
5. What is radiometric dating?
6. What has been found with radiometric dating?

7. How old is the Earth?

Review

1. How do scientists know that Earth is 4.6 billion years old?
2. Why were early estimates of Earth's age too young?
3. How does the modern geologic time scale differ from the original?

11.12 Formation of the Sun and Planets

- Sun and planets formed from a solar nebula about 4.6 billion years ago.

Do scientists just make this stuff up?

No! Although our Solar System formed nearly 5 billion years ago, we can see stars forming elsewhere in the galaxy, such as in the Large Magellanic cloud 160,000 light years away. Although we can't know for sure, astronomers think that our early solar system looked very much like this.

Formation of the Solar System

The most widely accepted explanation of how the solar system formed is called the **nebular hypothesis**. According to this hypothesis, the Sun and the planets of our solar system formed about 4.6 billion years ago from the collapse of a giant cloud of gas and dust, called a **nebula**.

The nebula was drawn together by gravity, which released gravitational potential energy. As small particles of dust and gas smashed together to create larger ones, they released kinetic energy. As the nebula collapsed, the gravity at the center increased and the cloud started to spin because of its angular momentum. As it collapsed further, the spinning got faster, much as an ice skater spins faster when he pulls his arms to his sides during a spin.

Much of the cloud's mass migrated to its center but the rest of the material flattened out in an enormous disk. The disk contained hydrogen and helium, along with heavier elements and even simple organic molecules.

Formation of the Sun and Planets

As gravity pulled matter into the center of the disk, the density and pressure at the center became intense. When the pressure in the center of the disk was high enough, nuclear fusion began. A star was born—the Sun. The burning star stopped the disk from collapsing further.

Meanwhile, the outer parts of the disk were cooling off. Matter condensed from the cloud and small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps, called planetesimals, attracted smaller clumps with their gravity. Gravity at the center of the disk attracted heavier particles,

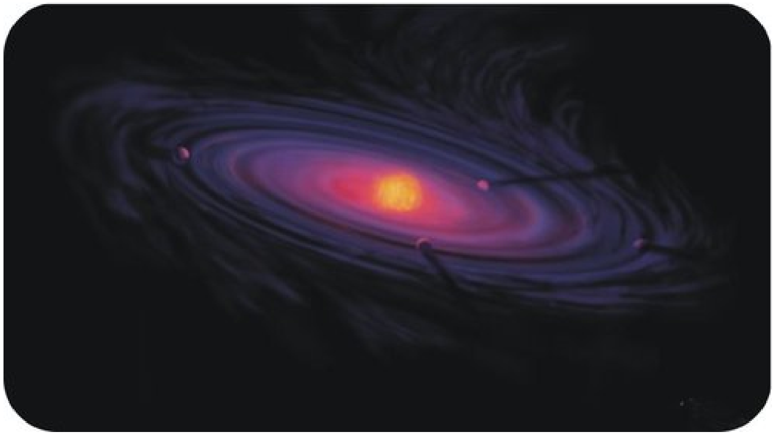


FIGURE 11.26
An artist's painting of a protoplanetary disk.

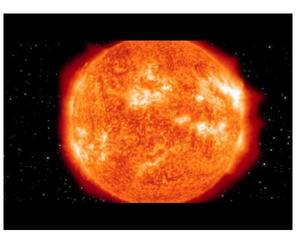
such as rock and metal and lighter particles remained further out in the disk. Eventually, the planetesimals formed protoplanets, which grew to become the planets and moons that we find in our solar system today.

Because of the gravitational sorting of material, the inner planets — Mercury, Venus, Earth, and Mars — formed from dense rock and metal. The outer planets — Jupiter, Saturn, Uranus and Neptune — condensed farther from the Sun from lighter materials such as hydrogen, helium, water, ammonia, and methane. Out by Jupiter and beyond, where it's very cold, these materials form solid particles.

The nebular hypothesis was designed to explain some of the basic features of the solar system:

- The orbits of the planets lie in nearly the same plane with the Sun at the center
- The planets revolve in the same direction
- The planets mostly rotate in the same direction
- The axes of rotation of the planets are mostly nearly perpendicular to the orbital plane
- The oldest moon rocks are 4.5 billion years

This video, from the ESA, discusses the Sun, planets, and other bodies in the Solar System and how they formed **(1a, 1d)**. The first part of the video explores the evolution of our view of the solar system starting with the early Greeks who reasoned that since some points of light - which they called planets - moved faster than the stars, they must be closer: http://www.youtube.com/watch?v=-NxfBOhQ1CY#38;feature=player_profilepage (8:34).



MEDIA
Click image to the left for more content.

Vocabulary

- **nebula**: An interstellar cloud of gas and dust.
- **nebular hypothesis**: The hypothesis that our solar system formed from a spinning cloud of gas and dust, or a nebula.

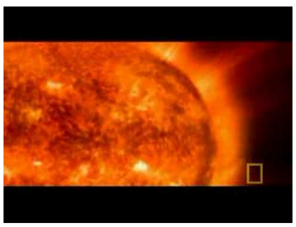
Summary

- A giant cloud of dust and gas, called a nebula, collapsed to form the solar system; this is the nebular hypothesis.
- The nebular hypothesis explains many of the features of the solar system like the orbital plane, the revolution and rotation of the planets, the relationship of the axes of rotation and the orbital plane and the age of moon rocks.
- Planets nearer the Sun are similar because they formed of denser metal and rocks, but planets further out are lighter and gaseous.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=B1AXbpYndGc



MEDIA

Click image to the left for more content.

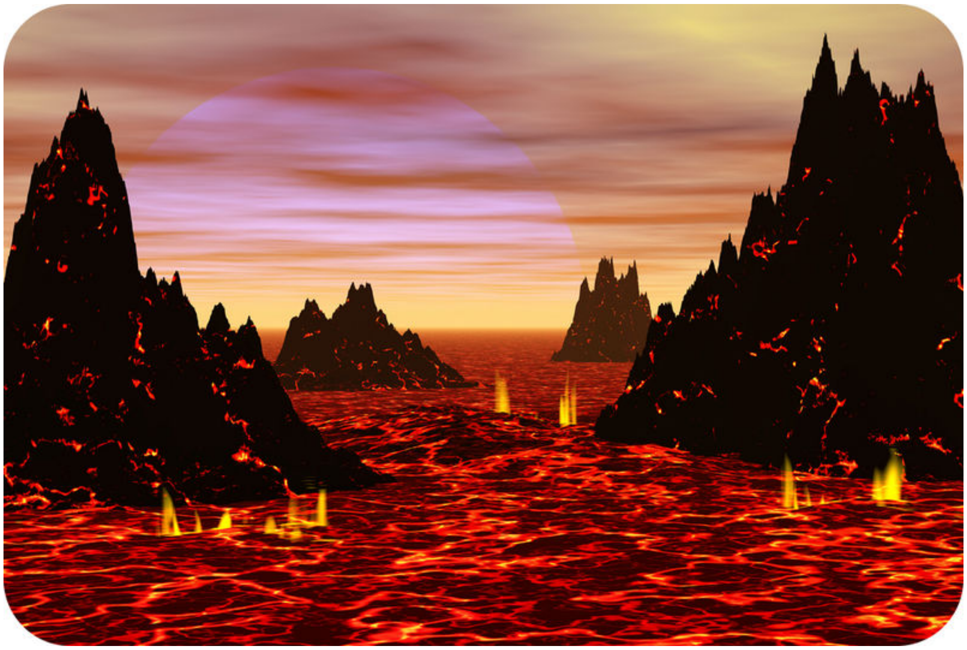
1. What is a protostar?
2. When does nuclear fusion begin?
3. When was our star born?
4. How long with the star burn?
5. How do scientists think our sun was born?
6. What was the Big Bang?

Review

1. What is the nebular hypothesis?
2. How do features we see elsewhere in our galaxy help us to understand the origin of our solar system?
3. How does the nebular hypothesis account for the observable features of the solar system?

11.13 Formation of Earth

- Earth formed with the rest of the solar system and differentiated into layers.



What was early Earth like?

Earth was not always the moderate and habitable planet it is today. In its earliest days, Earth was scorching hot and without an atmosphere or water. If life originated early on, it was wiped out by the terrible conditions.

Formation of Earth

Earth formed at the same time as the other planets. The history of Earth is part of the history of the Solar System.

Planets Form

Earth came together (accreted) from the cloud of dust and gas known as the solar nebula nearly 4.6 billion years ago, the same time the Sun and the rest of the solar system formed. Gravity caused small bodies of rock and metal orbiting the proto-Sun to smash together to create larger bodies. Over time, the planetoids got larger and larger until they became planets.

Molten Earth

When Earth first came together it was really hot, hot enough to melt the metal elements that it contained. Earth was so hot for three reasons:

- Gravitational contraction: As small bodies of rock and metal accreted, the planet grew larger and more massive. Gravity within such an enormous body squeezes the material in its interior so hard that the pressure swells. As Earth's internal pressure grew, its temperature also rose.

- Radioactive decay: Radioactive decay releases heat, and early in the planet's history there were many radioactive elements with short half lives. These elements long ago decayed into stable materials, but they were responsible for the release of enormous amounts of heat in the beginning.
- Bombardment: Ancient impact craters found on the Moon and inner planets indicate that asteroid impacts were common in the early solar system. Earth was struck so much in its first 500 million years that the heat was intense. Very few large objects have struck the planet in the past many hundreds of millions of year.

Differentiation

When Earth was entirely molten, gravity drew denser elements to the center and lighter elements rose to the surface. The separation of Earth into layers based on density is known as **differentiation**. The densest material moved to the center to create the planet's dense metallic core. Materials that are intermediate in density became part of the mantle (**Figure** 11.27).

FIGURE 11.27
Earth's interior: Inner core, outer core, mantle, and crust.

First Crust

Lighter materials accumulated at the surface of the mantle to become the earliest crust. The first crust was probably basaltic, like the oceanic crust is today. Intense heat from the early core drove rapid and vigorous mantle convection so that crust quickly recycled into the mantle. The recycling of basaltic crust was so effective that no remnants of it are found today.

Early Solar System Materials

There is not much material to let us know about the earliest days of our planet Earth. What there is comes from three sources: (1) zircon crystals, the oldest materials found on Earth, which show that the age of the earliest crust formed at least 4.4 billion years ago; (2) meteorites that date from the beginning of the solar system, to nearly 4.6 billion years ago (**Figure** 11.28); and (3) lunar rocks, which represent the early days of the Earth-Moon system as far back as 4.5 billion years ago.

FIGURE 11.28
The Allende Meteorite is a carbonaceous chondrite that struck Earth in 1969. The calcium-aluminum-rich inclusions are fragments of the earliest solar system.

Vocabulary

- **differentiation**: The separation of planetary materials by density to create distinctly different layers.

Summary

- In the beginning, Earth was exceedingly hot due to gravitational contraction, the radioactive decay of short-lived isotopes, and bombardment from meteorites.
- The molten Earth separated into layers by density in a process known as differentiation.
- We know about the early Earth from zircon crystals, meteorites that originated elsewhere in the solar system, and moon rocks.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=-x8-KMR0nx8

MEDIA

Click image to the left for more content.

1. What did the impacts to form the early Earth create?
2. Why were these impacts important?
3. What is caused by the heat?
4. How old is the Earth?
5. What does the heat in the core mean for the Earth?

Review

1. Radioactive elements inside the planet release heat now, but why was so much more heat released earlier in Earth's history?
2. Describe how and why Earth material separated into layers.
3. How do zircon crystals indicate when the first crust formed?

11.14 Formation of the Moon

- Moon's birth story accounts for its amazing features.

Why is this called the Genesis Rock?

The Genesis Rock was brought from the Moon to Earth by Apollo 15 astronauts. The rock is only 100 million years younger than the solar system and comes from the Moon's original crust.

How the Moon Formed

One of the most unique features of planet Earth is its large Moon. Unlike the only other natural satellites orbiting an inner planet, those of Mars, the Moon is not a captured asteroid. Understanding the Moon's birth and early history reveals a great deal about Earth's early days.

Features of the Moon

To determine how the Moon formed, scientists had to account for several lines of evidence:

- The Moon is large; not much smaller than the smallest planet, Mercury.

- Earth and Moon are very similar in composition.
- Moon's surface is 4.5 billion years old, about the same as the age of the solar system.
- For a body its size and distance from the Sun, the Moon has very little core; Earth has a fairly large core.
- The oxygen isotope ratios of Earth and Moon indicate that they originated in the same part of the solar system.
- Earth has a faster spin than it should have for a planet of its size and distance from the Sun.

Can you devise a "birth story" for the Moon that takes all of these bits of data into account?

Moon's Birth Story

Astronomers have carried out computer simulations that are consistent with these facts and have detailed a birth story for the Moon. A little more than 4.5 billion years ago, roughly 70 million years after Earth formed, planetary bodies were being pummeled by asteroids and planetoids of all kinds. Earth was struck by a Mars-sized asteroid (**Figure** 11.29).

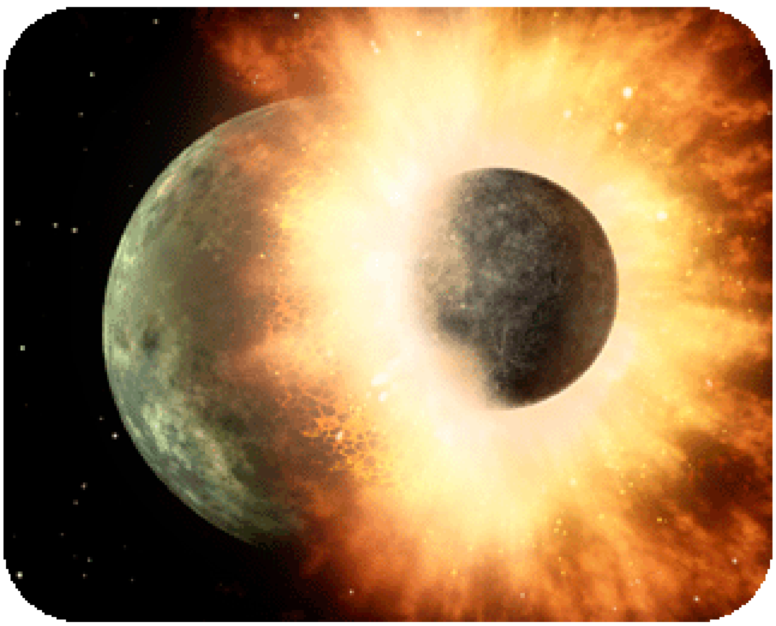


FIGURE 11.29
An artist's depiction of the impact that produced the Moon.

The tremendous energy from the impact melted both bodies. The molten material mixed up. The dense metals remained on Earth but some of the molten, rocky material was flung into an orbit around Earth. It eventually accreted into a single body, the Moon. Since both planetary bodies were molten, material could differentiate out of the magma ocean into core, mantle, and crust as they cooled. Earth's fast spin is from energy imparted to it by the impact.

Moon Rocks

Lunar rocks reveal an enormous amount about Earth's early days. The Genesis Rock, with a date of 4.5 billion years, is only about 100 million years younger than the solar system (See opening image). The rock is a piece of the Moon's anorthosite crust, which was the original crust. Why do you think Moon rocks contain information that is not available from Earth's own materials?

More information about the Genesis Rock from NASA is found here: http://www.nasa.gov/mission_pages/LRO/news/image_release042310.html.

Can you find how all of the evidence presented in the bullet points above is present in the Moon's birth story?

Summary

- The scientific explanation for how the Moon formed must take into account its features, such as its large size, internal structure, chemical composition, and spin.
- Earth was struck by a giant asteroid that melted the planet and asteroid and flung material into orbit where it coalesced and cooled to become the Moon.
- Moon's original crust is anorthosite, a feldspar-rich, light rock.

Practice

Use this resource to answer the questions that follow.

http://www.space.com/9926-moon-life.html

1. What is the mass of the moon?
2. Why is our moon unique?
3. What is the moon made of?
4. What created the moon?
5. How did the Earth maintain its integrity?
6. Why were the tides important to life on Earth?

Review

1. Relay the story of how the Moon formed. Integrate as many of the Moon's features into the story as possible.
2. Why are Earth and Moon roughly the same age as the rest of the solar system?
3. Why do scientists learn a lot about the early Earth from their studies of the Moon?

11.15 Early Atmosphere and Oceans

- Earth's early atmosphere formed from volcanic outgassing and meteorites, and the later evolution of photosynthesis released oxygen, allowing more complex life to evolve.

Where did the first atmosphere and oceans come from?

At first, Earth did not have an atmosphere or free water since the planet was too hot for gases and water to collect. The atmosphere and oceans that we see today evolved over time. The gases came from within the planet and from far out in the solar system.

Earth's First Atmosphere

Earth's first atmosphere was made of hydrogen and helium, the gases that were common in this region of the solar system as it was forming. Most of these gases were drawn into the center of the solar nebula to form the Sun. When Earth was new and very small, the solar wind blew off atmospheric gases that collected. If gases did collect, they were vaporized by impacts, especially from the impact that brought about the formation of the Moon.

Eventually things started to settle down and gases began to collect. High heat in Earth's early days meant that there were constant volcanic eruptions, which released gases from the mantle into the atmosphere (See opening image). Just as today, volcanic **outgassing** was a source of water vapor, carbon dioxide, small amounts of nitrogen, and other gases.

Scientists have calculated that the amount of gas that collected to form the early atmosphere could not have come entirely from volcanic eruptions. Frequent impacts by asteroids and comets brought in gases and ices, including water, carbon dioxide, methane, ammonia, nitrogen, and other volatiles from elsewhere in the solar system (**Figure** 11.30).

Calculations also show that asteroids and comets cannot be responsible for all of the gases of the early atmosphere, so both impacts and outgassing were needed.

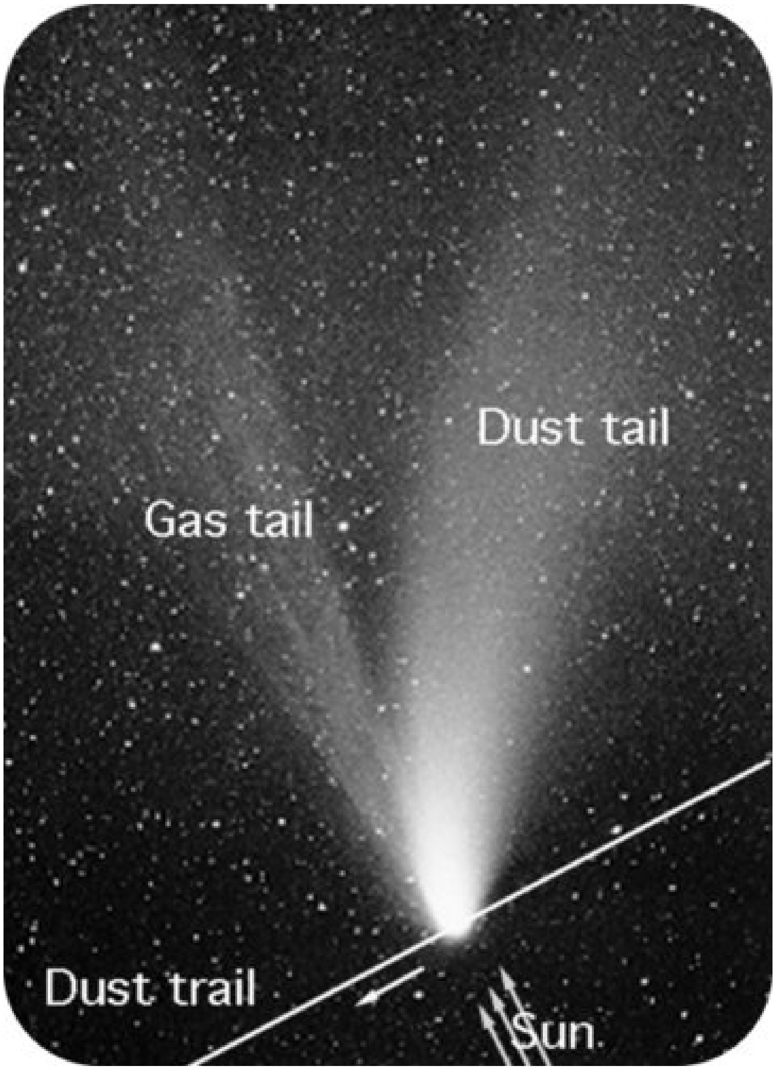


FIGURE 11.30
The gases that create a comet's tail can become part of the atmosphere of a planet.

Earth's Second Atmosphere

The second atmosphere, which was the first to stay with the planet, formed from volcanic outgassing and comet ices. This atmosphere had lots of water vapor, carbon dioxide, nitrogen, and methane but almost no oxygen. Why was there so little oxygen? Plants produce oxygen when they photosynthesize but life had not yet begun or had not yet developed photosynthesis. In the early atmosphere, oxygen only appeared when sunlight split water molecules into hydrogen and oxygen and the oxygen accumulated in the atmosphere.

Without oxygen, life was restricted to tiny simple organisms. Why is oxygen essential for most life on Earth?

1. Oxygen is needed to make ozone, a molecule made of three oxygen ions, O_3. Ozone collects in the atmospheric ozone layer and blocks harmful ultraviolet radiation from the Sun. Without an ozone layer, life in the early Earth was almost impossible.

2. Animals need oxygen to breathe. No animals would have been able to breathe in Earth's early atmosphere.

Early Oceans

The early atmosphere was rich in water vapor from volcanic eruptions and comets. When Earth was cool enough, water vapor condensed and rain began to fall. The water cycle began. Over millions of years enough precipitation collected that the first oceans could have formed as early as 4.2 to 4.4 billion years ago. Dissolved minerals carried by stream runoff made the early oceans salty. What geological evidence could there be for the presence of an early ocean? Marine sedimentary rocks can be dated back about 4 billion years.

By the Archean, the planet was covered with oceans and the atmosphere was full of water vapor, carbon dioxide, nitrogen, and smaller amounts of other gases.

Earth's Third Atmosphere

When photosynthesis evolved and spread around the planet, oxygen was released in abundance. The addition of oxygen is what created Earth's third atmosphere. This event, which occurred about 2.5 billion years ago, is sometimes called the oxygen catastrophe because so many organisms died. Although entire species died out and went extinct, this event is also called the Great Oxygenation Event because it was a great opportunity. The organisms that survived developed a use for oxygen through **cellular respiration**, the process by which cells can obtain energy from organic molecules. This opened up many opportunities for organisms to evolve to fill different niches and many new types of organisms first appeared on Earth.

Banded-Iron Formations

What evidence do scientists have that large quantities of oxygen entered the atmosphere? The iron contained in the rocks combined with the oxygen to form reddish iron oxides. By the beginning of the Proterozoic, banded-iron formations (BIFs) were forming. Banded-iron formations display alternating bands of iron oxide and iron-poor chert that probably represent a seasonal cycle of an aerobic and an anaerobic environment.

The oldest BIFs are 3.7 billion years old, but they are very common during the Great Oxygenation Event 2.4 billion years ago (**Figure** 11.31). By 1.8 billion years ago, the amount of BIF declined. In recent times, the iron in these formations has been mined, and that explains the location of the auto industry in the upper Midwest.

FIGURE 11.31
Banded-iron formation.

UV Protection

With more oxygen in the atmosphere, ultraviolet radiation could create ozone. With the formation of an ozone layer to protect the surface of the Earth from UV radiation, more complex life forms could evolve.

Vocabulary

- **cellular respiration**: Metabolic reactions in the cell that convert energy from nutrients into useable energy.
- **outgassing**: The transfer of gases from Earth's mantle to the atmosphere by volcanic eruptions.

Summary

- Earth's first atmosphere came from outgassing from the planet's interior and from asteroids and comets from elsewhere in the solar system.
- Earth's first and second atmosphere did not contain oxygen so there was no ozone layer to protect life from ultraviolet radiation and no oxygen for animals to breathe.
- Earth's third atmosphere contained oxygen that is a by-product of photosynthesis, allowing the evolution of animals and the formation of an ozone layer.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/earth/geology/earths_primordial_environs.html

1. What was the Earth;s early atmosphere like?

2. Where does the energy come from for chemical reactions?

3. What experiment provided evidence for the development of early life on Earth?

4. Why was UV able to reach the Earth's surface?

http://www.windows2universe.org/earth/past/earths_primordial_ocean.html

5. What is the Goldilocks theory?

6. How did the forming ocean produce the atmosphere?

7. Why do scientists believe that nitrogen dominates our current atmosphere?

Review

1. What was the source of gases in Earth's first atmosphere? What were those gases? What was missing?

2. What was the composition of Earth's third atmosphere? What is the important addition and where did that component come from?

3. What are banded-iron formations and why are they important to Earth historians?

11.16 Precambrian Continents

- Early continents were small and mantle convection was fast.

What did the first crust look like?

These ancient greenstones are metamophosed pillow lavas from much earlier in Earth history. These rocks are found in eastern Canada and similar rocks are found in cratons around the world.

Early Continents

The first crust was made of basaltic rock, like the current ocean crust. Partial melting of the lower portion of the basaltic crust began more than 4 billion years ago. This created the silica-rich crust that became the felsic continents.

Craton

The earliest felsic continental crust is now found in the ancient cores of continents, called the **cratons**. Rapid plate motions meant that cratons experienced many continental collisions. Little is known about the **paleogeography**, or the ancient geography, of the early planet, although smaller continents could have come together and broken up.

Geologists can learn many things about the Pre-Archean by studying the rocks of the cratons.

- Cratons also contain felsic igneous rocks, which are remnants of the first continents.
- Cratonic rocks contain rounded sedimentary grains. Of what importance is this fact? Rounded grains indicate that the minerals eroded from an earlier rock type and that rivers or seas also existed.

- One common rock type in the cratons is **greenstone**, a metamorphosed volcanic rock (**Figure** 11.32). Since greenstones are found today in oceanic trenches, what does the presence of greenstones mean? These ancient greenstones indicate the presence of subduction zones.

FIGURE 11.32
Ice age glaciers scraped the Canadian Shield down to the 4.28 billion year old greenstone in Northwestern Quebec.

Shield

Places the craton crops out at the surface is known as a **shield**. Cratons date from the Precambrian and are called Precambrian shields. Many Precambrian shields are about 570 million years old (**Figure** 11.33).

FIGURE 11.33
The Canadian Shield is the ancient flat part of Canada that lies around Hudson Bay, the northern parts of Minnesota, Wisconsin and Michigan and much of Greenland.

Platform

In most places the cratons were covered by younger rocks, which together are called a **platform**. Sometimes the younger rocks eroded away to expose the Precambrian craton (**Figure** 11.34).

FIGURE 11.34
The Precambrian craton is exposed in the Grand Canyon where the Colorado River has cut through the younger sedimentary rocks.

Early Convection

During the Pre-Archean and Archean, Earth's interior was warmer than today. Mantle convection was faster and plate tectonics processes were more vigorous. Since subduction zones were more common, the early crustal plates were relatively small.

Since the time that it was completely molten, Earth has been cooling. Still, about half the internal heat that was generated when Earth formed remains in the planet and is the source of the heat in the core and mantle today.

The presence of water on ancient Earth is revealed in a zircon crystal **(1c)**: http://www.youtube.com/watch?v=V21hFmZP5zM (3:13).

MEDIA
Click image to the left for more content.

Vocabulary

- **craton**: The ancient Precambrian felsic continental crust that forms the cores of continents.
- **greenstone**: A metamorphosed volcanic rock that forms at a subduction zone.
- **paleogeography**: The arrangement of the continents; ancient geography.
- **platform**: A craton and its overlying younger sedimentary rocks.
- **shield**: The part of a craton that crops out at the surface.

Summary

- The ancient core of a continent, at and beneath the surface, is its craton.

- The cratonic rock that is seen at the surface is called the shield. Where the shield is covered by younger sediments is the platform.
- Convection on early Earth was faster and so plate tectonics was faster. Since then, Earth has been cooling.

Practice

Use this resource to answer the questions that follow.

http://essayweb.net/geology/quicknotes/continents.shtml

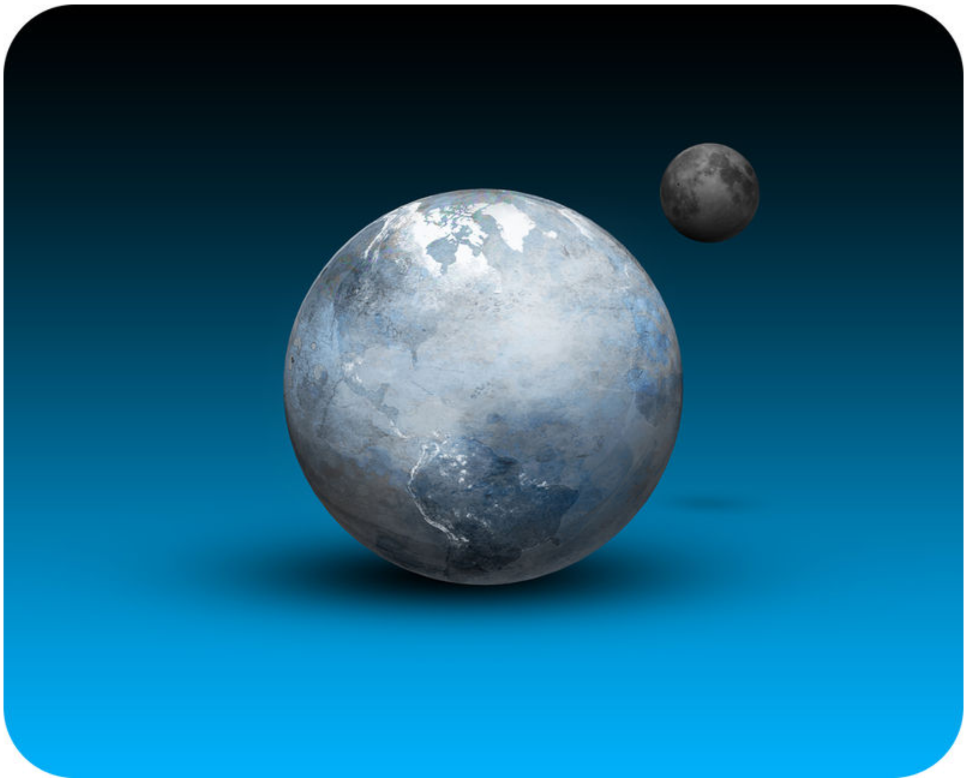
1. What was Yilgarn?
2. What was Yaalbara and when was it formed?
3. When was Ur formed?
4. How was Arctica formed?
5. What was Atlantica composed of?
6. How was Nena formed?
7. When was Columbia formed? When did it begin to break apart?
8. When was Rodinia formed?

Review

1. Why could the felsic continental crust not be Earth's first crust?
2. What are greenstones and why are they important in understanding early Earth history?
3. Why was plate tectonics more vigorous in the early Earth? What would plate tectonics have been like?

11.17 Precambrian Plate Tectonics

- Later Precambrian plate tectonics resembled modern plate tectonics.



Was Earth ever so cold that it was completely encased in ice?

There is a hypothesis that much of the planet was covered by ice at the end of the Precambrian. This hypothesis is called Snowball Earth. One line of evidence is the rapid evolution of life in the Ediacara and Cambrian periods. It is thought that when the ice melted and conditions were favorable, life evolved rapidly.

Precambrian Plate Tectonics

By the end of the Archean, about 2.5 billion years ago, plate tectonics processes were completely recognizable. Small Proterozoic continents known as **microcontinents** collided to create **supercontinents**, which resulted in the uplift of massive mountain ranges.

The history of the North American craton is an example of what generally happened to the cratons during the Precambrian. As the craton drifted, it collided with microcontinents and oceanic island arcs, which were added to the continents. Convergence was especially active between 1.5 and 1.0 billion years ago. These lands came together to create the continent of Laurentia.

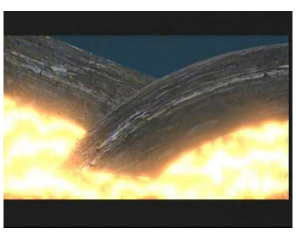
About 1.1 billion years ago, Laurentia became part of the supercontinent Rodinia (**Figure** 11.35). Rodinia probably contained all of the landmass at the time, which was about 75% of the continental landmass present today.

Rodinia broke up about 750 million years ago. The geological evidence for this breakup includes large lava flows that are found where continental rifting took place. Seafloor spreading eventually started and created the oceans between the continents.

FIGURE 11.35
Rodinia as it came together about 1.1 billion years ago.

The breakup of Rodinia may have triggered Snowball Earth around 700 million years ago.

This video explores the origin of continents and early plate tectonics on the young Earth **(1c)**: http://www.youtube.com/watch?v=QDqskltCixA (5:17).



MEDIA
Click image to the left for more content.

Vocabulary

- **microcontinent**: A fragment of crust that is smaller than a continent.
- **supercontinent**: A collection of continents that have come together because of the plate tectonics processes.

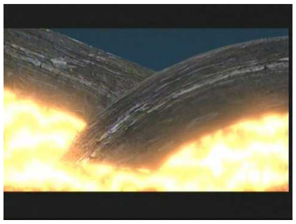
Summary

- About 2 billion years after Earth formed, plate tectonics processes were similar to those around today.
- Microcontinents collided together to create larger continents and supercontinents.
- The supercontinent of Rodinia came together about 1.1 billion years ago and broke apart about 750 million years ago.

Practice

Use this resource to answer the questions that follow.

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



MEDIA

Click image to the left for more content.

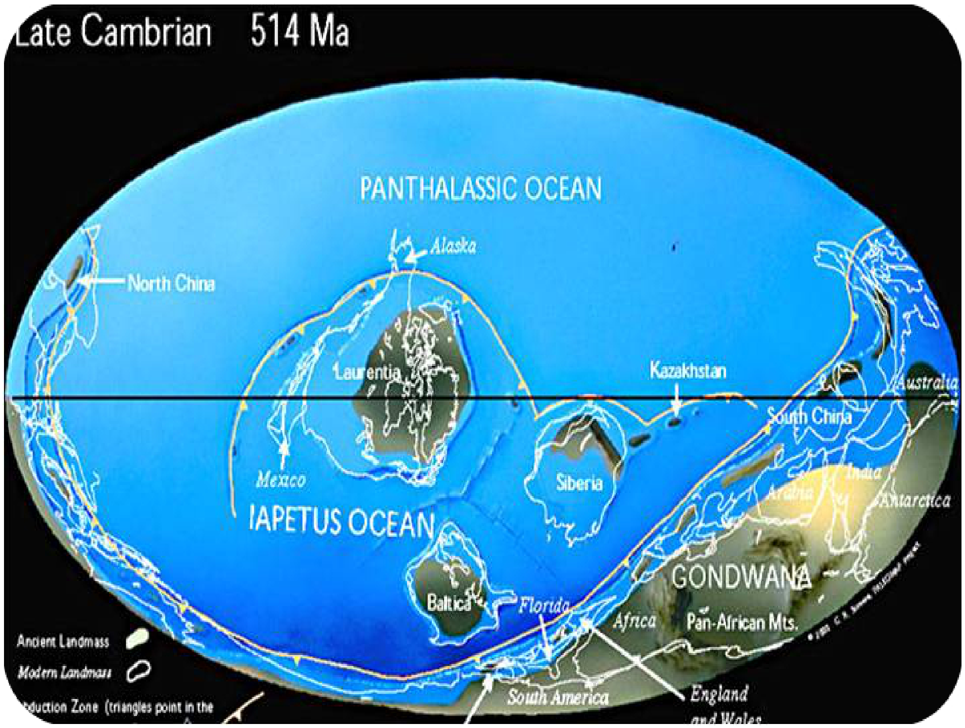
1. What was the first continent?
2. When was Arctica formed?
3. When was Atlantica formed?
4. What happened 1.8 billion years ago?
5. How was Rodinia formed?
6. What is the driving mechanisms for the movement of the plates?
7. What produces the heat?

Review

1. Why did it take 2 billion years for plate tectonics to be similar to the way it is today?
2. What evidence is there for Snowball Earth? What evidence would you look for to test the hypothesis?
3. After Rodinia broke apart, what happened to the continents?

11.18 Paleozoic Plate Tectonics

- Continental collisions that form supercontinents create mountain ranges by the process of orogeny.



Why are the continents near the South Pole?

The continents joined during the Paleozoic and they were also not in their current latitudes. In the late Cambrian, for example, they were clustered around the south polar region. It's probably just chance that they found their way there.

The Paleozoic

The Paleozoic is the furthest back era of the Phanerozoic and it lasted the longest. But the Paleozoic was relatively recent, beginning only 570 million years ago. Compared with the long expanse of the Precambrian, the Phanerozoic is recent history. Much more geological evidence is available for scientists to study so the Phanerozoic is much better known.

The Paleozoic begins and ends with a supercontinent. At the beginning of the Paleozoic, the supercontinent Rodinia began to split up. At the end, Pangaea came together.

Formation of Pangaea

A mountain-building event is called an **orogeny**. Orogenies take place over tens or hundreds of millions of years. As continents smash into microcontinents and island arcs collided, mountains rise.

Geologists find evidence for the orogenies that took place while Pangaea was forming in many locations. For example, Laurentia collided with the Taconic Island Arc during the Taconic Orogeny (**Figure** 11.36). The remnants of this mountain range make up the Taconic Mountains in New York.

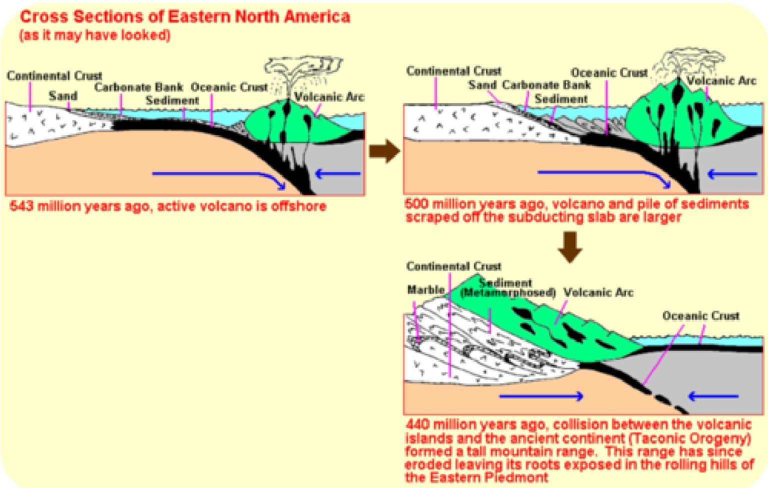


FIGURE 11.36
The Taconic Orogeny is an example of a collision between a continent and a volcanic island arc.

Laurentia experienced other orogenies as it merged with the northern continents. The southern continents came together to form Gondwana. When Laurentia and Gondwana collided to create Pangaea, the Appalachians rose. Geologists think they may once have been higher than the Himalayas are now.

Pangaea

Pangaea was the last supercontinent on Earth. Evidence for the existence of Pangaea was what Alfred Wegener used to create his continental drift hypothesis, which was described in Concept Plate Tectonics.

As the continents move and the land masses change shape, the shape of the oceans changes too. During the time of Pangaea, about 250 million years ago, most of Earth's water was collected in a huge ocean called Panthalassa (**Figure** 11.37).

Vocabulary

- **orogeny**: A mountain building event, usually taking place over tens or hundreds of millions of years.

Summary

- The Paleozoic began with the supercontinent Rodinia and ended with the supercontinent Pangaea.
- As continents come together, orogenies build up mountain ranges.
- Pangaea was a giant landmass made of all of the continents around 250 million years ago.

Practice

Use this resource to answer the questions that follow.

http://www.burkemuseum.org/static/geo_history_wa/Dance%20of%20the%20Giant%20Continents.htm

1. When did Rodinia form?

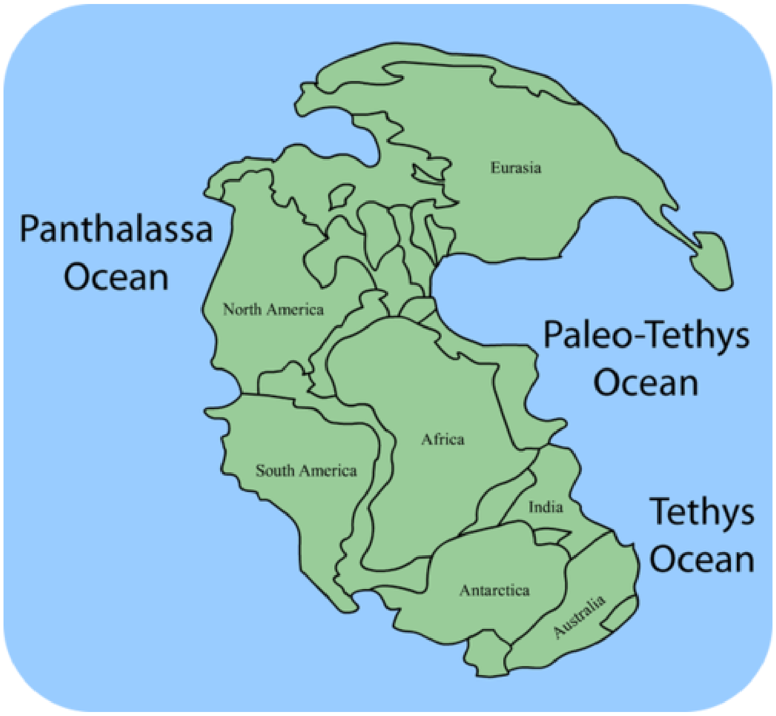


FIGURE 11.37
Pangea was the sole landform 250 million years ago, leaving a huge ocean called Panthalassa, along with a few smaller seas.

2. What does Rodinia mean?
3. How long was Rodinia the dominant land form?
4. Describe the atmosphere at this time.
5. What coastline emerged when Rodinia broke apart?
6. When did Pangaea form?
7. What does Pangaea mean?

Review

1. What happens to create an orogeny? How are plate tectonics processes related to orogenies?
2. How did Pangaea come together?
3. How is the creation of Pangaea related to events like the Taconic orogeny?

11.19 Paleozoic and Mesozoic Seas

- Six Paleozoic and Mesozoic marine transgressions and regressions were caused by glaciers melting and growing for example.

Do you like the beach? If so, the Paleozoic may be for you!

If we were living right now at the time of a marine transgression, there would be a lot more beach. Of course, it would be hard to find land for all of the people to live on or for all the crops to grow.

Marine Transgressions and Regressions

Some of the most important events of the Paleozoic and Mesozoic were the rising and falling of sea level over the continents. Sea level rises over the land during a **marine transgression**. During a **marine regression**, sea level retreats. During the Paleozoic there were four complete cycles of marine transgressions and regressions. There were two additional cycles during the Mesozoic (**Figure** 11.38).

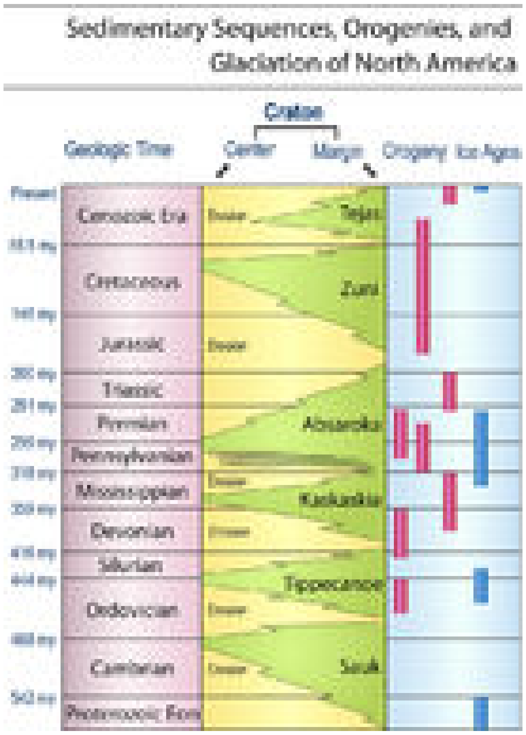


FIGURE 11.38
Six marine transgressions and regressions have occurred during the Phanerozoic.

One of two things must happen for sea level to change in a marine transgression: either the land must sink or the water level must rise. What could cause sea level to rise? When little or no fresh water is tied up in glaciers and ice caps, sea level is high. Sea level also appears to rise if land is down dropped. Sea level rises if an increase in seafloor spreading rate buoys up the ocean crust, causing the ocean basin to become smaller.

What could cause sea level to fall in a marine regression?

Geologists think that the Paleozoic marine transgressions and regressions were the result of the decrease and increase in the size of glaciers covering the lands.

Rock Facies

Geologists know about marine transgressions and regressions from the sedimentary rock record. These events leave characteristic rock layers known as sedimentary **facies**. On a shoreline, sand and other coarse grained rock fragments are commonly found on the beach where the wave energy is high. Away from the shore in lower energy environments, fine-grained silt that later creates shale is deposited. In deeper, low-energy waters, carbonate mud that later hardens into limestone is deposited.

Grand Canyon

The Paleozoic sedimentary rocks of the Grand Canyon (**Figure** 11.39) contain evidence of marine transgressions and regressions, but even there the rock record is not complete. Look at the sequence in the figure below and see if you can determine whether the sea was transgressing or regressing. At the bottom, the Tonto Group represents a marine transgression: sandstone (11), shale (10), and limestone (9) laid down during 30 million years of the

Cambrian Period. The Ordovician and Silurian are unknown because of an unconformity. Above that is freshwater limestone (8), which is overlain by limestone (7) and then shale (6), indicating that the sea was regressing. After another unconformity, the rocks of the Supai Group (5) include limestone, siltstone, and sandstone indicative of a regressing sea. Above those rocks are shale (4), sandstone (3), a limestone and sandstone mix (2) showing that the sea regressed and transgressed and finally limestone (1) indicating that the sea had come back in.

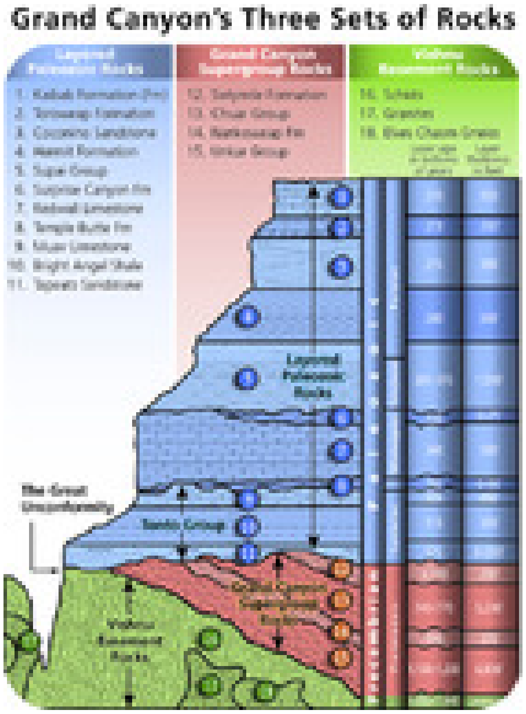


FIGURE 11.39

The Paleozoic sedimentary rocks of the Grand Canyon were deposited during marine transgressions and regressions.

Vocabulary

- **facies**: Characteristic sedimentary rock layers that indicate the processes and environments in which they were formed.
- **marine regression**: The falling of sea level so that seas no longer cover the continents.
- **marine transgression**: The rising of sea level over the continents.

Summary

- Sea level depends on the amount of water tied up in ice and, locally, the position of the land.
- Facies are characteristic rock layers, such as sandstone, shale, limestone for a marine transgression and the reverse for a regression.
- The Grand Canyon has an incomplete record of the four marine transgressions and regression of the Paleozoic.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/news/history-archaeology-news/utah-dig-missions-wcvin/

1. What are the paleontologists searching for in Utah?

2. How many years ago was there a sea in Utah?

3. How far did the sea extend?

4. What does tropic shale contain?

5. How do the scientists date the shale?

6. What do they learn from the fossils?

Review

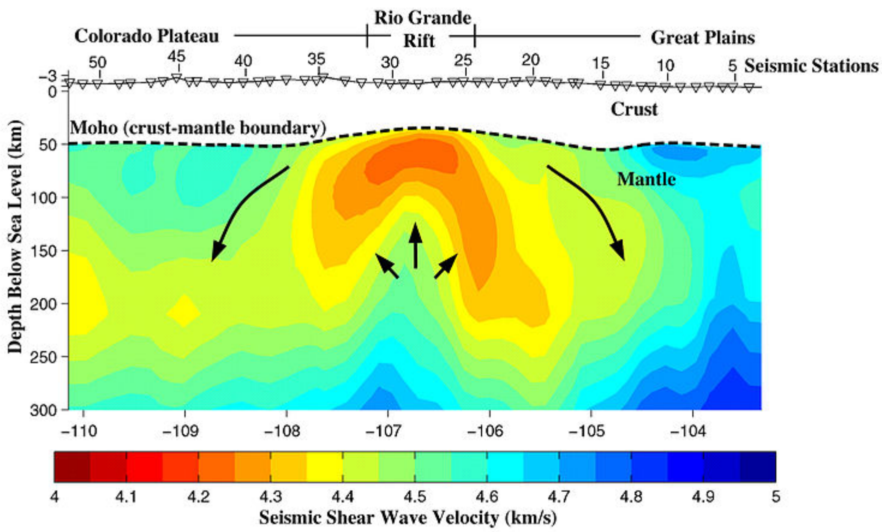
1. How do scientists use sedimentary facies to recognize a marine transgression or regression?

2. What are the possible causes of a marine transgression? What are the possible causes of a marine regression?

3. What must geologists have found to know that there were two more transgressions and regressions in the Mesozoic?

11.20 Mesozoic Plate Tectonics

- Pangaea split apart, the world ocean fragmented, and the Atlantic Ocean formed.



Why would a supercontinent break up?

A continent is a giant insulating blanket that does not allow mantle heat to escape very effectively. This image is of shear wave velocity beneath New Mexico where hot material is trapped beneath the North American plate. The hot material is causing rifting to begin at the Rio Grande Rift.

Supercontinent Breakup

As heat builds up beneath a supercontinent, continental rifting begins. Basaltic lavas fill in the rift and eventually lead to seafloor spreading and the formation of a new ocean basin. This basalt province is where Africa is splitting apart and generating basalt lava.

The Breakup of Pangaea

At the end of the Paleozoic there was one continent and one ocean. When Pangaea began to break apart about 180 million years ago, the Panthalassa Ocean separated into the individual but interconnected oceans that we see today on Earth.

The Atlantic Ocean basin formed as Pangaea split apart. The seafloor spreading that pushed Africa and South America apart is continuing to enlarge the Atlantic Ocean (**Figure** 11.40).

As the continents moved apart there was an intense period of plate tectonic activity. Seafloor spreading was so vigorous that the mid-ocean ridge buoyed upwards and displaced so much water that there was a marine transgression. Later in the Mesozoic those seas regressed and then transgressed again.

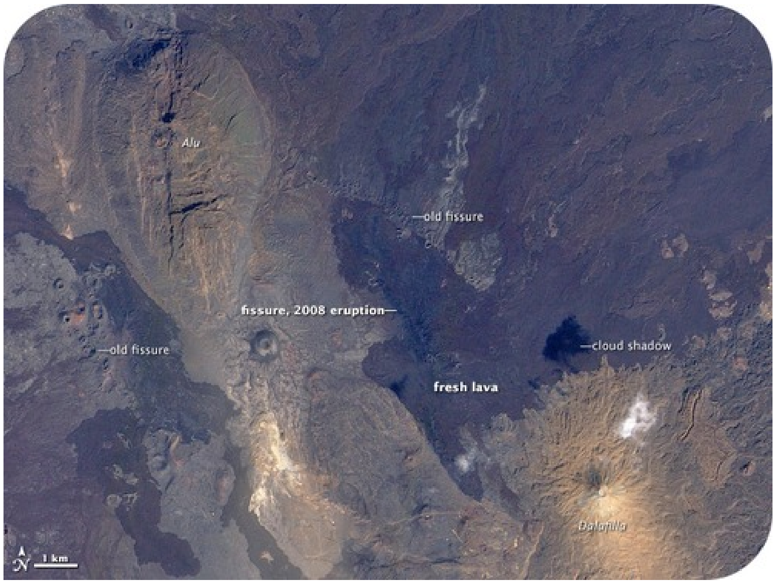


FIGURE 11.40
In the Afar Region of Ethiopia, Africa is splitting apart. Three plates are pulling away from a central point.

Growth of Continents

The moving continents collided with island arcs and microcontinents so that mountain ranges accreted onto the continents' edges. The subduction of the oceanic Farallon plate beneath western North America during the late Jurassic and early Cretaceous produced igneous intrusions and other structures. The intrusions have since been uplifted so that they are exposed in the Sierra Nevada Mountains (**Figure** 11.41).

FIGURE 11.41
The snow-covered Sierra Nevada is seen striking SE to NW across the eastern third of the image. The mountain range is a line of uplifted batholiths from Mesozoic subduction.

Summary

- Continents keep mantle heat from escaping, which may eventually lead to continental rifting.
- Continents grow as microcontinents or igneous activity add continental crust to an existing continent.
- When a supercontinent breaks apart, new seafloor forms between the new continental masses.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What was Pangaea?
2. What creates the heat inside the Earth?
3. What is plate tectonics?
4. Why causes plate tectonics?
5. Explain why Pangaea broke apart.

Review

1. Would you say that Pangaea is still breaking up? Why or why not?
2. How does the rate of plate tectonics activity affect sea level?
3. What caused the igneous intrusions that make up the Sierra Nevada mountains?

11.21 Cenozoic Plate Tectonics

- The geology of the Cenozoic is familiar to us.

What defines the beginning of the Quaternary and the Holocene?

The most recent period of the Cenozoic is the Quaternary, which began about 2.6 million years ago. The most recent epoch is the Holocene, which began around 12,000 years ago. Go back to the lesson on human evolution in Concept Life History to figure out what events mark the beginning of these time periods.

Cenozoic

The Cenozoic began around 65.5 million years ago and continues today. Although it accounts for only about 1.5% of the Earth's total history, as the most recent era it is the one scientists know the most about. Much of what has been discussed elsewhere in Concepts Earth Science describes the geological situation of the Cenozoic. A few highlights are mentioned here.

Plate Tectonics

The paleogeography of the era was very much like it is today. Early in the Cenozoic, blocks of crust uplifted to form the Rocky Mountains, which were later eroded away and then uplifted again. Subduction off of the Pacific Northwest formed the Cascades volcanic arc. The Basin and Range province that centers on Nevada is where crust is being pulled apart.

Evolution of the San Andreas Fault

The San Andreas Fault has grown where the Pacific and North American plates meet. The plate tectonic evolution of that plate boundary is complex and interesting (**Figure** 11.42). The Farallon Plate was subducting beneath the North American Plate 30 Ma. By 20 Ma the Pacific Plate and East Pacific Rise spreading center had started to subduct, splitting the Farallon Plate into two smaller plates. Transform motion where the Pacific and North American plates meet formed the San Andreas Fault. The fault moved inland and at present small sea floor spreading basins along with the transform motion of the San Andreas are splitting Baja California from mainland Mexico.

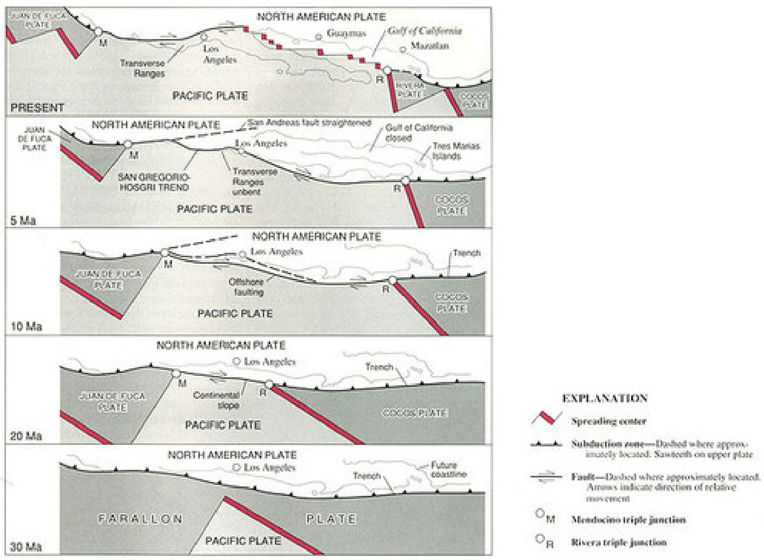


FIGURE 11.42
This figure shows the evolution of the San Andreas Fault zone from 30 million years ago (bottom) to present (top).

Although most plate tectonic activity involves continents moving apart, smaller regions are coming together. Africa collided with Eurasia to create the Alps. India crashed into Asia to form the Himalayas.

Ice Ages

As the continents moved apart, climate began to cool. When Australia and Antarctica separated, the Circumpolar Current could then move the frigid water around Antarctica and spread it more widely around the planet.

Antarctica drifted over the south polar region and the continent began to grow a permanent ice cap in the Oligocene. The climate warmed in the early Miocene but then began to cool again in the late Miocene and Pliocene when glaciers began to form. During the Pleistocene ice ages, which began 2.6 million years ago, glaciers advanced and retreated four times (**Figure** 13.85). During the retreats, the climate was often warmer than it is today.

These continental ice sheets were extremely thick, like the Antarctic ice cap is today (**Figure** 11.44) .

The Pleistocene ice ages guided the evolution of life in the Cenozoic, including the evolution of humans.

Summary

- During the Cenozoic, the crust that had once been joined as Pangaea has mostly been moving apart.
- Subduction of the Farallon plate has resulted in the formation of the Rocky Mountains and the San Andreas Fault.
- The Pleistocene was marked by four advances of ice, the remnants of which are found today.

FIGURE 11.43
Glacial ice at its maximum during the Pleistocene.

FIGURE 11.44
This continental glacier over Antarctica is up to 4,000 meters (12,000 feet) thick.

Practice

Use this resource to answer the questions that follow.

http://www.videopediaworld.com/video/26196/Historical-Geography-The-Cenozoic-Era

1. What are the two divisions of the Cenozoic era?

2. What mountains formed during this time?
3. What was carved out of the Colorado Basin?
4. How much of the land was covered in ice?
5. How did animal populations change?

Review

1. Why did the plate boundary that runs up California change from convergent to transform?
2. How is subduction responsible for the Rocky Mountains, the Cascades and the Basin and Range?
3. What is the history of the advance and retreat of ice during the Pleistocene?

Summary

Fossils are remnants of living creatures that can indicate something about the ecosystem and the environmental conditions that were present at the time they lived. Fossils can help geologists decipher the geological history of an area, as can clues from rocks. The principles of relative dating allow geologists to decipher the order of geological events and correlation allows them to determine the geological history of a region. Absolute age dating gives accurate dates for geological events, provided the proper materials are available and the proper techniques are followed. The most accurate and widely used absolute age dating technique is radiometric dating, which uses the ratios of radioactive isotopes to indicate age. Using these techniques, and some from astronomy, scientists have reconstructed a history of Earth and the solar system. The solar system began as a cloud of dust and gas that contracted by gravity until the center ignited to form a star and clumps of matter came together to form the planets. Shortly after Earth formed, a giant asteroid struck the planet, which melted both bodies, and flung material out into Earth's orbit. That material coalesced into the Moon. Earth had to cool before it could support an atmosphere, but when it did precipitation provided the water that filled the ocean basins. Life evolved slowly, and it was not until the evolution of photosynthesis that oxygen could collect in the atmosphere. The presence of oxygen led to the formation of the protective ozone layer and gases for animals to breathe. The early Earth was hot and so convection and plate tectonics were faster than today. From the time of the Archean, plate tectonics processes were similar to today. From then until now, supercontinents formed and broke apart, seas transgressed and regressed, and ice ages came and went.

11.22 References

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CHAPTER 12 Natural Resources

Chapter Outline

Introduction

How important are natural resources to you?

Look around you. Wherever you happen to be and whatever you are doing, you're using natural resources. Since you're reading this you're probably on a screen attached to some sort of computer, which uses metals, plastics that come from fossil fuels, and many other materials. The computer is powered by electricity, which may come from a nearby coal or nuclear plant or possibly from solar panels on the roof of your house. One thing is certain, modern life requires lots of natural resources!

12.1 Introduction to Energy Resources

- Define energy.
- Describe energy's forms of storage and release.
- Explain the law of conservation of energy.

Where does this young basketball player get his energy?

He gets his energy from the Sun. Not directly, of course. He eats food, which used sunlight to grow, or he eats something that ate something that used sunlight to grow. When he shoots the ball, some of the energy goes into the ball and hopefully the ball goes into the hoop. Three points!

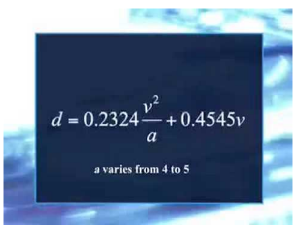
Energy Basics

Energy is the ability to do work or produce change. Every living thing needs energy to perform its daily functions and even more energy to grow. Plants get energy from the "food" they make by photosynthesis, and animals get energy directly or indirectly from that food. People also use energy for many things, such as cooking food, keeping ice cream cold in the freezer, heating a house, constructing a skyscraper, or lighting their homes. Because billions of people all around the world use energy, there is a huge need for energy resources. Energy conservation is something everyone can do now to help reduce the strain on energy resources.

Conservation of Energy

The law of conservation of energy says that energy cannot be created or destroyed. This means that even though energy changes form, the total amount of energy always stays the same. How does energy get converted from one type to another when you kick a soccer ball? When your body breaks down the food you eat, it stores the energy from the food as **chemical energy**. But some of this stored energy has to be released to make your leg muscles move. The chemical energy is converted to another form of energy called **kinetic energy**. Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy from the kick. So you can think of the action of kicking the ball as a story of energy changing forms.

To learn the quadratic equations related to getting a rapidly moving car to overcome its kinetic energy and come to a stop, watch this video (**I&E 1e**): http://www.youtube.com/watch?v=v-Z2-jxCqVw#38;feature=related (6:01).



MEDIA
Click image to the left for more content.

Potential energy is energy that is stored. Potential energy has the potential to do work or the potential to be converted into other forms of energy. If a ball is sitting on the very edge at the top of the hill, it is not moving, but it has a lot of potential energy.

Animations showing the conversion of potential energy to kinetic energy can be seen at the following sites:

- http://www.physicsclassroom.com/mmedia/energy/se.cfm
- http://www.physicsclassroom.com/mmedia/energy/ce.cfm
- http://www.physicsclassroom.com/mmedia/energy/dg.cfm

Fuel

If you read a book beneath a lit lamp, that lamp has energy from electricity. The energy to make the electricity comes from **fuel**. Fuel has energy that it releases. A fuel is any material that can release energy in a chemical change.

What are some examples of fuel, and what are they used for?

1. Food is fuel for your body.
2. Sunlight is the energy plants need to make food by photosynthesis.
3. Gasoline is fuel for cars.
4. Hydrogen is fuel for the Sun.

For a fuel to be useful, its energy must be released in a way that can be controlled. Controlling the release of energy makes it possible for the energy to be used to do work.

Heat

When fuel is used for its energy, it is usually burned, and most of the energy is released as **heat** (**Figure** 12.1). The heat may then be used to do work. Think of a person striking a match to set some small twigs on fire. After the twigs burn for a while, they get hot enough to make some larger sticks burn. The fire keeps getting hotter, and soon it is hot enough to burn whole logs. Pretty soon the fire is roaring, and a pot of water placed on the fire starts to boil. Some of the liquid water evaporates.

FIGURE 12.1
A controlled fire.

What is the source of energy for boiling and evaporating the water? Although some chemical energy from the match was put into starting the fire, the heat to boil and evaporate the water comes from the energy that was stored in the wood. The wood is the fuel for the fire.

Vocabulary

- **chemical energy**: Energy that is stored in the chemical bonds in molecules.
- **energy**: The ability to do work or change matter
- **fuel**: Material that releases energy as it changes chemically.
- **heat**: Energy associated with the movement of atoms or molecules that can be transferred.
- **kinetic energy**: The energy that an object in motion has because of its motion.
- **potential energy**: Energy stored within a physical system that has the potential to do work.

Summary

- Energy is the ability to do work. Energy cannot be created or destroyed; it can only change form.
- Fuel stores energy that can be released during use.

- Heat is the motion of atoms due to the use of energy.

Practice

Use this resource to answer the questions that follow.

Forms of Energy

http://bit.ly/nlcOxb

MEDIA

Click image to the left for more content.

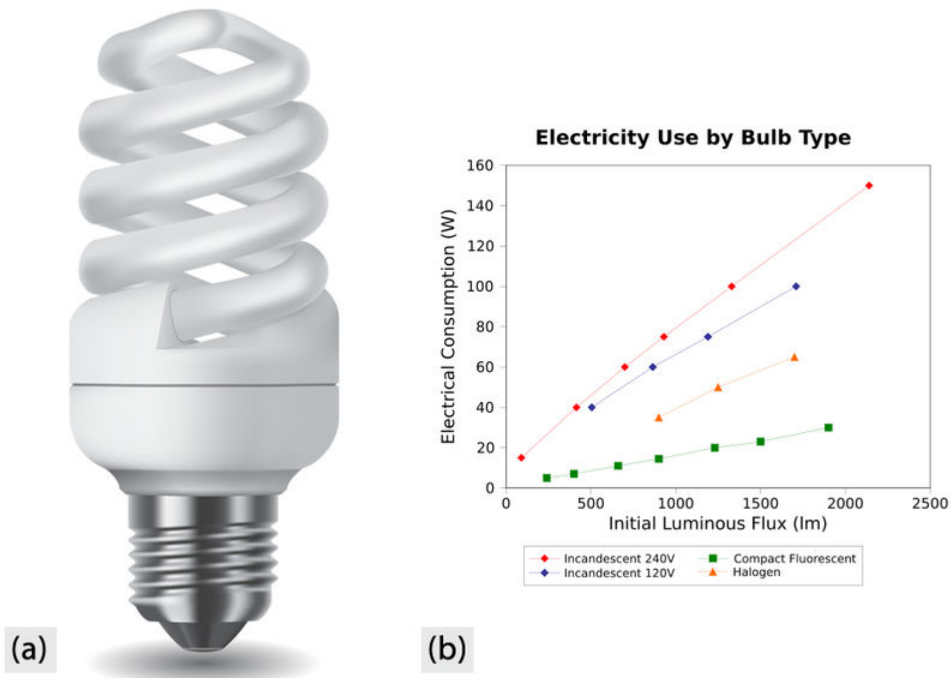
1. What is energy?
2. What is chemical energy used for?
3. What produces electrical energy?
4. What is the source of light energy?
5. List examples of mechanical energy.
6. What produces thermal energy?
7. What is nuclear energy?

Review

1. Give an example of how the law of conservation of energy works.
2. Compare and contrast chemical energy, kinetic energy, and potential energy.
3. Think about a candle flame and a bathtub full of hot water. Which has the highest temperature and which has the highest heat? What's the difference?

12.2 Obtaining Energy Resources

- Describe how useable energy from an energy source is obtained and measured.



Have you converted to compact fluorescent light bulbs at your house?

Compact fluorescent light bulbs are more efficient than incandescent light bulbs. Look at the chart and try to see how much more efficient. The answer is that they could be as much as six times more efficient. So why aren't all people using compact fluorescent bulbs all the time? Early ones were large and expensive, and many people don't like the color of the light. But they are much more environmentally friendly.

Net energy

Net energy is the amount of useable energy available from a resource after subtracting the amount of energy needed to make the energy from that resource available. For example, every 5 barrels of oil that are made available for use require 1 barrel for extracting and refining the petroleum. What is the net energy from this process? About 4 barrels (5 barrels minus 1 barrel).

What happens if the energy needed to extract and refine oil increases? Why might that happen? The energy cost of an energy resource increases when the easy deposits of that resource have already been consumed. For example, if all the nearshore petroleum in a region has been extracted, more costly drilling must take place further offshore (**Figure** 12.2). If the energy cost of obtaining energy increases, the resource will be used even faster.

Net-Energy Ratio

The **net-energy ratio** demonstrates the difference between the amount of energy available in a resource and the amount of energy used to get it. If it takes 8 units of energy to make available 10 units of energy, then the net-energy

FIGURE 12.2
Offshore drilling is taking place in deeper water than before. It takes a lot of energy to build a deep drilling platform and to run it.

ratio is 10/8 or 1.25. What does a net-energy ratio larger than 1 mean? What if the net-energy ratio is less than 1? A net-energy ratio larger than 1 means that there is a net gain in usable energy; a net-energy ratio smaller than one means there is an overall energy loss.

Table 12.1 shows the net-energy ratios for some common energy sources.

TABLE 12.1: **Net-Energy Ratios for Common Energy Sources**

Energy Source	Net-energy Ratio
Solar Energy	5.8
Natural Gas	4.9
Petroleum	4.5
Coal-fired Electricity	2.5-5.1

Notice from the table that solar energy yields much more net energy than other sources. This is because it takes very little energy to get usable solar energy. Sunshine is abundant and does not need to be found, extracted, or transported very far. The range for coal-fired electricity is because of the differing costs of transporting the coal. What does this suggest about using coal to generate electricity? The efficiency is greater in areas where the coal is locally mined and does not have to be transported great distances (**Figure** 12.3).

This is not to say that solar energy is less expensive than other types of energy. The cost of energy is dependent on lots of different factors, such as the cost of the equipment needed to harness the energy. If solar power cost less to use, it would be more widespread.

Energy Efficiency

Energy efficiency describes how much useful work is extracted from one unit of energy. Remember that although energy is not created or destroyed, it's just transferred from one form to another, some energy is nearly always lost in the transfer as heat. By saying that the work must be useful, it is possible to account for the energy that is lost to non-useful work. For example, some energy may not be doing useful work if the equipment is not running well (maybe a piston is moving sideways a bit rather than just up and down).

Higher energy efficiency is desirable because:

- Less energy is being wasted.
- Non-renewable resources will last longer.
- The cost is kept lower.

Because so much of the energy we use is from fossil fuels, we need to be especially concerned about using them efficiently. Sometimes our choices affect energy efficiency. For example, transportation by cars and airplanes is less energy-efficient than transportation by boats and trains.

Vocabulary

- **energy efficiency**: The amount of useful work that is done by a unit of energy.
- **net energy**: The amount of usable energy available from an energy resource.
- **net-energy ratio**: The ratio between the useful energy present in a type of fuel, and the energy used to extract and process the fuel.

Summary

- Net energy is the amount of that is actually useable from an energy resource. Net-energy ratio is the ratio of the amount of useable energy from a resource and the amount it takes to make that energy useful.
- Many factors besides net-energy ratio go into determining if a type of energy will be used.
- An energy source with high energy efficiency provides a lot of work for the amount of energy used.

Practice

Use this resource to answer the questions that follow.

http://www.loseyourexcuse.gov/index.html#/index

Explore this site and then go to Lost Excuses Land and explore the rooms to answer these questions:

1. Which type of computer uses more energy, laptops or desktops?

2. What did you discover about screensavers?

3. How much money can replacing an old thermostat save?

4. What is the easiest way to save energy in the home?

5. How can power strips save energy?

6. How can blinds save energy?

7. List some other examples of how energy could be saved in the home.

Review

1. Compare and contrast net energy, the net-energy ratio, and energy efficiency.

2. Since the net-energy ratio for solar energy is higher than other types of energy, why don't we use solar for electricity almost exclusively?

3. Why would the energy needed to make a type of energy useful increase or decrease? In other words, why would the net-energy ratio change?

12.3 Energy Conservation

How much energy can you save?

By turning off the lights, keeping rooms at a reasonable temperature in summer and winter, driving a fuel-efficient car or taking the bus, and many other things, society can save a lot of energy. By saving energy we reduce the financial and environmental costs of collecting that energy, and the pollution and greenhouse gases that come from using that energy. In all, it's a win-win situation!

Energy Conservation

What benefits are there from energy conservation? Conserving energy means that less energy is needed, which reduces costs, ensures that non-renewable energy sources will last longer, and reduces political and environmental impacts.

What are the two ways that energy can be conserved? (1) Use less energy, and (2) use energy more efficiently.

The pie chart (**Figure** 12.4) shows how energy is used in the United States.

Table 12.2 shows some ways that people can decrease energy use and use energy more efficiently in transportation, residences, industries, and office settings.

TABLE 12.2: **Ways to Use Energy More Efficiently**

Where Energy is Used	How We Can Use Less Energy	How We Can Use Energy More Efficiently
Transportation	Ride a bike or walk instead of taking a car.	Increase fuel efficiency in cars.
	Reduce the number of trips you make.	Buy and drive smaller cars.

TABLE 12.2: (continued)

Where Energy is Used	How We Can Use Less Energy	How We Can Use Energy More Efficiently
	Use public transportation.	Build cars from lighter and stronger materials.
		Drive at speeds at or below 90 kilometers per hour (55 miles per hour).
Residential	Turn off lights when not in a room.	Replace old appliances with newer more efficient models.
	Only run appliances when necessary.	Insulate your home.
	Unplug appliances when not in use.	Make sure windows and doors are well sealed.
	Wear a sweater instead of turning up heat.	Use LED bulbs if available, or compact fluorescent light bulbs (and dispose of properly!).
	Use fans instead of turning down air conditioner.	
	Engage in activities that do not involve electronics.	
	Rely on sunlight instead of artificial light.	
Industrial	Recycle materials like soda cans and steel.	Practice conservation in factories.
	Reduce use of plastic, paper, and metal materials.	Reuse materials.
		Design equipment to be more efficient.
Commercial (businesses, shopping areas, etc.)	Turn off appliances and equipment when not in use.	Use fluorescent lighting.
		Set thermostats to automatically turn off heat or air conditioning when buildings are closed.

Using less energy, or using energy more efficiently, will help conserve our energy resources. Since many of the energy resources we depend upon are non-renewable, we need to make sure that we waste them as little as possible.

Energy saving tips from the U.S. Department of Energy: http://www.energy.gov/energytips.htm.

The U.S. Department of Energy has a video to let you know how a home energy audit will help you to make your home more energy efficient. Be sure to follow links to the "Do it yourself" page. http://www.energysavers.gov/your_home/energy_audits/index.cfm/mytopic=11160

Summary

- Conserving energy is is cleaner and cheaper than finding new energy.
- To conserve energy, use less energy and be more efficient about the energy you use.
- There are many ways to conserve energy in your own life, such as walking or taking the bus, wearing a sweater instead of turning up the heat, etc.

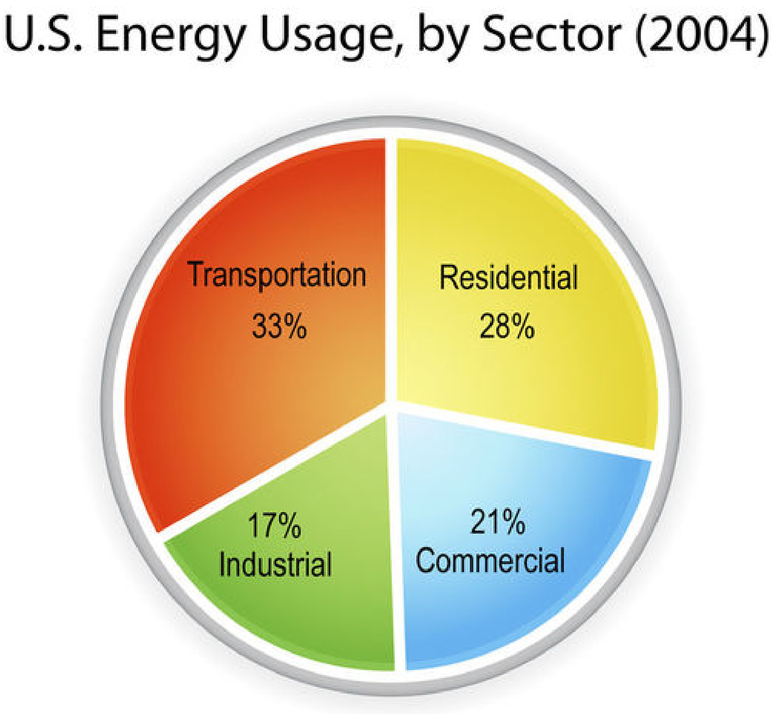


FIGURE 12.4
Almost one-half of the energy used in the United States is for transportation and home use. This means individual choices can make a big impact on energy conservation.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=QG3HNQiEaTM

MEDIA
Click image to the left for more content.

1. What will the population be in 2030?
2. How much will our energy demands increase by 2030?
3. What is energy efficiency?
4. How can industries optimize their energy efficiency?
5. What can be done to make vehicles more efficient?
6. How effective can using energy efficiently be?

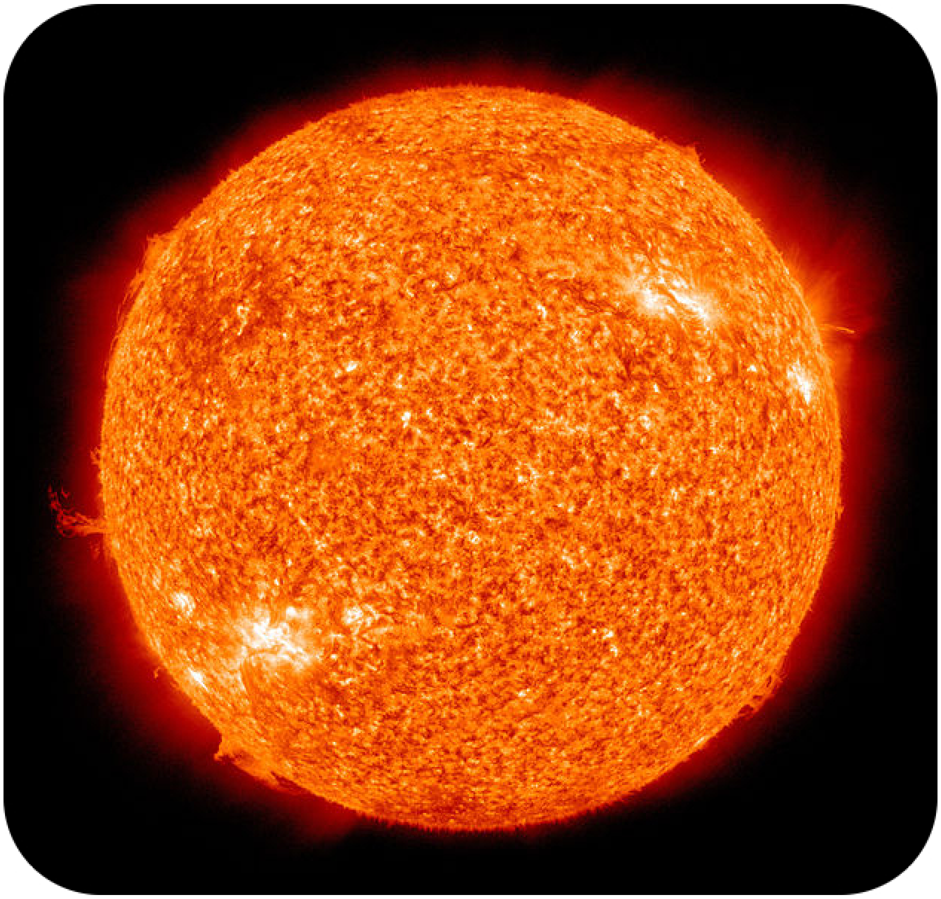
Review

1. Why is conservation the best way to stretch our energy resources?
2. List some ways that society can conserve energy.

3. List some ways that you and the other members of your household can conserve energy.

12.4 Renewable vs Non-Renewable Energy Resources

- Define renewable resource and nonrenewable resource.
- Compare and contrast renewable and nonrenewable resources.
- Identify renewable and nonrenewable resources.



What is the source of nearly all of Earth's energy?

The source of nearly all energy on Earth is our star, the Sun. Solar energy feeds almost all life on Earth, is trapped in fossil fuels, and is the reason wind blows and water flows. Earth's other big source of energy is the planet's internal heat.

Types of Energy Resources

Energy resources are either renewable or nonrenewable. **Nonrenewable resources** are used faster than they can be replaced, so the supply available to society is limited. **Renewable resources** will not run out because they are replaced as quickly as they are used (see example in **Figure** 12.5). Can you think of some renewable and nonrenewable energy sources?

FIGURE 12.5
An old windmill in Big Sur, California.

Nonrenewable Resources

Fossil fuels — coal, oil, and natural gas — are the most common example of nonrenewable energy resources. Fossil fuels are formed from fossils, the partially decomposed remains of once living plants and animals. These fossils took millions of years to form. When fossil fuels are burned for energy, they release pollutants into the atmosphere. Fossil fuels also release carbon dioxide and other greenhouse gases, which are causing global temperatures to rise.

Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal. These resources are either virtually limitless like the Sun, which will continue to shine for billions of years, or will be replaced faster than we can use them. Amounts of falling water or wind will change over the course of time, but they are quite abundant. Biomass energy, like wood for fire, can be replaced quickly.

The use of renewable resources may also cause problems. Some are expensive, while some, such as trees, have other uses. Some cause environmental problems. As the technology improves and more people use renewable energy, the prices may come down. At the same time, as we use up fossil fuels such as coal, oil, and natural gas, these nonrenewable resources will become more expensive. At some point, even if renewable energy costs are high, nonrenewable energy will be even more expensive. Ultimately, we will have to use renewable sources.

Important Things to Consider about Energy Resources

With both renewable and nonrenewable resources, there are at least two important things to consider. One is that we have to have a practical way to turn the resource into a useful form of energy. The other is that we have to consider what happens when we turn the resource into energy.

For example, if we get much less energy from burning a fuel than we put into making it, then that fuel is probably not a practical energy resource. On the other hand, if another fuel gives us large amounts of energy but creates large amounts of pollution, that fuel also may not be the best choice for an energy resource.

Electrical Grids

No matter what the source, once it is generated electricity has go move from place to place. It does so by an electrical grid. Many communities have electrical grids that were built decades ago. These grids are inefficient and have high failure rates.

The electrical grids of the future are likely to be **smart grids**. Smart grids start with electricity production from one or more power generation sources. The electricity is streamed through multiple networks out to millions of consumers. Smart meters are placed with the consumers. They supply information on the state of the electrical system. Operators know within minutes if the power goes out, rather than having to wait for phone calls from consumers. Smart meters measure consumption and assist consumers in using power when it is more economical, even turning on or off appliances in homes or workplaces to smooth demand. Smart grids are essential for integrating renewable energy sources, such as solar and wind, into the network because they have highs and lows in their supply.

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge.

Find out more at http://www.kqed.org/quest/television/climate-watch-unlocking-the-grid.

MEDIA

Click image to the left for more content.

Vocabulary

- **fossil fuel**: A hydrocarbon created from the remains of formerly living organisms that can be used for energy.
- **nonrenewable resources**: Resources that are being used faster than they can be replaced or their availability is limited to what is currently on Earth; e.g. fossil fuels.
- **renewable resources**: Resources that are limitless or that are replaced more quickly than we can use them.
- **smart grid**: A computer operated electrical grid that knows the status of all of the components of the grid and can act smartly to smooth out distribution and deal with problems.

Summary

- Non-renewable resources are used faster than they can be replaced. Once they're gone, they are, for all practical purposes, gone. Renewable resources are so abundant or are replaced so rapidly that, for all practical purposes, they can't run out.
- Fossil fuels are the most commonly used non-renewable resources. Renewable resources include solar, wind, hydro, and (possibly) biomass.
- A resource may take so much energy to harness that it doesn't provide much net energy.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Renewable and Nonrenewable Energy**

1. What is nonrenewable energy?

2. What are fossil fuels?
3. What are the forms of renewable energy?
4. How does hydroelectric energy work?
5. What is the concern with hydroelectric energy?
6. What problem has been cause by the use of fossil fuels?
7. What are oil companies expecting to occur by 2050?

Review

1. What does it mean that a form of energy might take more energy to harness than it provides?
2. Are renewable resources always renewable, or can they become nonrenewable?
3. Why aren't renewable resources used for everything that we use energy for?

12.5 Fossil Fuel Formation

- Describe the formation of fossil fuels.

What exactly is powering this car?

There was an old ad suggesting that you put a tiger in your tank was referring to the strength and speed of these wild cats. But it might also have been referring to the use of organic material to power an engine. When your tank is full of gas, it doesn't have a tiger in it, but it does have ancient plants, plankton, and other formerly living creatures. Not a pegasus though!

Formation of Fossil Fuels

Can you name some fossils? How about dinosaur bones or dinosaur footprints? Animal skeletons, teeth, shells, coprolites (otherwise known as feces), or any other remains or traces from a living creature that becomes rock is a **fossil**.

The same processes that formed these fossils also created some of our most important energy resources, **fossil fuels**. Coal, oil, and natural gas are fossil fuels. Fossil fuels come from living matter starting about 500 million years ago. Millions of years ago, plants used energy from the Sun to form sugars, carbohydrates, and other energy-rich carbon compounds. As plants and animals died, their remains settled on the ground on land and in swamps, lakes, and seas (**Figure** 12.6).

Over time, layer upon layer of these remains accumulated. Eventually, the layers were buried so deeply that they were crushed by an enormous mass of earth. The weight of this earth pressing down on these plant and animal remains created intense heat and pressure. After millions of years of heat and pressure, the material in these layers

FIGURE 12.6
This wetland may look something like an ancient coal-forming swamp.

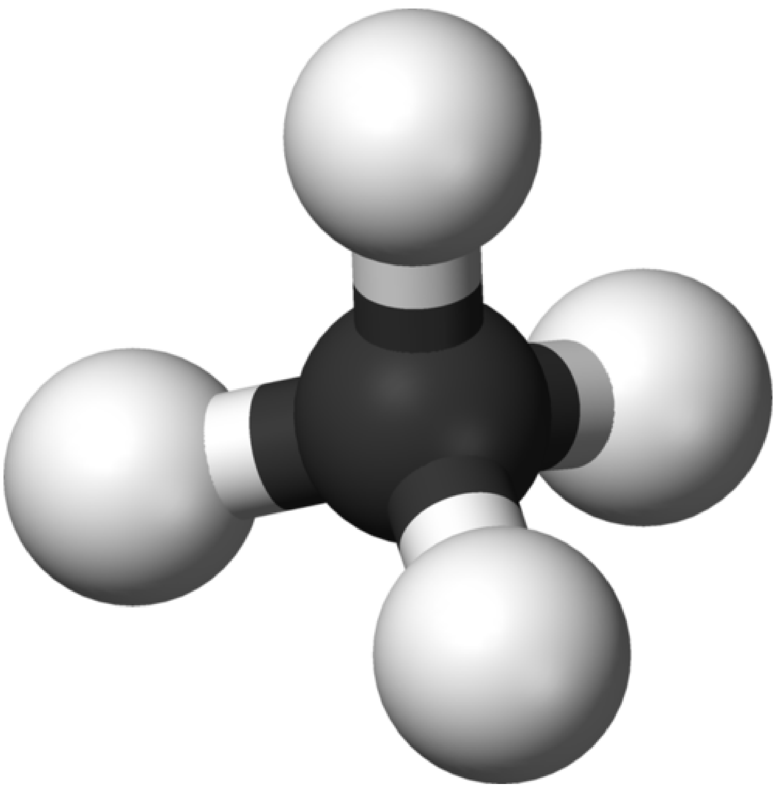


FIGURE 12.7
Hydrocarbons are made of carbon and hydrogen atoms. This molecule with one carbon and four hydrogen atoms is methane.

turned into chemicals called **hydrocarbons** (**Figure** 12.7). An animated view of a hydrocarbon is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CH4_3.MPG.

Hydrocarbons can be solid, liquid, or gaseous. The solid form is what we know as coal. The liquid form is petroleum, or crude oil. Natural gas is the gaseous form.

The solar energy stored in fossil fuels is a rich source of energy. Although fossil fuels provide very high quality energy, they are non-renewable.

Vocabulary

- **fossil**: Any remains or trace of an ancient organism.
- **fossil fuel**: A hydrocarbon created from the remains of formerly living organisms that can be used for energy.
- **hydrocarbon**: A chemical compound containing hydrogen and carbon that is used for energy.

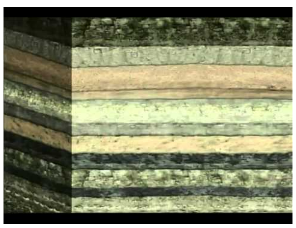
Summary

- Hydrocarbons are molecules made of one carbon and four hydrogen atoms.
- Ancient living organisms are buried quickly and altered by intense heat and pressure to form fossil fuels.
- Fossil fuels include solid coal, liquid petroleum, and liquid natural gas.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=XoyqQgmwY9E



MEDIA

Click image to the left for more content.

1. What is natural gas and crude oil made from?
2. Why are these products called fossil fuels?
3. What type of environment did the microorganisms live in?
4. What covered the organisms?
5. What is bio-genesis?
6. How were the biotic materials cooked?

Review

1. Why are coal, petroleum, and natural gas called fossil fuels?
2. How do fossil fuels form?
3. What is the actual source of energy in a fossil fuel?

12.6 Coal Power

- Explain how coal forms and is used.
- Describe the environmental consequences of burning coal.

What was the foundation of the Industrial Revolution?

The Industrial Revolution was the change in society that resulted from people learning to use fossil fuels. By harnessing fossil fuels, work could be done more rapidly and more cheaply, allowing people to manufacture goods cheaply and efficiently.

Coal

Coal, a solid fossil fuel formed from the partially decomposed remains of ancient forests, is burned primarily to produce electricity. Coal use is undergoing enormous growth as the availability of oil and natural gas decreases and cost increases. This increase in coal use is happening particularly in developing nations, such as China, where coal is cheap and plentiful.

Coal is black or brownish-black. The most common form of coal is bituminous, a sedimentary rock that contains impurities such as sulfur (**Figure** 12.8). Anthracite coal has been metamorphosed and is nearly all carbon. For this reason, anthracite coal burns more cleanly than bituminous coal.

FIGURE 12.8
Bituminous coal is a sedimentary rock.

Coal Formation

Coal forms from dead plants that settled at the bottom of ancient swamps. Lush coal swamps were common in the tropics during the Carboniferous period, which took place more than 300 million years ago (**Figure** 12.9). The climate was warmer then.

Mud and other dead plants buried the organic material in the swamp, and burial kept oxygen away. When plants are buried without oxygen, the organic material can be preserved or fossilized. Sand and clay settling on top of the decaying plants squeezed out the water and other substances. Millions of years later, what remains is a carbon-containing rock that we know as coal.

Coal Use

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal (**Figure** 12.10). California once had a number of small coal mines, but the state no longer produces coal. To turn coal into electricity, the rock is crushed into powder, which is then burned in a furnace that has a boiler. Like other fuels, coal releases its energy as heat when it burns. Heat from the burning coal boils the water in the boiler to make steam. The steam spins turbines, which turn generators to create electricity. In this way, the energy stored in the coal is converted to useful energy like electricity.

Consequences of Coal Use

For coal to be used as an energy source, it must first be mined. Coal mining occurs at the surface or underground by methods that are described in the "Concept Materials of Earth's Crust" (**Figure** 12.11). Mining, especially

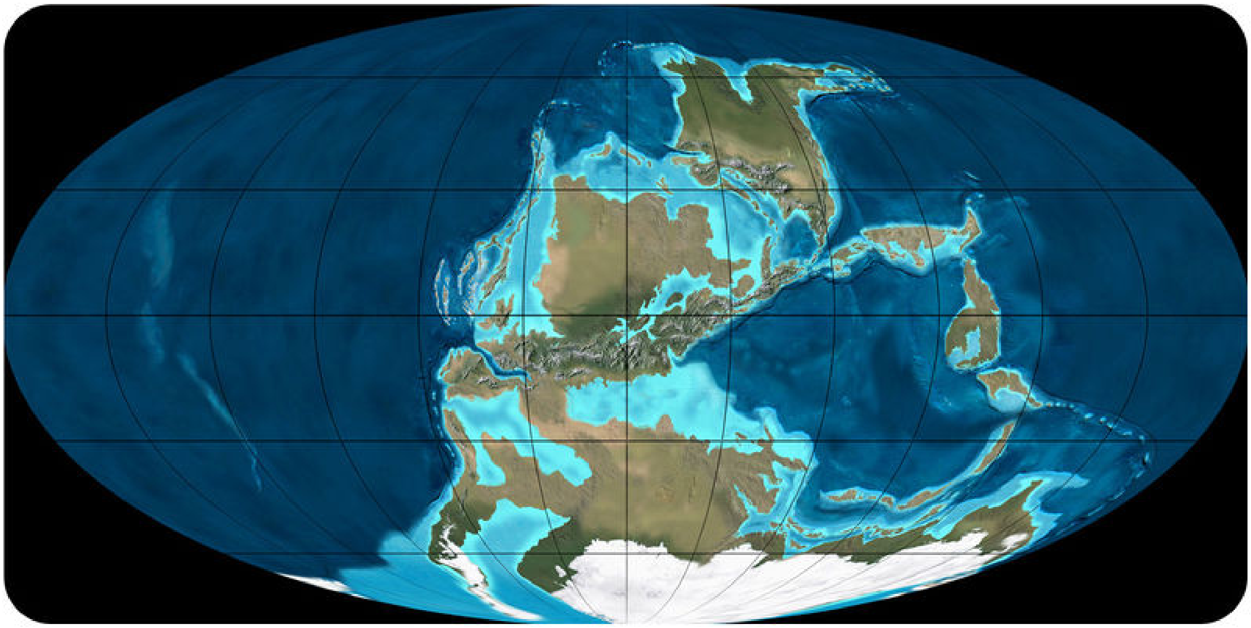


FIGURE 12.9
The location of the continents during the Carboniferous period. Notice that quite a lot of land area is in the region of the tropics.

underground mining, can be dangerous. In April 2010, 29 miners were killed at a West Virginia coal mine when gas that had accumulated in the mine tunnels exploded and started a fire.

Coal mining exposes minerals and rocks from underground to air and water at the surface. Many of these minerals contain the element sulfur, which mixes with air and water to make sulfuric acid, a highly corrosive chemical. If the sulfuric acid gets into streams, it can kill fish, plants, and animals that live in or near the water.

Vocabulary

- **coal**: A solid fossil fuel from ancient dead organisms used for electricity.

Summary

- Coal is solid fossil fuels formed primarily from ancient swamp plants, especially during the Carboniferous.
- Coal is the source of most electricity.
- Coal mining may bring dangerous materials into the air and coal burning is sometimes quite dirty.

Practice

Use this resource to answer the questions that follow.

http://science.discovery.com/videos/how-do-they-do-it-coal-mining.html

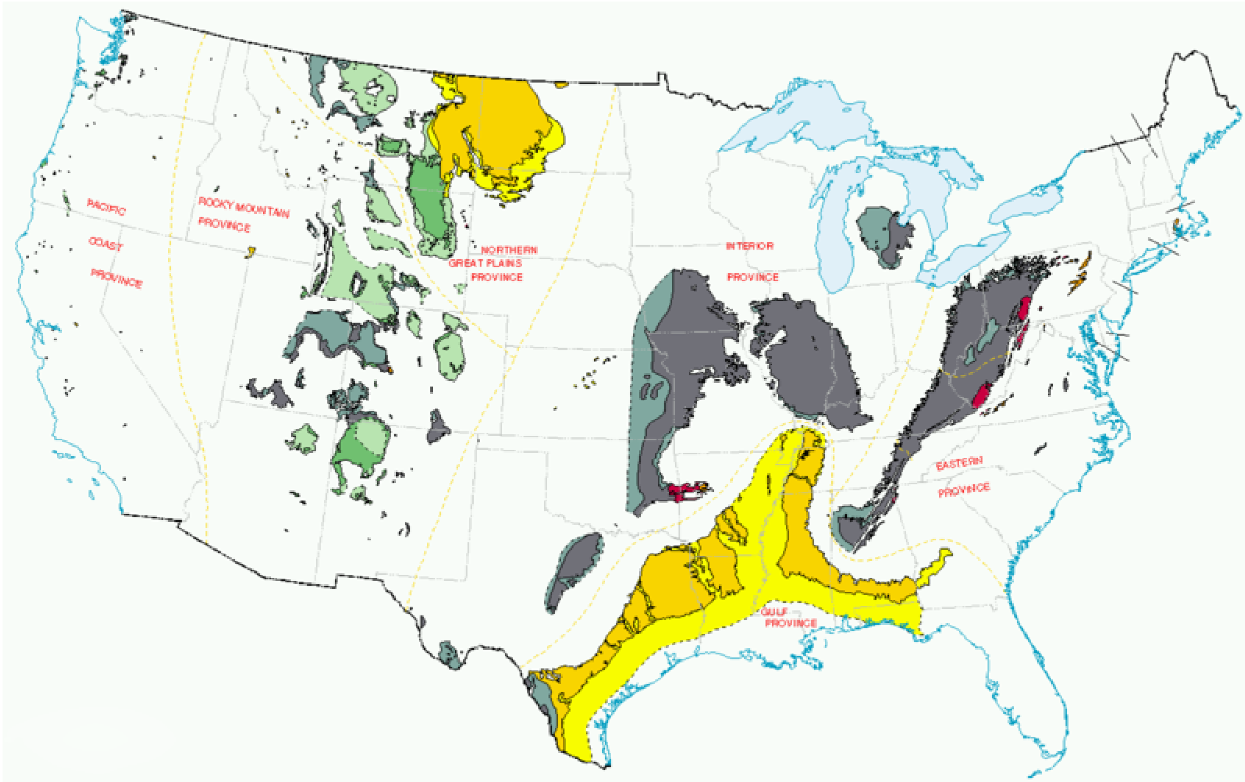


FIGURE 12.10

United States coal-producing regions in 1996. Orange is highest grade anthracite; red is low volatile bituminous; gray and gray-green is medium to high-volatile bituminous; green is subbituminous; and yellow is the lowest grade lignite.

MEDIA

Click image to the left for more content.

1. How much electricity is produced from coal?
2. Where is the largest underground coal mining complex?
3. How much coal does it produce?
4. How long have they been mining at this site?
5. What is a continuous miner?
6. How is the coal processed?
7. What waste is produced?
8. How quickly is the coal processed?

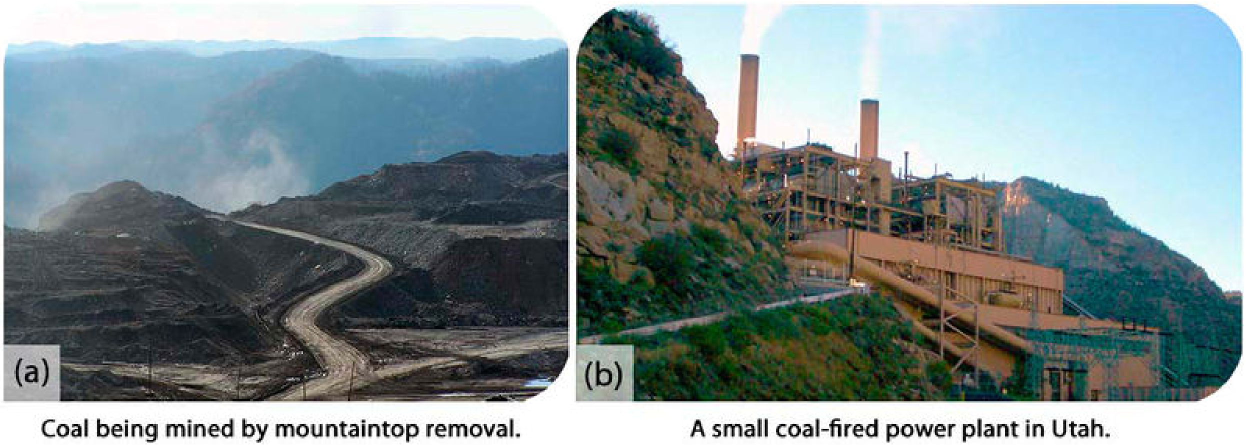


FIGURE 12.11
The coal used in power plants must be mined. One method to mine coal is by mountaintop removal.

Review

1. How does coal form?
2. There are swamps today. Why is coal not a renewable resource?
3. What are some of the environmental consequences of coal use?

12.7 Petroleum Power

- Explain how petroleum forms and is used.
- Describe the environmental consequences of petroleum use.

What is the connection between ancient swamps and the Indy 500?

Many forms of fun and transportation are made possible by liquid petroleum. Petroleum is the result of plants dying in ancient swamps.

Oil

Oil is a liquid fossil fuel that is extremely useful because it can be transported easily and can be used in cars and other vehicles. Oil is currently the single largest source of energy in the world.

Oil Formation

Oil from the ground is called **crude oil**, which is a mixture of many different hydrocarbons. Crude oil is a thick dark brown or black liquid hydrocarbon. Oil also forms from buried dead organisms, but these are tiny organisms that live on the sea surface and then sink to the seafloor when they die. The dead organisms are kept away from oxygen by layers of other dead creatures and sediments. As the layers pile up, heat and pressure increase. Over millions of years, the dead organisms turn into liquid oil.

Oil Production

In order to be collected, the oil must be located between a porous rock layer and an impermeable layer (**Figure** 12.12). Trapped above the porous rock layer and beneath the impermeable layer, the oil will remain between these layers until it is extracted from the rock.

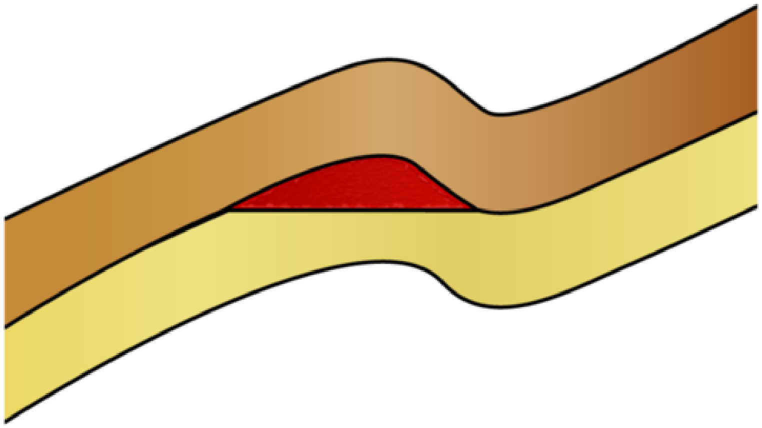


FIGURE 12.12
Oil (red) is found in the porous rock layer (yellow) and trapped by the impermeable layer (brown). The folded structure has allowed the oil to pool so a well can be drilled into the reservoir.

- An animation of an oil deposit forming is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/ENTRAP_3.MPG.
- The oil pocket is then drilled into from the surface. An animation of an oil deposit being drilled is shown here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/DRILL_3.MPG.
- Sideways drilling allows a deposit that lies beneath land that cannot be drilled to be mined for oil: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/HORDRI_3.MPG.

To separate the different types of hydrocarbons in crude oil for different uses, the crude oil must be refined in refineries like the one shown in **Figure** 12.13. Refining is possible because each hydrocarbon in crude oil boils at a different temperature. When the oil is boiled in the refinery, separate equipment collects the different compounds.

FIGURE 12.13
Refineries like this one separate crude oil into many useful fuels and other chemicals.

Oil Use

Most of the compounds that come out of the refining process are fuels, such as gasoline, diesel, and heating oil. Because these fuels are rich sources of energy and can be easily transported, oil provides about 90% of the energy used for transportation around the world. The rest of the compounds from crude oil are used for waxes, plastics, fertilizers, and other products.

Gasoline is in a convenient form for use in cars and other transportation vehicles. In a car engine, the burned gasoline mostly turns into carbon dioxide and water vapor. The fuel releases most of its energy as heat, which causes the gases to expand. This creates enough force to move the pistons inside the engine and to power the car.

Consequences of Oil Use

The United States does produce oil, but the amount produced is only about one-quarter as much as the nation uses. The United States has only about 1.5% of the world's proven oil reserves, so most of the oil used by Americans must be imported from other nations.

The main oil-producing regions in the United States are the Gulf of Mexico, Texas, Alaska, and California (**Figure** 12.14). An animation of the location of petroleum basins in the contiguous United States can be seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/BASINS_3.MPG.

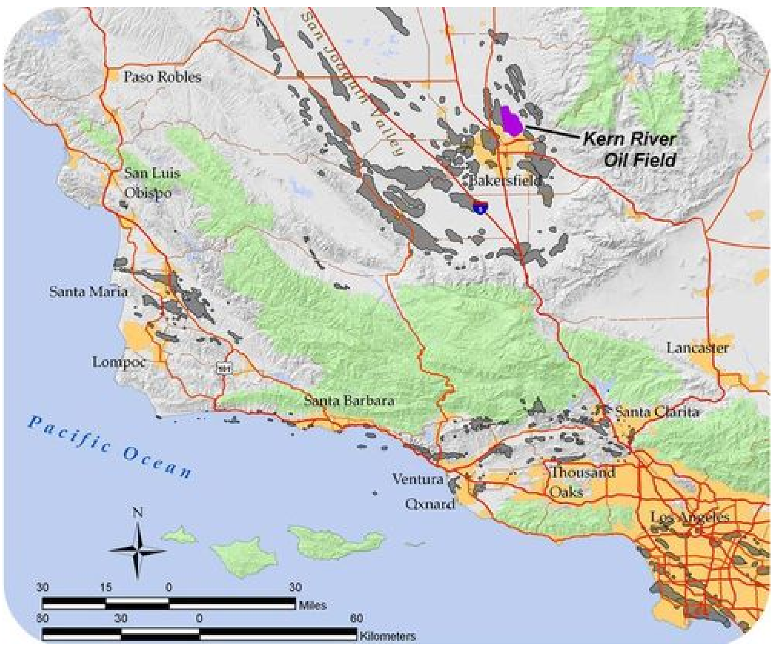


FIGURE 12.14
Most of California's oil fields, such as the Kern River, are in the southern San Joaquin Valley. Oil collects in permeable sedimentary rocks from the top of folds like the one shown above.

As in every type of mining, mining for oil has environmental consequences. Oil rigs are unsightly (**Figure** 12.15), and spills are too common (**Figure** 12.16).

Vocabulary

- **crude oil**: Unrefined oil as it is taken from the ground; a fossil fuel.
- **oil**: A liquid fossil fuel from ancient dead organisms used for transportation and other products.

Summary

- Liquid fossil fuels include petroleum, which is useful for vehicles because it is easily stored and transported.
- Petroleum is also extremely important for materials like waxes, plastics, fertilizers, and other products.
- Extracting petroleum from the ground and transporting it can be damaging to the environment.

FIGURE 12.15
Drill rigs at the Kern River Oil Field in California.

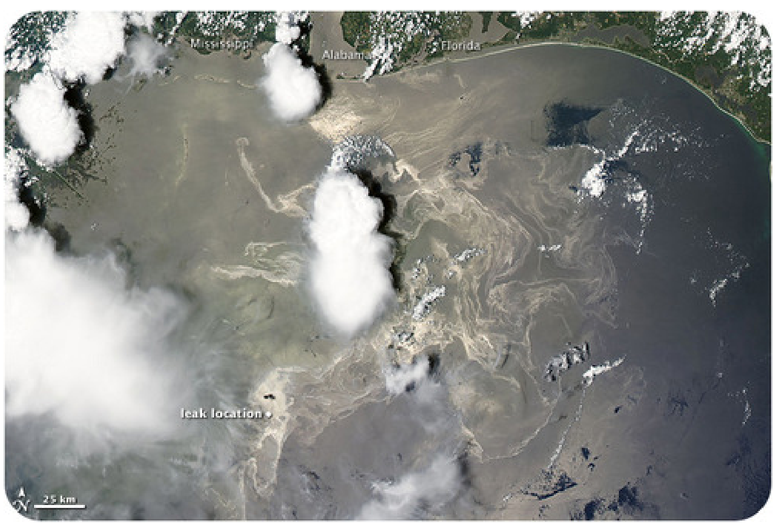


FIGURE 12.16
A deadly explosion on an oil rig in the Gulf of Mexico in April 2010 led to a massive oil spill. When this picture was taken in July 2010, oil was still spewing into the Gulf. The long-term consequences of the spill are being studied and are as yet unknown.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=rgrUwPWjj2Q

MEDIA
Click image to the left for more content.

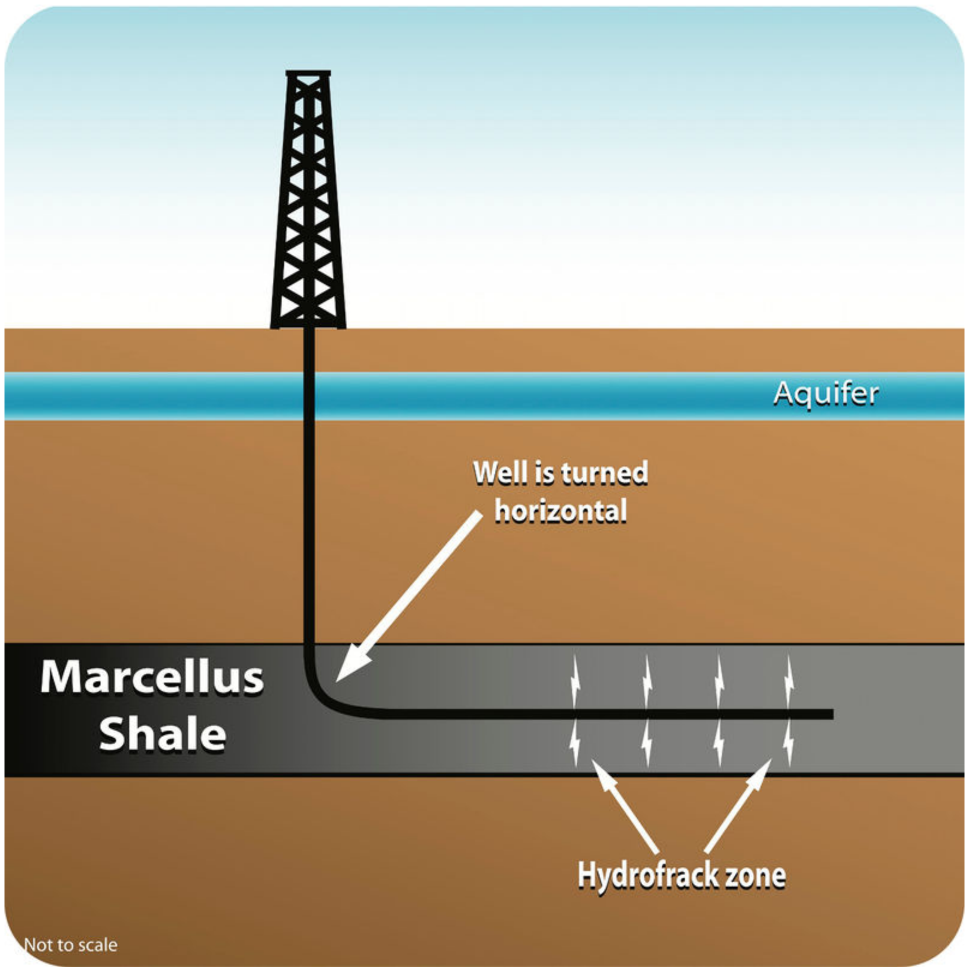
1. What produced the fossil fuels?
2. What is sediment?
3. What is kerogen? How is it produced?
4. How do we find oil?
5. How do we get the oil out of the ground?
6. Why is drilling mud pumped down the pipe?
7. What are cuttings?
8. What does the pumping unit do?
9. What happens at the refinery?
10. What does fractional distillation produce?
11. What are petrochemicals used for?
12. What other products are made from oil?

Review

1. Why is it harder to find a substitute for petroleum than it is for coal? Think about what these fuels are used for.
2. Why are there more likely to be hazardous consequences for deep oil drilling than for the shallow drilling that's been taking place for centuries?
3. How is crude oil formed?

12.8 Natural Gas Power

- Explain how natural gas forms and is used.
- Describe the consequences of natural gas extraction.



What caused the recent earthquakes in Ohio and Oklahoma?

The process of extracting natural gas, known as fracking, injects liquid waste into deep wells. Coincidentally, locations where seismic activity is virtually unknown have begun to experience earthquakes. Is fracking related to earthquake activity? Many geologists think the link is undeniable.

Natural Gas

Natural gas, often known simply as gas, is composed mostly of the hydrocarbon methane. The amount of natural gas being extracted and used in the Untied States is increasing rapidly.

Natural Gas Formation

Natural gas forms under the same conditions that create oil. Organic material buried in the sediments harden to become a shale formation that is the source of the gas. Although natural gas forms at higher temperatures than crude oil, the two are often found together.

The formation of an oil and gas deposit that can be mined is seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/PETSYS_3.MPG.

The largest natural gas reserves in the United States are in the Appalachian Basin, Texas, and the Gulf of Mexico region (**Figure** 12.17). California also has natural gas, found mostly in the Central Valley. In the northern Sacramento Valley and the Sacramento Delta, a sediment-filled trough formed along a location where crust was pushed together (an ancient convergent margin).

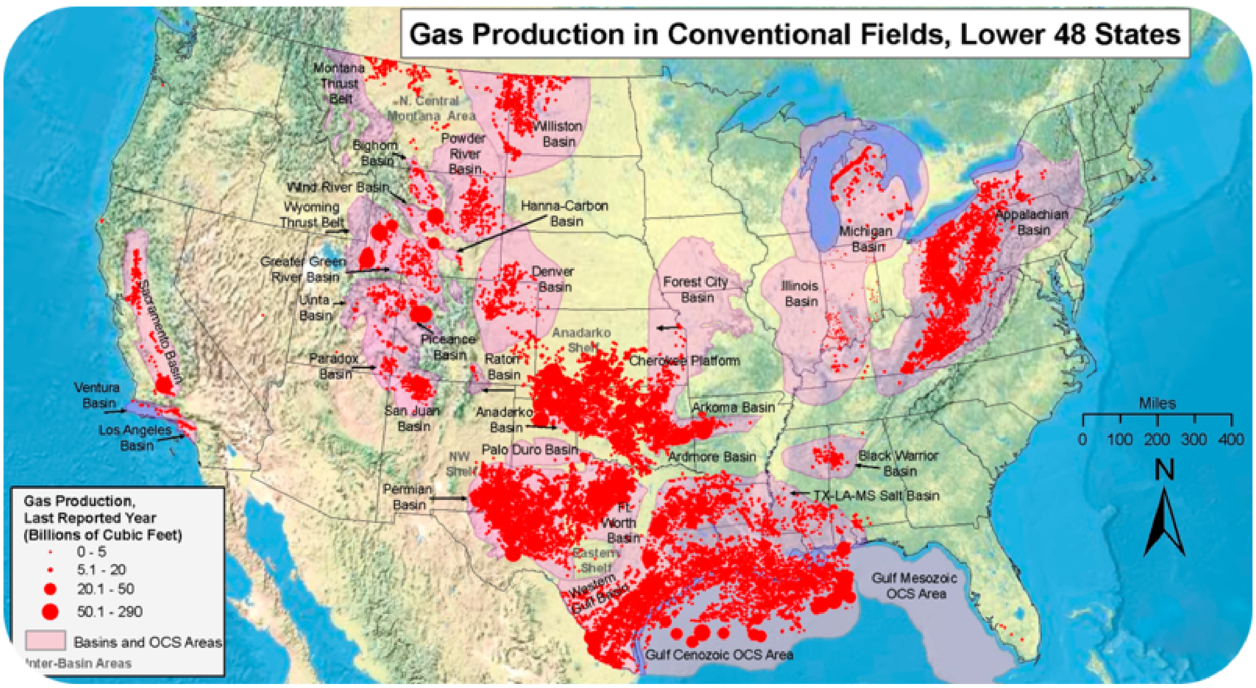


FIGURE 12.17
Gas production in the lower 48 United States.

- An animation of global natural gas reserves is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GLOBE_3.MPG.

Natural Gas Use

Like crude oil, natural gas must be processed before it can be used as a fuel. Some of the chemicals in unprocessed natural gas are poisonous to humans. Other chemicals, such as water, make the gas less useful as a fuel. Processing natural gas removes almost everything except the methane. Once the gas is processed, it is ready to be delivered and used. Natural gas is delivered to homes for uses such as cooking and heating. Like coal and oil, natural gas is also burned to generate heat for powering turbines. The spinning turbines turn generators, and the generators create electricity.

Consequences of Natural Gas Use

Natural gas burns much cleaner than other fossil fuels, meaning that it causes less air pollution. Natural gas also produces less carbon dioxide than other fossil fuels do for the same amount of energy, so its global warming effects are less (**Figure** 12.18).

FIGURE 12.18
A natural gas drill rig in Texas.

- See the pollution created by a car burning gasoline and a car burning natural gas in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/GASPOL_3.MPG.

Unfortunately, drilling for natural gas can be environmentally destructive. One technique used is hydraulic fracturing, also called **fracking**, which increases the rate of recovery of natural gas. Fluids are pumped through a borehole to create fractures in the reservoir rock that contains the natural gas. Material is added to the fluid to prevent the fractures from closing. The damage comes primarily from chemicals in the fracturing fluids. Chemicals that have been found in the fluids may be carcinogens (cancer-causing), radioactive materials, or endocrine disruptors, which interrupt hormones in the bodies of humans and animals. The fluids may get into groundwater or may runoff into streams and other surface waters. As noted above, fracking may cause earthquakes.

Vocabulary

- **fracking**: Nickname for hydraulic fracturing. A technique for retrieving natural gas involves creating fractures in a rock layer by injecting large amounts of water.
- **natural gas**: A fossil fuel composed of the hydrocarbon methane.

Summary

- Natural gas forms with crude oil but at higher temperatures.
- Natural gas burns more cleanly than petroleum and produces fewer greenhouse gases.
- Hydraulic fracturing, known as fracking, is a relatively new method for extracting natural gas, which may be linked to groundwater contamination and the generation of small earthquakes in non-seismic regions.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=zmAwkYLEV80

MEDIA

Click image to the left for more content.

1. What is fracking?
2. Explain how natural gas is extracted.
3. What used to cause additional fracking?
4. What is the concern with fracking?
5. What law is the gas company exempted from?

Review

1. You'll be hearing a lot about fracking in the coming years. What is it and how does it work?
2. How is natural gas different from crude oil and how does it form differently?
3. Why is natural gas considered more environmentally sound than other fossil fuels?

12.9 Fossil Fuel Reserves

- Describe the limitations of traditional and alternative fossil fuels.

How much is left?

The answer to that question depends on what we as a society are willing to do to get fossil fuels. How much are we willing to damage the environment to extract and transport fossil fuels? How much are we willing to raise atmospheric greenhouse gas levels and further alter climate? The Keystone Pipeline would bring crude oil from tar sands to the U.S., but for the time being, that project is on hold.

Fossil Fuel Reserves

Fossil fuels provide about 85% of the world's energy at this time. Worldwide fossil fuel usage has increased many times over in the past half century (coal – 2.6x, oil – 8x, natural gas – 14x) because of population increases, because of increases in the number of cars, televisions, and other fuel-consuming uses in the developed world, and because of lifestyle improvements in the developing world.

- Past and predicted use of different types of energy in the United States can be seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/MAXGAS_3.MPG.

The amount of fossil fuels that remain untapped is unknown, but can likely be measured in decades for oil and natural gas and in a few centuries for coal (**Figure** 12.19).

Alternative Fossil Fuels

As the easy-to-reach fossil fuel sources are depleted, alternative sources of fossil fuels are increasingly being exploited (**Figure** 12.20). These include oil shale and tar sands. **Oil shale** is rock that contains dispersed oil that has

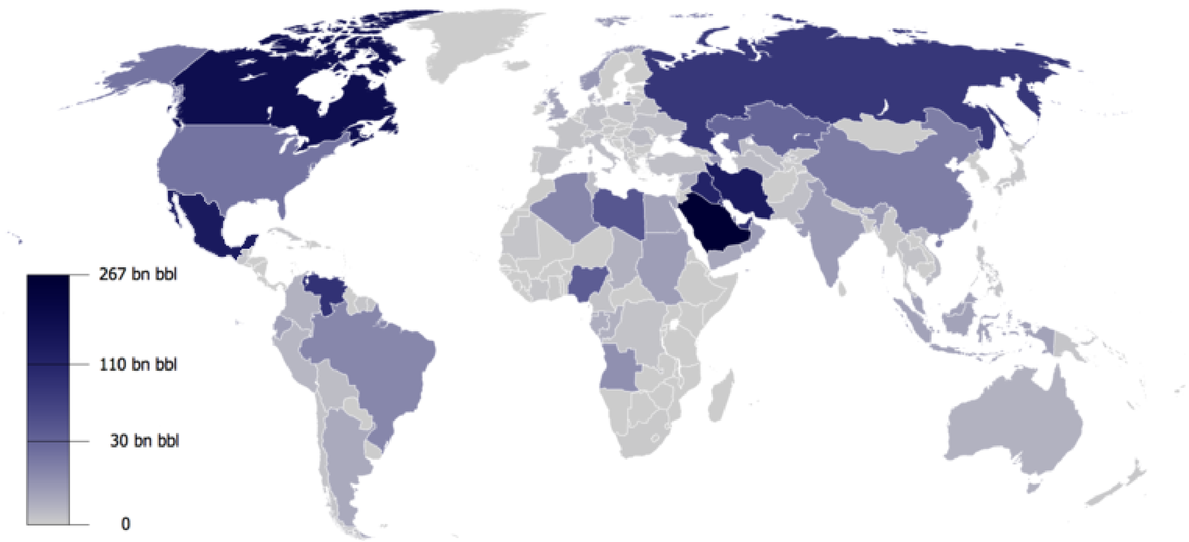


FIGURE 12.19
Worldwide oil reserves.

not collected in reservoirs. To extract the oil from the shale requires enormous amounts of hot water. **Tar sands** are rocky materials mixed with very thick oil. The tar is too thick to pump and so tar sands are strip-mined. Hot water and caustic soda are used to separate the oil from the rock.

FIGURE 12.20
A satellite image of an oil-sands mine in Canada.

The environmental consequences of mining these fuels, and of fossil fuel use in general, along with the fact that these fuels do not have a limitless supply, are prompting the development of alternative energy sources in some regions.

Vocabulary

- **oil shale**: Sedimentary rock rich in oil that can be mined using heat and enormous quantities of water.
- **tar sands**: Sands mixed with oil that can be mined using water and caustic soda.

Summary

- Easy to get at fossil fuels are running out, but there are other sources that are harder to get at that are still available.
- Oil shales and tar sands are two of the alternative sources of fossil fuels that are much in the news.
- The need for fossil fuels continues to grow as people in the developed work use more and more people in the developing world want them.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=6MJQOyeRvBc

MEDIA
Click image to the left for more content.

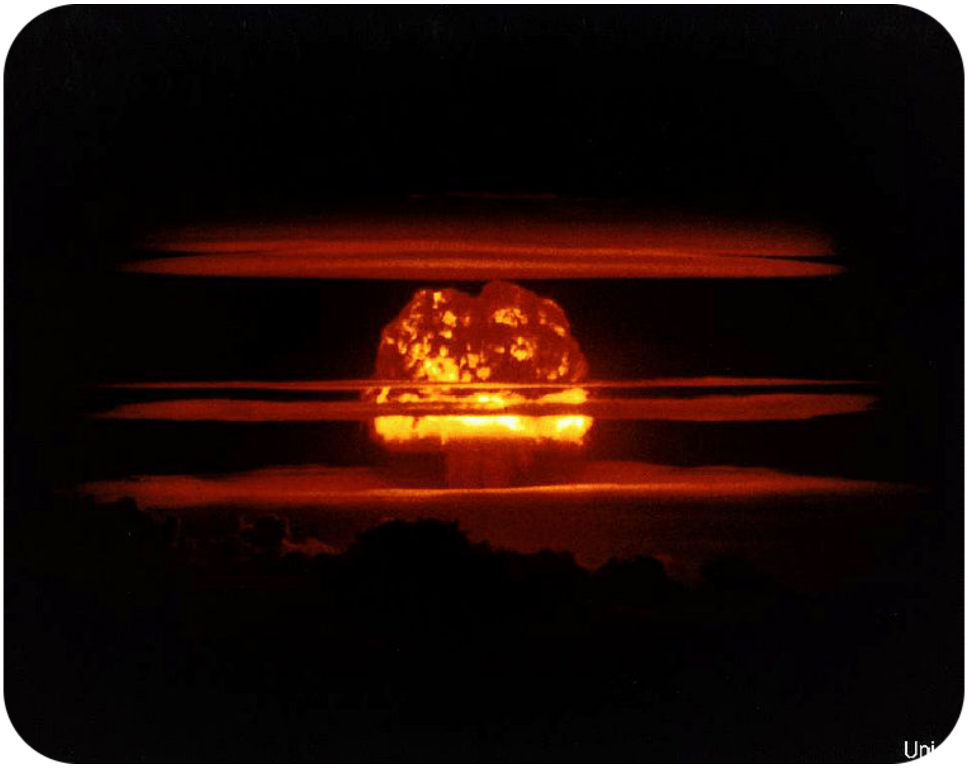
1. How much oil shale is there in the United States?
2. Hoe much oil can be produced from oil shale?
3. Where is the Green River Formation?
4. What is oil shale?
5. How many barrels does OSEC plan to produce each day?

Review

1. What are oil shales and tar sands?
2. How do scientists and politicians determine how much fossil fuel is left? Why is this number undoubtedly inaccurate?
3. Why is the need for fossil fuels increasing?

12.10 Nuclear Power

- Explain how nuclear energy is harnessed and used, and describe its consequences.



What does an atomic bomb have to do with energy generation?

Splitting atoms releases enormous amounts of energy. To be useful rather than destructive, nuclear power plants must be safeguarded, but this attempt is not always successful.

Nuclear Energy

When the nucleus of an atom is split, it releases a huge amount of energy called **nuclear energy**. For nuclear energy to be used as a power source, scientists and engineers have learned to split nuclei and to control the release of energy (**Figure** 12.21).

Nuclear Energy Use

Nuclear power plants, such as the one seen in **Figure** 12.22, use uranium, which is mined, processed, and then concentrated into fuel rods. When the uranium atoms in the fuel rods are hit by other extremely tiny particles, they split apart. The number of tiny particles allowed to hit the fuel rods needs to be controlled, or they would cause a dangerous explosion. The energy from a nuclear power plant heats water, which creates steam and causes a turbine to spin. The spinning turbine turns a generator, which in turn produces electricity.

Many countries around the world use nuclear energy as a source of electricity. In the United States, a little less than 20% of electricity comes from nuclear energy.

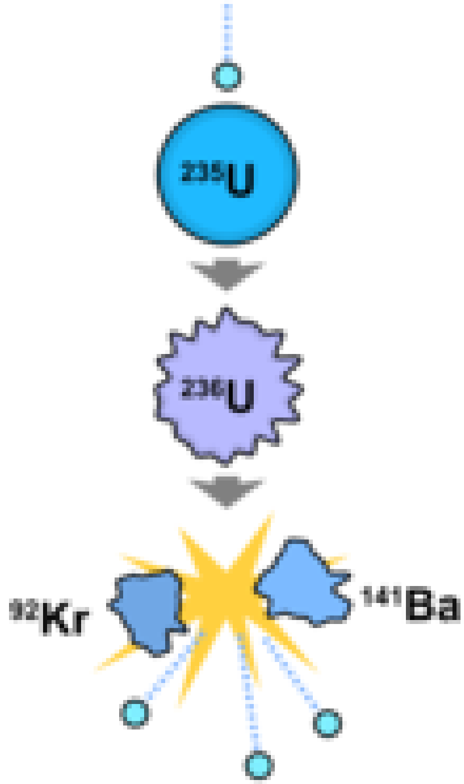


FIGURE 12.21
When struck by a tiny particle, Uranium-235 breaks apart and releases energy.

FIGURE 12.22
Nuclear power plants like this one provide France with almost 80% of its electricity.

Consequences of Nuclear Power

Nuclear power is clean. It does not pollute the air. However, the use of nuclear energy does create other environmental problems. Uranium must be mined (**Figure** 12.23). The process of splitting atoms creates radioactive waste, which remains dangerous for thousands or hundreds of thousands of years. As yet, there is no long-term solution for storing this waste.

The development of nuclear power plants has been on hold for three decades. Accidents at Three Mile Island and

FIGURE 12.23
Uranium mine near Moab, Utah.

Chernobyl, Ukraine verified people's worst fears about the dangers of harnessing nuclear power (**Figure** 12.24).

FIGURE 12.24
Damaged building near the site of the Chernobyl disaster.

Recently, nuclear power appeared to be making a comeback as society looked for alternatives to fossil fuels. After all, nuclear power emits no pollutants, including no greenhouse gases. But the 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Japan may have resulted in a new fear of nuclear power. The cause of the disaster was a 9.0 magnitude earthquake and subsequent tsunami, which compromised the plant. Although a total meltdown was averted, the plant experienced multiple partial meltdowns, core breaches, radiation releases, and cooling failures. The plant is scheduled for a complete cold shutdown before the end of 2011.

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky.

Find out more at http://science.kqed.org/quest/audio/new-nuclear/.

MEDIA

Click image to the left for more content.

Vocabulary

- **nuclear energy**: Energy that is released from the nucleus of an atom when it is changed into another atom.

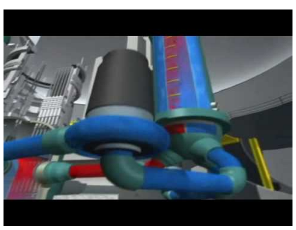
Summary

- Nuclear energy is released when the nucleus of an atom is split.
- Nuclear power plants use uranium in fuel rods, which later become nuclear waste. Nuclear waste can be dangerous for hundreds of thousands of years.
- Periodic accidents involving nuclear power plants seem to slow down the development of nuclear power in many countries.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=VJfIbBDR3e8



MEDIA

Click image to the left for more content.

1. How many countries use nuclear power?

2. What is used to produce the electricity in the power plant?

3. What releases the heat in nuclear plants?

4. What is used as the fuel?

5. What are the two types of reactors?

6. What is the function of the control rods?

Review

1. How is nuclear energy generated?

2. Since the waste from nuclear power plants is dangerous for up to hundreds of thousands of years, how do you think it should be safeguarded?

3. Do you think that the nuclear disaster in Japan in 2011 should affect how nations develop or choose not to develop their nuclear resources? What about nations that are not near a subduction zone?

12.11 Solar Power

- Explain how solar energy is collected and used.

Since so much of the energy we use came ultimately from the Sun, why don't we just get our power directly from the Sun?

That's a good question. Can you answer it?

Solar Energy

Energy from the Sun comes from the lightest element, hydrogen, fusing together to create the second lightest element, helium. Nuclear fusion on the Sun releases tremendous amounts of solar energy. The energy travels to the Earth, mostly as visible light. The light carries the energy through the empty space between the Sun and the Earth as **radiation**.

Solar Power Use

Solar energy has been used for power on a small scale for hundreds of years, and plants have used it for billions of years. Unlike energy from fossil fuels, which almost always come from a central power plant or refinery, solar power can be harnessed locally (**Figure** 12.25). A set of solar panels on a home's rooftop can be used to heat water for a swimming pool or can provide electricity to the house.

Society's use of solar power on a larger scale is just starting to increase. Scientists and engineers have very active, ongoing research into new ways to harness energy from the Sun more efficiently. Because of the tremendous amount of incoming sunlight, solar power is being developed in the United States in southeastern California, Nevada, and Arizona.

Solar power plants turn sunlight into electricity using a large group of mirrors to focus sunlight on one place, called a receiver (**Figure** 12.26). A liquid, such as oil or water, flows through this receiver and is heated to a high temperature

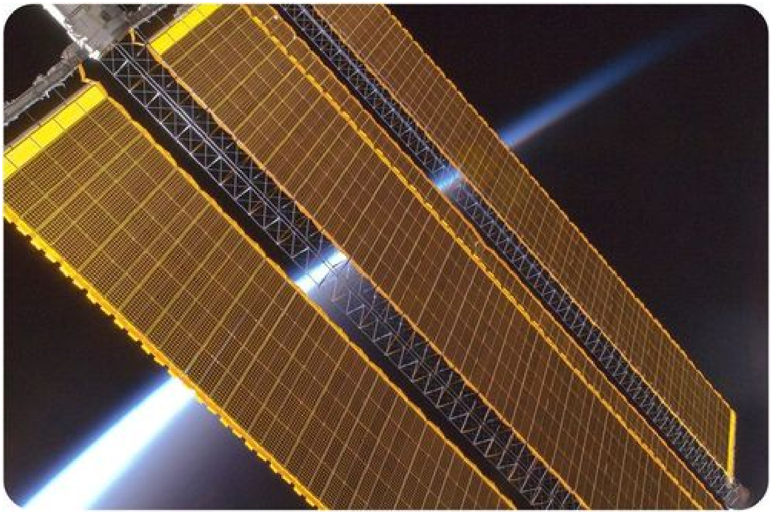


FIGURE 12.25
Solar panels supply power to the International Space Station.

by the focused sunlight. The heated liquid transfers its heat to a nearby object that is at a lower temperature through a process called **conduction**. The energy conducted by the heated liquid is used to make electricity.

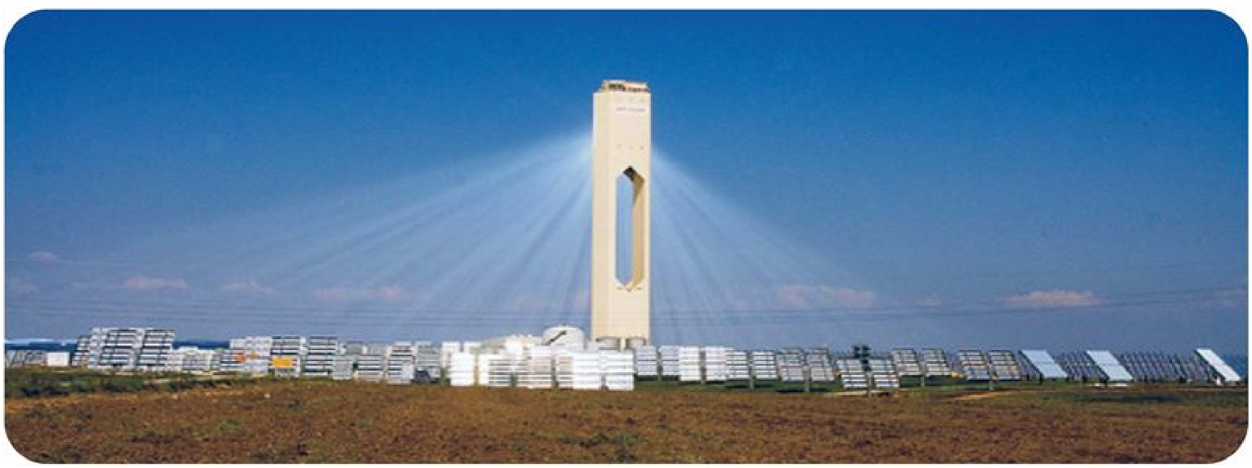


FIGURE 12.26
This solar power plant uses mirrors to focus sunlight on the tower in the center. The sunlight heats a liquid inside the tower to a very high temperature, producing energy to make electricity.

A video of how solar energy can be concentrated so that it can be used for power: http://www1.eere.energy.gov/multimedia/video_csp.html.

Consequences of Solar Power Use

Solar energy has many benefits. It is extremely abundant, widespread, and will never run out. But there are problems with the widespread use of solar power.

- Sunlight must be present. Solar power is not useful in locations that are often cloudy or dark. However, storage technology is being developed.
- The technology needed for solar power is still expensive. An increase in interested customers will provide incentive for companies to research and develop new technologies and to figure out how to mass-produce existing technologies (**Figure** 12.27).
- Solar panels require a lot of space. Fortunately, solar panels can be placed on any rooftop to supply at least some of the power required for a home or business.

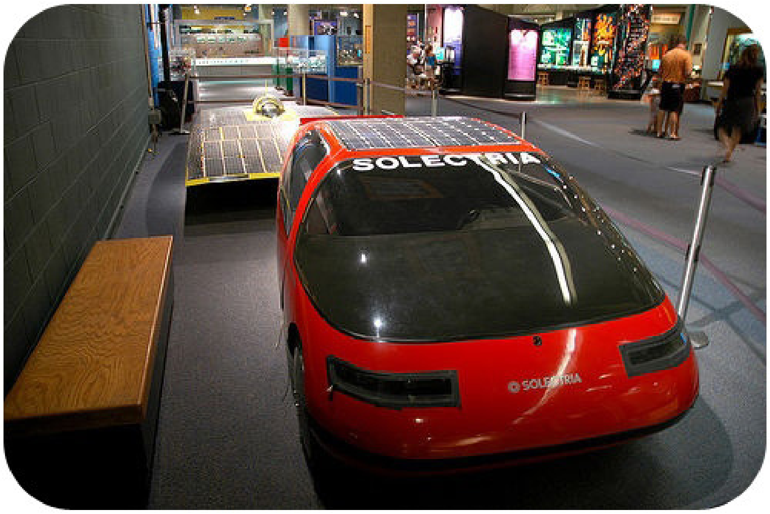


FIGURE 12.27
This experimental car is one example of the many uses that engineers have found for solar energy.

Vocabulary

- **conduction**: The process in which energy moves from a location of higher temperature to a location of lower temperature as heat. The material does not move, just the heat.
- **radiation**: The movement of energy through empty space between objects by electromagnetic waves.

Summary

- Solar energy is the result of nuclear fusion in our nearest star.
- A liquid is heated and moves that energy by conduction.
- Solar power is expensive, but as demand increases technology improves and costs decrease.

Practice

Use this resource to answer the questions that follow.

https://www.eeremultimedia.energy.gov/solar/videos/solar_power_basics

1. What does solar power do for the planet?
2. What is diffuse light?
3. Explain passive solar heating.
4. What is solar thermal energy used for?
5. Explain how concentrating solar power works.

6. How do photovoltaic panels work?
7. What are the advantages of photovoltaic panels?
8. List the advantages to using solar power.

Review

1. How is solar power collected on a large scale?
2. What are some of the downsides of depending on solar energy?
3. What are some of the positive sides of using solar energy?

12.12 Hydroelectric Power

- Explain how energy from falling water is harnessed for hydroelectric power.
- Describe the consequences of hydroelectric power use.

Did the idea for the first dam come from beavers?

Beavers have been building dams for a long time, for food, for a home, and for protection from predators. They probably haven't realized that they can use a dam for hydroelectric power, although are we sure there aren't little TVs in those lodges?

Water Power

Water covers 70% of the planet's surface, and water power (hydroelectric power) is the most widely used form of renewable energy in the world. Hydroelectric power from streams provides almost one fifth of the world's electricity.

Hydroelectric Power

Remember that potential energy is the energy of an object waiting to fall. Water held behind a dam has a lot of potential energy.

In a hydroelectric plant, a dam across a riverbed holds a stream to create a reservoir. Instead of flowing down its normal channel, the water is allowed to flow into a large turbine. As the water moves, it has kinetic energy, which makes the turbine spin. The turbine is connected to a generator, which makes electricity (**Figure** 12.28).

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have already been dammed. In California, about 14.5% of the total electricity comes from hydropower. The

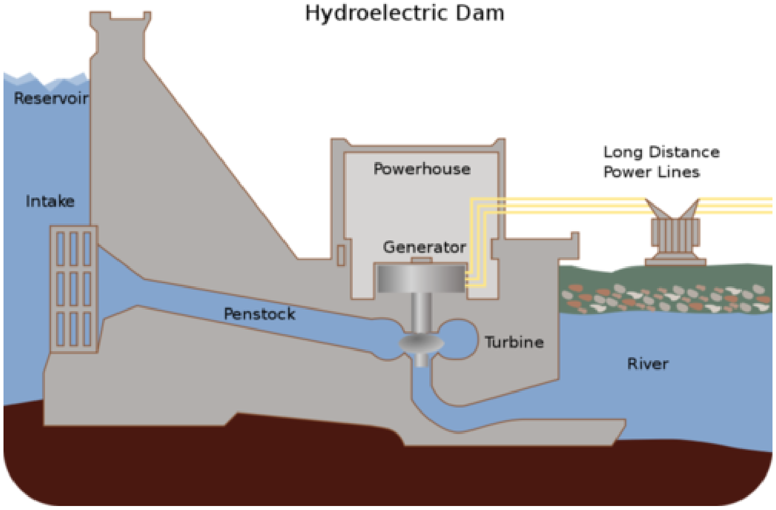


FIGURE 12.28
A cross-section of a hydroelectric plant.

state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges, where large streams descend down a steep grade.

Consequences of Water Power Use

The major benefit of hydropower is that it generates power without releasing any pollution. Hydropower is also a renewable resource since the stream will keep on flowing. However, there are a limited number of suitable dam sites. Hydropower also has environmental problems. When a large dam disrupts a river's flow, it changes the ecosystem upstream. As the land is flooded by rising water, plants and animals are displaced or killed. Many beautiful landscapes, villages, and archeological sites have been drowned by the water in a reservoir (**Figure** 12.29).

FIGURE 12.29
Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

The dam and turbines also change the downstream environment for fish and other living things. Dams slow the release of silt so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels.

Ocean Water Power

The energy of waves and tides can be used to produce water power. Tidal power stations may need to close off a narrow bay or estuary. Wave power applications have to be able to withstand coastal storms and the corrosion of seawater. Because of the many problems with them, tide and wave power plants are not very common.

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

Find out more at http://science.kqed.org/quest/audio/harnessing-power-from-the-sea/.

Adobe Flash

MEDIA

Click image to the left for more content.

Summary

- Hydroelectric power is clean and is important in many regions of the world.
- Hydropower has downsides like the changes dams make to a river's ecosystem.
- Hydropower utilizes the energy of falling water.

Practice

Use this resource to answer the questions that follow.

http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Hydroelectric Power**

1. How is hydroelectric power generated?

2. What does the height of the water determine?

3. How is the turbine rotated?

4. What are the advantages of hydroelectric power?

5. What are the disadvantages of hydroelectric power?

Review

1. How does energy transition from one form to another as water moves from behind a dam to downstream of a dam?

2. Describe how hydroelectric energy is harnessed.

3. What are some of the downsides of using hydroelectric power?

12.13 Wind Power

- Explain how wind energy is harnessed and used, and describe its consequences.

What does "NIMBY" stand for?

Not in my backyard. As much as any type of power source, wind power pits people who are concerned about the environment against, well, people who are concerned about the environment. Some people want the benefits of clean wind power but don't want the turbines in their vicinity.

Wind Energy

Energy from the Sun also creates wind, which can be used as wind power. The Sun heats different locations on Earth by different amounts. Air that becomes warm rises and then sucks cooler air into that spot. The movement of air from one spot to another along the ground creates wind. Since wind is moving, it has kinetic energy.

Wind power is the fastest growing renewable energy source in the world. Windmills are now seen in many locations, either individually or, more commonly, in large fields.

"Wind Powering America" follows the development of wind power in the United States over the past several years: http://www.windpoweringamerica.gov/wind_installed_capacity.asp.

Wind Power Use

Wind is the source of energy for wind power. Wind has been used for power for centuries. For example, windmills were used to grind grain and pump water. Sailing ships traveled by wind power long before ships were powered by fossil fuels. Wind can be used to generate electricity, as the moving air spins a turbine to create electricity (**Figure** 12.30).

FIGURE 12.30
Wind turbines like the ones shown above turn wind into electricity without creating pollution.

This animation shows how wind power works: http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501.

Consequences of Wind Power

Wind power has many advantages. It does not burn, so it does not release pollution or carbon dioxide. Also, wind is plentiful in many places. Wind, however, does not blow all of the time, even though power is needed all of the time. Just as with solar power, engineers are working on technologies that can store wind power for later use.

Windmills are expensive and wear out quickly. A lot of windmills are needed to power a region, so nearby residents may complain about the loss of a nice view if a wind farm is built. Coastlines typically receive a lot of wind, but wind farms built near beaches may cause unhappiness for local residents and tourists.

The Cape Wind project off of Cape Cod, Massachusetts has been approved but is generating much controversy. Opponents are in favor of green power but not at that location. Proponents say that clean energy is needed and the project would supply 75% of the electricity needed for Cape Cod and nearby islands (**Figure** 12.31).

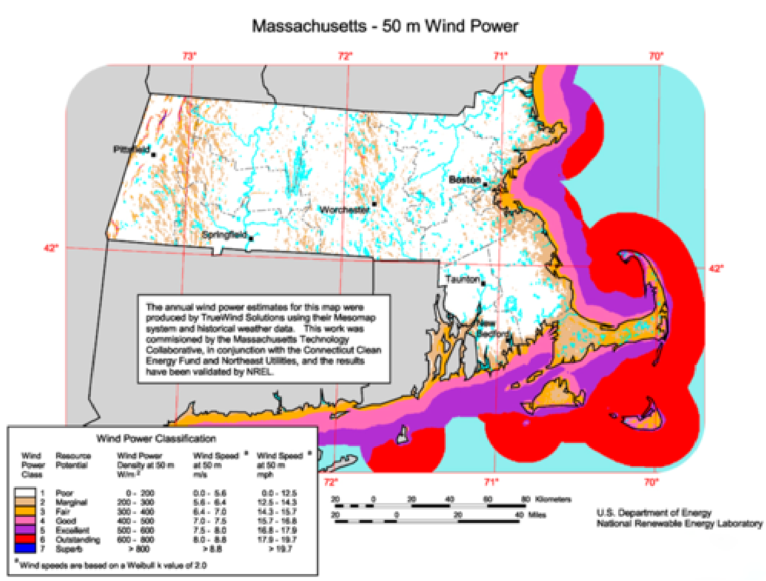


FIGURE 12.31
Cape Wind off of Cape Cod in Massachusetts receives a great deal of wind (red color) but is also popular with tourists for its beauty.

California was an early adopter of wind power. Windmills are found in mountain passes, where the cooler Pacific Ocean air is sucked through on its way to warmer inland valleys. Large fields of windmills can be seen at Altamont Pass in the eastern San Francisco Bay Area, San Gorgonio Pass east of Los Angeles, and Tehachapi Pass at the southern end of the San Joaquin Valley.

Summary

- Wind contains energy, which can move a turbine and generate electricity.
- Wind power is clean and does not release greenhouse gases, but some people complain about the spread of windmills across certain locations.
- Wind has been used as a local energy source for centuries and is now being scaled up for use regionally.

Practice

Use this resource to answer the questions that follow.

http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10501

1. How much has wind power production increased in the United States?
2. How do wind turbines work?
3. What is the wind vane for?
4. What does an anemometer measure?
5. What is the yaw drive for?
6. What is the wind potential in your state?
7. What are the advantages of an off grid system?
8. What are the advantages of wind farms?

Review

1. Describe what causes wind and how wind energy can be harnessed.
2. What are some of the downsides of using wind power?
3. Why do you think that wind is the fastest growing non-renewable energy source?

12.14 Geothermal Power

- Explain how geothermal energy is harnessed and used.

How could geothermal energy be used just about anywhere?

Geothermal energy comes from heat deep below the surface of the Earth. That heat may come to the surface naturally or it may be available through drilling. Nothing must be done to the geothermal energy. It is a resource that can be used without processing.

Geothermal Energy

The heat that is used for geothermal power may come to the surface naturally as hot springs or geysers, like The Geysers in northern California. Where water does not naturally come to the surface, engineers may pump cool water into the ground. The water is heated by the hot rock and then pumped back to the surface for use. The hot water or steam from a geothermal well spins a turbine to make electricity.

Geothermal energy is clean and safe. The energy source is renewable since hot rock is found everywhere in the Earth, although in many parts of the world the hot rock is not close enough to the surface for building geothermal power plants. In some areas, geothermal power is common (**Figure** 12.32).

In the United States, California is a leader in producing geothermal energy. The largest geothermal power plant in the state is in the Geysers Geothermal Resource Area in Napa and Sonoma Counties. The source of heat is thought to be a large magma chamber lying beneath the area.

FIGURE 12.32
A geothermal energy plant in Iceland. Iceland gets about one fourth of its electricity from geothermal sources.

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses.

Find out more at http://www.kqed.org/quest/television/geothermal-heats-up2.

MEDIA
Click image to the left for more content.

Summary

- Most geothermal energy being used now is in regions where hot material comes to the surface.
- Hot rocks are everywhere below Earth's surface so geothermal energy could be used anywhere with drilling.
- Geothermal energy is clean and does not release greenhouse gases.

Practice

Use this resource to answer the questions that follow.

http://www1.eere.energy.gov/geothermal/egs_animation.html

1. What is an enhanced geothermal system?
2. How is an appropriate site found?
3. What can occur where the fractures are created in the rock?
4. How is the heat extracted?
5. How can the system be expanded?
6. What is the future of geothermal energy?

Review

1. How is geothermal energy harnessed?

2. How would it be possible for a geothermal plant to gather energy if the hot material was not located at the surface?
3. Why is geothermal energy becoming more popular?

12.15 Energy from Biomass

- Explain how biomass energy is harnessed and used, and describe its consequences.

Why is algae better than corn for biofuel?

Algae is a better alternative for producing biofuel than traditional crops because crops could be used for other things, like feeding people.

Biomass

Biomass is the material that comes from plants and animals that were recently living. Biomass can be burned directly, such as setting fire to wood. For as long as humans have had fire, people have used biomass for heating and cooking. People can also process biomass to make fuel, called **biofuel**. Biofuel can be created from crops, such as corn or algae, and processed for use in a car (**Figure** 12.33). The advantage to biofuels is that they burn more cleanly than fossil fuels. As a result, they create less pollution and less carbon dioxide.

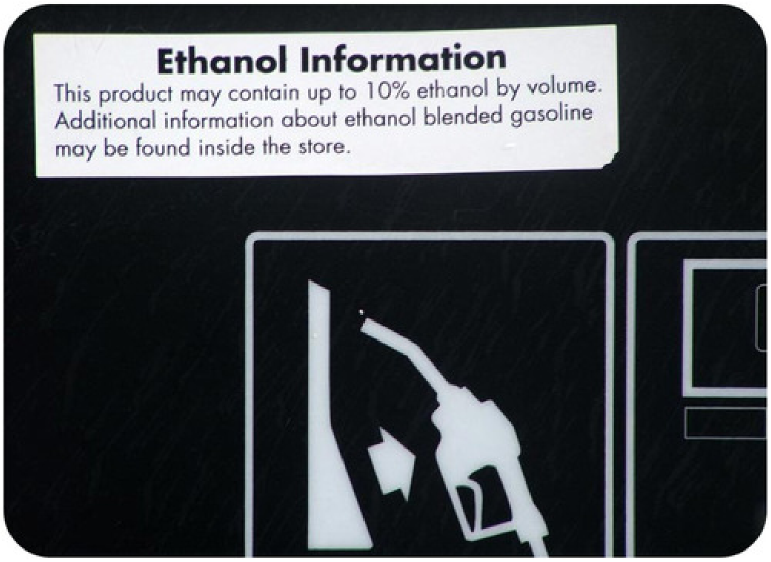


FIGURE 12.33
Biofuels, such as ethanol, are added to gasoline to cut down the amount of fossil fuels that are used.

Organic material, like almond shells, can be made into electricity. Biomass power is a great use of wastes and is more reliable than other renewable energy sources, but harvesting biomass energy uses energy and biomass plants produce pollutants including greenhouse gases.

Find out more at http://science.kqed.org/quest/audio/how-green-is-biomass-energy/.

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Cow manure can have a second life as a source of methane gas, which can be converted to electricity. Not only that food scraps can also be converted into green energy.

Find out more at http://science.kqed.org/quest/video/from-waste-to-watts-biofuel-bonanza/.

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Food that is tossed out produces methane, a potent greenhouse gas. But that methane from leftovers can be harnessed and used as fuel. Sounds like a win-win situation.

Find out more at http://science.kqed.org/quest/audio/power-up-with-leftovers/.

MEDIA
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Consequences of Biomass Use

In many instances, the amount of energy, fertilizer, and land needed to produce the crops used make biofuels mean that they often produce very little more energy than they consume. The fertilizers and pesticides used to grow the crops run off and become damaging pollutants in nearby water bodies or in the oceans.

To generate biomass energy, break down the cell walls of plants to release the sugars and then ferment those sugars to create fuel. Corn is a very inefficient source; scientists are looking for much better sources of biomass energy.

See more at http://www.kqed.org/quest/television/biofuels-beyond-ethanol.

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Algae Biofuels

Research is being done into alternative crops for biofuels. A very promising alternative is algae. Growing algae requires much less land and energy than crops. Algae can be grown in locations that are not used for other things, like in desert areas where other crops are not often grown. Algae can be fed agricultural and other waste so valuable resources are not used. Much research is being done to bring these alternative fuels to market. Many groups are researching the use of algae for fuel.

Many people think that the best source of biomass energy for the future is algae. Compared to corn, algae is not a food crop, it can grow in many places, it's much easier to convert to a usable fuel, and it's carbon neutral.

Find out more at http://science.kqed.org/quest/video/algae-power/.

MEDIA
Click image to the left for more content.

Vocabulary

- **biofuel**: A fuel made from living materials, usually crop plants.

Summary

- Biofuels are useful because they are liquid and can go into a gas tank unlike many other types of alternative energy.

- Algae is the focus of much research because it is a very promising alternative to traditional crops for biofuels.
- Biofuels have been used for as long as people have been burning wood for warmth or to cook their food.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. How much gas is produced from corn?
2. What was the Model T designed to run on?
3. Why are cell phones forbidden in the factory?
4. How much ethanol does the factory produce?
5. Is corn an efficient energy source? Explain your answer.

Review

1. What are the advantages of algae over other sources of biofuels?
2. Why are some crops, like corn, not necessarily a good source of biofuels?
3. How can an energy source produce very little energy more than the energy it takes to produce it?

12.16 Materials Humans Use

- Identify resources commonly consumed by human uses.

What resources are in those electronics?

Everyone may realize that we use resources like trees, copper, water, and gemstones, but how many of us realize the tremendous variety of elements we need to make a single electronic device? A tablet computer with a touch screen contains many common chemical elements and a variety of rare earth elements.

Common Materials We Use from the Earth

People depend on natural resources for just about everything that keeps us fed and sheltered, as well as for the things that keep us entertained. Every person in the United States uses about 20,000 kilograms (40,000 pounds) of minerals every year for a wide range of products, such as cell phones, TVs, jewelry, and cars. **Table** 12.3 shows some common objects, the materials they are made from, and whether they are renewable or nonrenewable.

TABLE 12.3: Common Objects We Use From the Earth

Common Object	Natural Resources Used	Are These Resources Renewable or Nonrenewable?
Cars	15 different metals, such as iron, lead, and chromium to make the body.	Nonrenewable
Jewelry	Precious metals like gold, silver, and platinum. Gems like diamonds, rubies, emeralds, turquoise.	Nonrenewable

TABLE 12.3: (continued)

Common Object	Natural Resources Used	Are These Resources Renewable or Nonrenewable?
Electronic Appliances (TV's, computers, DVD players, cell phones, etc.)	Many different metals, like copper, mercury, gold.	Nonrenewable
Clothing	Soil to grow fibers such as cotton. Sunlight for the plants to grow. Animals for fur and leather.	Renewable
Food	Soil to grow plants. Wildlife and agricultural animals.	Renewable
Bottled Water	Water from streams or springs. Petroleum products to make plastic bottles.	Nonrenewable and Renewable
Gasoline	Petroleum drilled from wells.	Nonrenewable
Household Electricity	Coal, natural gas, solar power, wind power, hydroelectric power.	Nonrenewable and Renewable
Paper	Trees; Sunlight Soil.	Renewable
Houses	Trees for timber. Rocks and minerals for construction materials, for example, granite, gravel, sand.	Nonrenewable and Renewable

Summary

- Many objects, such as a car, contain many types of resources.
- Resources may be renewable or nonrenewable, and an object may contain some of each.
- Rare earth elements and other unusual materials are used in some electronic devices.

Practice

Use this resource to answer the questions that follow.

http://www.bbc.co.uk/news/world-asia-pacific-13777439

1. What products require rare earth elements?

2. What is neodymium used for?

3. What is lanthanum used for?

4. What is praseodymium used for?

5, What is cerium used to produce?

6. What is gadolinium used in?

7. What country controls 97% of the rare earth elements?

8. What is the largest rare earth mine in the world?

9. Why are rare earth elements difficult to extract?

10. What type of mines are used to extract rare earth elements?

11. How many tons of rare earth elements did China export in 2010?

12. Why is China now limiting their exports?

Review

1. What resources are important to you that are renewable? Nonrenewable?
2. What resources do you use that you could use less or not use at all?
3. How might one of these resources go from being renewable to nonrenewable?

12.17 Finding and Mining Ores

- Describe how ore deposits are located, mined, and refined to become useful materials.

Why is the football team in San Francisco named the 49ers?

Football team names sometimes reflect the history of a region. The San Francisco 49ers are a reference to the California Gold Rush, when immigrants from around the United States came to what would become The Golden State to mine placer deposits. What that has to do with football is anyone's guess!

Ore Deposits

Some minerals are very useful. An **ore** is a rock that contains minerals with useful elements. Aluminum in bauxite ore (**Figure** 12.34) is extracted from the ground and refined to be used in aluminum foil and many other products. The cost of creating a product from a mineral depends on how abundant the mineral is and how much the extraction and refining processes cost. Environmental damage from these processes is often not figured into a product's cost. It is important to use mineral resources wisely.

Finding and Mining Minerals

Geologic processes create and concentrate minerals that are valuable natural resources. Geologists study geological formations and then test the physical and chemical properties of soil and rocks to locate possible ores and determine their size and concentration.

A mineral deposit will only be mined if it is profitable. A concentration of minerals is only called an **ore deposit** if it is profitable to mine. There are many ways to mine ores.

FIGURE 12.34
Aluminum is made from the aluminum-bearing minerals in bauxite.

Surface Mining

Surface mining allows extraction of ores that are close to Earth's surface. Overlying rock is blasted and the rock that contains the valuable minerals is placed in a truck and taken to a refinery. As pictured in **Figure** 12.35, surface mining includes open-pit mining and mountaintop removal. Other methods of surface mining include strip mining, placer mining, and dredging. Strip mining is like open pit mining but with material removed along a strip.

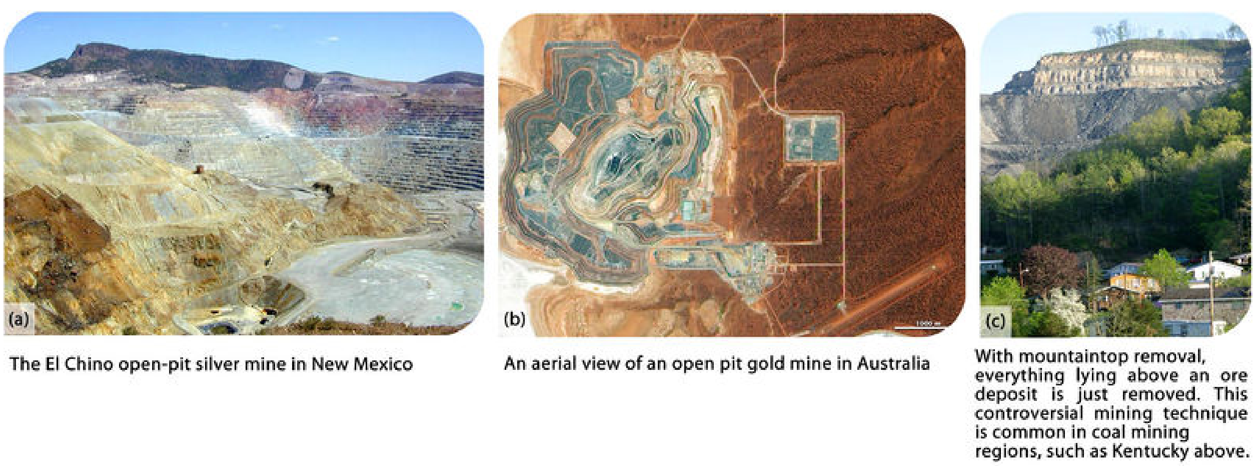

FIGURE 12.35
These different forms of surface mining are methods of extracting ores close to Earth's surface.

Placers are valuable minerals found in stream gravels. California's nickname, the Golden State, can be traced back to the discovery of placer deposits of gold in 1848. The gold weathered out of hard metamorphic rock in the western Sierra Nevada, which also contains deposits of copper, lead, zinc, silver, chromite, and other valuable minerals. The gold traveled down rivers and then settled in gravel deposits. Currently, California has active mines for gold and silver and for non-metal minerals such as sand and gravel, which are used for construction.

Underground Mining

Underground mining is used to recover ores that are deeper into Earth's surface. Miners blast and tunnel into rock to gain access to the ores. How underground mining is approached — from above, below, or sideways — depends on the placement of the ore body, its depth, the concentration of ore, and the strength of the surrounding rock.

Underground mining is very expensive and dangerous. Fresh air and lights must also be brought into the tunnels for the miners, and accidents are far too common.

FIGURE 12.36
Underground mine.

Ore Extraction

The ore's journey to becoming a useable material is only just beginning when the ore leaves the mine (**Figure** 12.37). Rocks are crushed so that the valuable minerals can be separated from the waste rock. Then the minerals are separated out of the ore. A few methods for extracting ore are:

- heap leaching: the addition of chemicals, such as cyanide or acid, to remove ore.
- flotation: the addition of a compound that attaches to the valuable mineral and floats.
- smelting: roasting rock, causing it to segregate into layers so the mineral can be extracted.

To extract the metal from the ore, the rock is melted at a temperature greater than 900^{o}C, which requires a lot of energy. Extracting metal from rock is so energy-intensive that if you recycle just 40 aluminum cans, you will save the energy equivalent of one gallon of gasoline.

Vocabulary

- **ore**: A type of rock that contains useful minerals.
- **ore deposit**: A mineral deposit that contains enough minerals to be mined for profit.
- **placer**: Valuable metal found in modern or ancient stream gravels.

FIGURE 12.37
Enormous trucks haul rock containing ore from a mine site to where the rock is processed.

FIGURE 12.38
A steel mill.

Summary

- An ore deposit must be profitable to mine by definition. If it is no longer profitable, it is no longer an ore deposit.
- Surface mines are created for mineral deposits that are near the surface; underground mines are blasted into rock to get at deeper deposits.
- Ore is extracted from rock by heap leaching, flotation or smelting.

Practice

Use this resource to answer the questions that follow.

MEDIA

Click image to the left for more content.

1. What is the Superpit?
2. How large is the Superpit?
3. How is gold extracted from this mine?
4. What is Australia's rank in gold mining?
5. What minerals is Australia the leading country for?

Review

1. What sorts of changes can transform a deposit that is an ore into a deposit that is not an ore?
2. Why is the production of the metal to create your aluminum soda can energy-intensive?
3. How is ore taken from a rock and made into a metal like a copper wire?

12.18 Availability of Natural Resources

- Explain how factors such as abundance, price, and politics influence the availability and cost of resources.

What is electronic waste?

We obtain resources of developing nations. We also dump waste on these nations. Many of our electronic wastes, which we think are being recycled, end up in developing countries. These are known as electronic waste or **e-waste**. People pick through the wastes looking for valuable materials that they can sell, but this exposes them to many toxic compounds that are hazardous to them and the environment.

Resource Availability

Supply

From the table in the previous lesson you can see that many of the resources we depend on are nonrenewable. Nonrenewable resources vary in their availability; some are very abundant and others are rare. Materials, such as gravel or sand, are technically nonrenewable, but they are so abundant that running out is no issue. Some resources are truly limited in quantity: when they are gone, they are gone, and something must be found that will replace them. There are even resources, such as diamonds and rubies, that are valuable in part because they are so rare.

Price

Besides abundance, a resource's value is determined by how easy it is to locate and extract. If a resource is difficult to use, it will not be used until the price for that resource becomes so great that it is worth paying for. For example, the oceans are filled with an abundant supply of water, but desalination is costly, so it is used only where water is really limited (**Figure** 12.39). As the cost of desalination plants comes down, more will likely be built.

FIGURE 12.39
Tampa Bay, Florida, has one of the few desalination plants in the United States.

Politics

Politics is also part of determining resource availability and cost. Nations that have a desired resource in abundance will often **export** that resource to other countries, while countries that need that resource must **import** it from one of the countries that produces it. This situation is a potential source of economic and political trouble.

Of course the greatest example of this is oil. 11 countries have nearly 80% of all of the world's oil (**Figure** 12.40). However, the biggest users of oil, the United States, China, and Japan, are all located outside this oil-rich region. This leads to a situation in which the availability and price of the oil is determined largely by one set of countries that have their own interests to look out for. The result has sometimes been war, which may have been attributed to all sorts of reasons, but at the bottom, the reason is oil.

Waste

The topic of overconsumption was touched on in Concept Life on Earth. Many people in developed countries, such as the United States and most of Europe, use many more natural resources than people in many other countries. We have many luxury and recreational items, and it is often cheaper for us to throw something away than to fix it or just hang on to it for a while longer. This consumerism leads to greater resource use, but it also leads to more waste. Pollution from discarded materials degrades the land, air, and water (**Figure** 12.41).

Natural resource use is generally lower in developing countries because people cannot afford many products. Some of these nations export natural resources to the developed world since their deposits may be richer and the cost of labor lower. Environmental regulations are often more lax, further lowering the cost of resource extraction.

Vocabulary

- **e-waste**: Nickname for electronic waste.
- **export**: To send a resource or product to another country.
- **import**: To receive a resource or product from another country.

Summary

- The availability of a resource depends on how much of it there is and how hard it is to extract, refine, and transport to where it is needed.

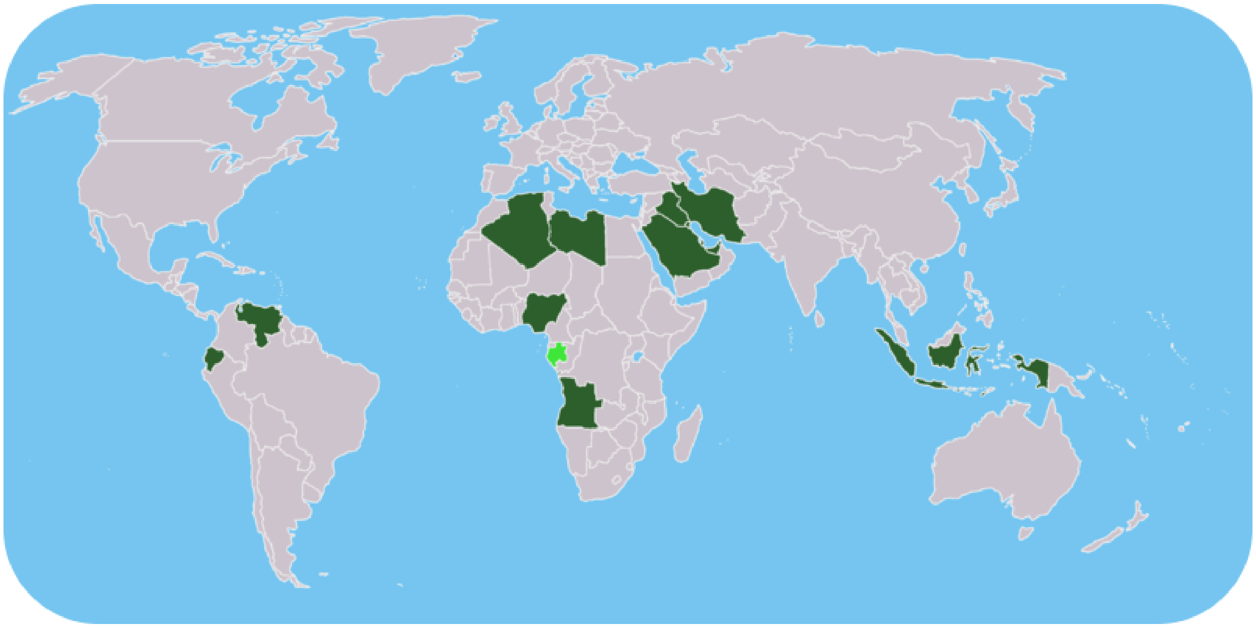

FIGURE 12.40
The nations in green are the 11 biggest producers of oil; they are Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

FIGURE 12.41
Pollution from discarded materials degrades the environment and reduces the availability of natural resources.

- Politics plays an important role in resource availability since an unfavorable political situation can make a resource unavailable to a nation.
- Increased resource use generally means more waste; electronic waste from developed nations is a growing problem in the developing world.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=0JZey9GJQP0

MEDIA

Click image to the left for more content.

1. Why are they melting computer circuit boards?
2. What toxic gases are given off?
3. What metals are they extracting from these computers?
4. What do CRTs contain?
5. What do computer batteries contain?
6. How can these chemicals harm people?
7. How much does recycling a computer cost in India?
8. What companies have committed to reducing the toxic chemicals in their products?

Review

1. Why does electronic waste that is generated in developed nations get dumped in developing nations?
2. Why is politics important in the availability of resources?
3. Why do some nations consume more goods and generate more waste than others?

12.19 Natural Resource Conservation

- Describe forms of natural resource conservation.
- Explain why natural resource conservation is important.

Can you make a difference?

Yes! You can conserve natural resources every day with every decision you make. Should you recycle that can? Yes! Should you buy a bottle of water or drink from the water fountain? Fountain! Should you walk or ride your bike to school or ask for a ride? Walk - it's good exercise too!

Conserving Natural Resources

So that people in developed nations maintain a good lifestyle and people in developing nations have the ability to improve their lifestyles, natural resources must be conserved and protected (**Figure** 12.42). People are researching ways to find renewable alternatives to non-renewable resources. Here is a checklist of ways to conserve resources:

- Buy less stuff (use items as long as you can, and ask yourself if you really need something new).
- Reduce excess packaging (drink tap water instead of water from plastic bottles).
- Recycle materials such as metal cans, old cell phones, and plastic bottles.

FIGURE 12.42
Recycling can help conserve natural resources.

- Purchase products made from recycled materials.
- Reduce pollution so that resources are maintained.
- Prevent soil erosion.
- Plant new trees to replace those that are cut down.
- Drive cars less, take public transportation, bicycle, or walk.
- Conserve energy at home (turn out lights when they are not needed).

Conserving natural resources are explored in a set of National Geographic videos found at http://video.nationalgeographic.com/video/environment/habitats-environment/rainforests. Search for these videos:

- "Mamirarua" is a sustainable development reserve that is protecting the Amazon
- "Vancouver Rain Forest" explores an alliance between conservationists and logging companies

Or find ways to go green from National Geographic Conservation in Action series: http://video.nationalgeographic.com/video/environment/going-green-environment/conservation-in-action

- "Sustainable Logging"
- The problem with plastic bags is discussed in "Edward Norton: Bag the Bag"
- Trying to mitigate problems caused by intensive logging in Ecuador while helping the people who live there improve their standards of living is in "Ecuador Conservation"

Summary

- To conserve natural resources it is important to use less resources or even eliminate the use of some resources.
- It is important to watch unintended consumption; e.g. with packaging.
- To reduce resource use, work on making some renewable: plant trees or use recycled products.

Practice

Use this resource to answer the questions that follow.

http://www.energyhog.org/childrens.htm

Play the game to answer these questions.

1. What are energy hogs?
2. List 3 ways to save energy in the living room.
3. List 3 ways you can conserve energy in the kitchen.
4. List 2 ways to save water in the bathroom.
5. List 2 ways to conserve energy in the bedroom.
6. How can energy be conserved in the attic?

Review

1. Why should you use renewable resources rather than nonrenewable resources when possible?
2. Why should you recycle materials when possible?
3. Why should you drink tap water or install a filter on your tap for filtered water?

Summary

Natural resources, including energy resources, may be renewable or non-renewable. Non-renewable resources will not be replaced faster than they can be used up; when they're gone, they're gone. Renewable resources can be replaced as rapidly or more rapidly than they are used, so they can supply human activities forever. Fossil fuels are very popular non-renewable resources. Cheap, abundant fossil fuels have been responsible for the development of modern human society due to their impact in transportation, industrialization and agriculture. Nuclear energy is also non-renewable because the necessary element uranium is limited. Renewable resources tend to be clean, with less or even no pollution or greenhouse gas emissions, but they come with their own problems. Some are relatively expensive, hard to develop, or difficult to find locations for. Increasing demand for renewable resources increases the research going into them, so the technologies are improving and becoming less expensive. Still, there are some problems that may not be resolved except on a case-by-case basis, such as the siting of wind farms. The best and cheapest way to increase resource availability is conservation, which can be done by an individual, a family, an industry or a society.

12.20 References

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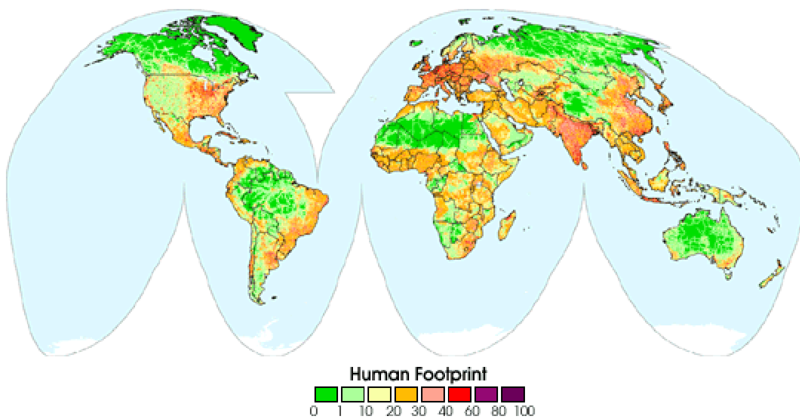
Chapter 13 Human Impacts on the Earth Environment

Chapter Outline

Introduction



Surely Earth is too big for humans to impact it too much...

Many people think that Earth is so large that human activities couldn't possibly be making much of an impact on the planet. But human populations have expanded at a more than exponential rate and it is human ingenuity from advances in farming that has kept so many people alive. The map above depicts a quantitative analysis of human influence around the world. Low scores are the least human influence; higher scores are greater impact. Taken into account were population density, land transformation, human access, and power infrastructure. Human access and land transformation alter ecosystems and bring in pollution and invasive species, which decrease biodiversity. This concept explores some of the impacts that humans have had on Earth's systems.

13.1 Growth of Human Populations

- Describe the rate of current human population growth.

What will stop population growth?

It took all of human history until 1802 for the human population to reach its first billion. It took just 12 years for it to acquire its most recent billion. Although the growth rate is predicted to slow later this century, there's no end to population growth in sight. Yet, the population can't continue to grow forever. How will it stop?

Human Population Numbers

Human population growth over the past 10,000 years has been tremendous (**Figure** 13.1). The entire human population was estimated to be

- 5 million in 8000 B.C.
- 300 million in A.D. 1
- 1 billion in 1802
- 3 billion in 1961
- 7 billion in 2011

As the human population continues to grow, different factors limit population in different parts of the world. What might be a limiting factor for human population in a particular location? Space, clean air, clean water, and food to feed everyone are limiting in some locations.

An interactive map of where human population growth has been over time: http://www.pbs.org/wgbh/nova/worldbalance/numbers.html.

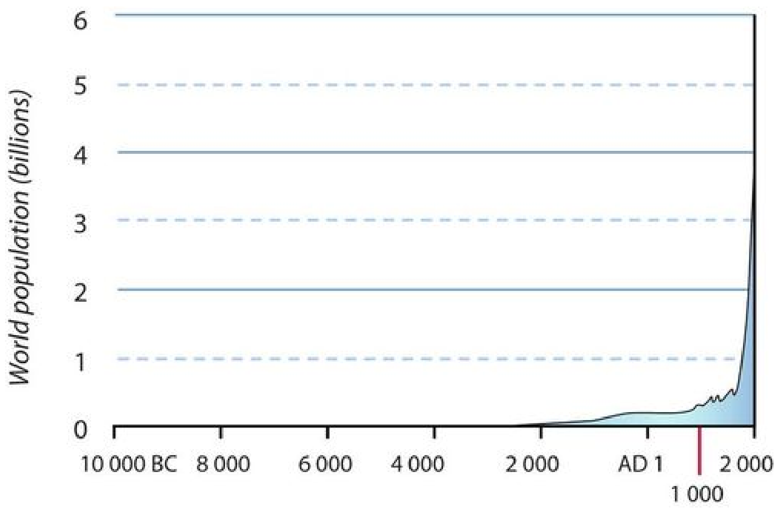


FIGURE 13.1
Human population from 10,000 BC through 2000 AD, showing the exponential increase in human population that has occurred in the last few centuries.

The Rate of Growth

Not only has the population increased, but the rate of population growth has increased (**Figure** 13.2). The population was estimated to reach 7 billion in 2012, but it did so in 2011, just 12 years after reaching 6 billion.

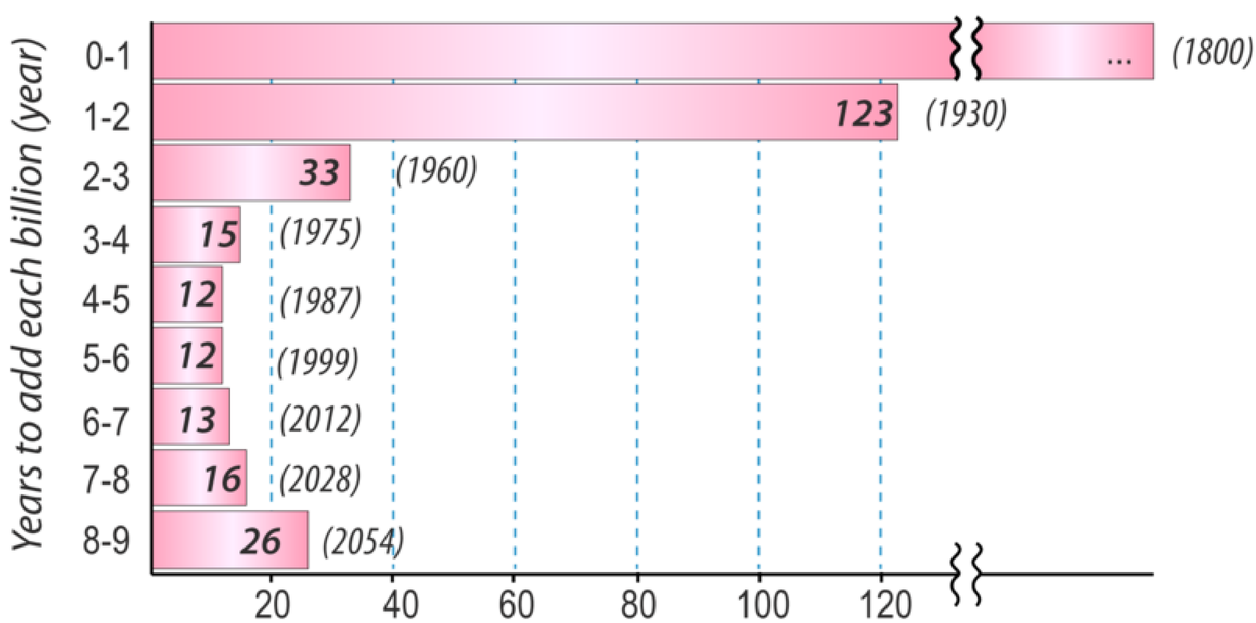


FIGURE 13.2
The amount of time between the addition of each one billion people to the planet's population, including speculation about the future.

Although population continues to grow rapidly, the rate that the growth rate is increasing has declined. Still, a recent estimate by the United Nations estimates that 10.1 billion people will be sharing this planet by the end of the century.

The total added will be about 3 billion people, which is more than were even in existence as recently as 1960.

Summary

- The human population is growing more than exponentially.
- The human population is increasing, the rate of human population growth is increasing, but the rate at which the rate of growth is increasing has declined.
- The United Nations estimates a population of 10.1 billion by the end of the century yet that is much less than the number we would expect if 1 billion people were being added every 12 years.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=sc4HxPxNrZ0

MEDIA

Click image to the left for more content.

1. What was the population in 1800?
2. What was the population in 1930?
3. What could the population be in 2045?
4. What is the average lifespan of people today?
5. What was the average lifespan of people in 1960?
6. What is a megacity?
7. How many megacities were there in 1975?
8. How many megacities are there now?
9. Explain what the world needs.
10. How much of the population lacks adequate sanitation?

Review

1. What does it mean that the human population growth rate is increasing?
2. What does it mean that the rate that the growth rate is increasing has declined?
3. What factors may someday limit human population growth?

13.2 Agriculture and Human Population Growth

- Explain how advances in agriculture have led to leaps in population numbers.

What's your vision of a chicken farm?

In many nations, farming today is industrial, growing the maximum amount of food for the minimum price, often without much thought as to the long-term social or environmental consequences. These industrial food production plants are a long way from the farms of the past.

Advances in Agriculture and Population

Every major advance in agriculture has allowed global population to increase. Early farmers could settle down to a steady food supply. Irrigation, the ability to clear large swaths of land for farming efficiently, and the development of farm machines powered by fossil fuels allowed people to grow more food and transport it to where it was needed.

Hunters and Gatherers

What is Earth's carrying capacity for humans? Are humans now exceeding Earth's carrying capacity for our species? Many anthropologists say that the carrying capacity of humans on the planet without agriculture is about 10 million (**Figure** 13.3). This population was reached about 10,000 years ago. At the time, people lived together in small bands of hunters and gatherers. Typically men hunted and fished; women gathered nuts and vegetables.

Obviously, human populations have blown past this hypothetical carrying capacity. By using our brains, our erect posture, and our hands, we have been able to manipulate our environment in ways that no other species has ever done. What have been the important developments that have allowed population to grow?

FIGURE 13.3
In a hunter-gatherer society, people relied on the resources they could find where they lived.

Farming

About 10,000 years ago, we developed the ability to grow our own food. Farming increased the yield of food plants and allowed people to have food available year round. Animals were domesticated to provide meat. With agriculture, people could settle down, so that they no longer needed to carry all their possessions (**Figure** 13.4). They could develop better farming practices and store food for when it was difficult to grow. Agriculture allowed people to settle in towns and cities.

When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** 13.5), some people were then able to do other types of work, such as crafts or shop keeping.

The Industrial Revolution

The next major stage in the growth of the human population was the **Industrial Revolution**, which started in the late 1700s (**Figure** 13.6). This major historical event marks when products were first mass-produced and when fossil fuels were first widely used for power.

The Green Revolution

The **Green Revolution** has allowed the addition of billions of people to the population in the past few decades. The Green Revolution has improved agricultural productivity by:

- Improving crops by selecting for traits that promote productivity; recently, genetically engineered crops have been introduced.
- Increasing the use of artificial fertilizers and chemical **pesticides**. About 23 times more fertilizer and 50 times more pesticides are used around the world than were used just 50 years ago (**Figure** 13.7).
- Agricultural machinery: plowing, tilling, fertilizing, picking, and transporting are all done by machines. About 17% of the energy used each year in the United States is for agriculture.

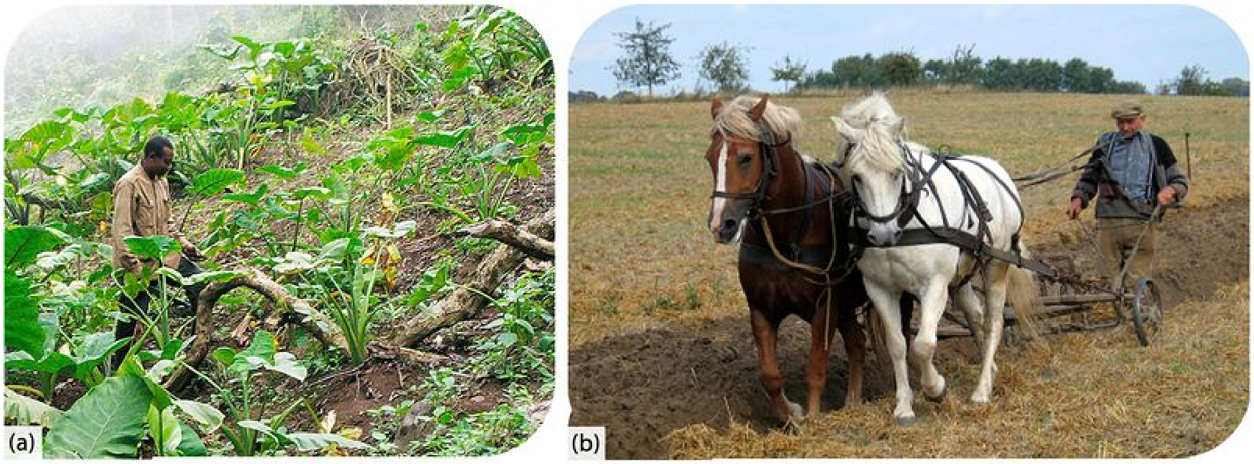


FIGURE 13.4

(a) Like early farmers, subsistence farmers today grow only enough food for their families, with perhaps a bit extra to sell, barter, or trade. (b) More advanced farming practices allowed a single farmer to grow food for many more people.

FIGURE 13.5

Farming has increasingly depended on machines. Such advanced farming practices allow one farmer to feed many more people than in the past.

- Increasing access to water. Many farming regions depend on groundwater, which is not a renewable resource. Some regions will eventually run out of this water source. Currently about 70% of the world's fresh water is used for agriculture.

The Green Revolution has increased the productivity of farms immensely. A century ago, a single farmer produced enough food for 2.5 people, but now a farmer can feed more than 130 people. The Green Revolution is credited for feeding 1 billion people that would not otherwise have been able to live.

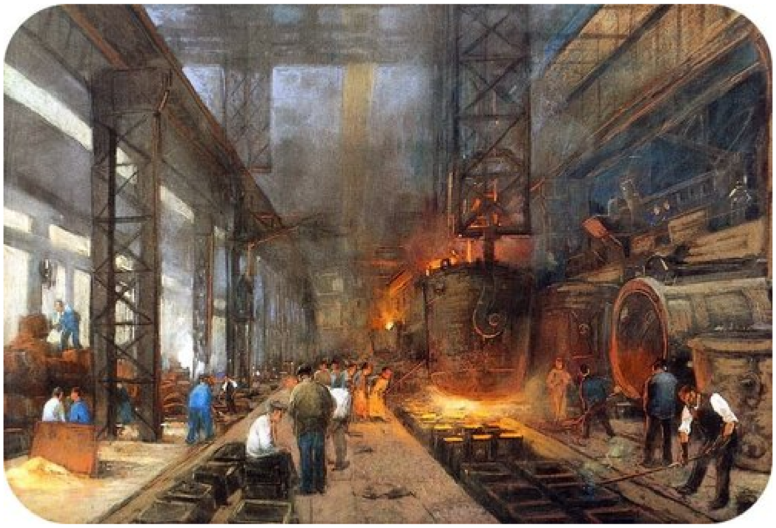


FIGURE 13.6
Early in the Industrial Revolution, large numbers of people who had been freed from food production were available to work in factories.

FIGURE 13.7
Rows of a single crop and heavy machinery are normal sights for modern day farms.

The Future

The flip side to this is that for the population to continue to grow, more advances in agriculture and an ever increasing supply of water will be needed. We've increased the carrying capacity for humans by our genius: growing crops, trading for needed materials, and designing ways to exploit resources that are difficult to get at, such as groundwater. And most of these resources are limited.

The question is, even though we have increased the carrying capacity of the planet, have we now exceeded it (**Figure** 13.8)? Are humans on Earth experiencing **overpopulation**?

There is not yet an answer to that question, but there are many different opinions. In the eighteenth century, Thomas Malthus predicted that human population would continue to grow until we had exhausted our resources. At that point, humans would become victims of famine, disease, or war. This has not happened, at least not yet. Some scientists think that the carrying capacity of the planet is about 1 billion people, not the 7 billion people we have today. The limiting factors have changed as our intelligence has allowed us to expand our population. Can we continue to do this indefinitely into the future?

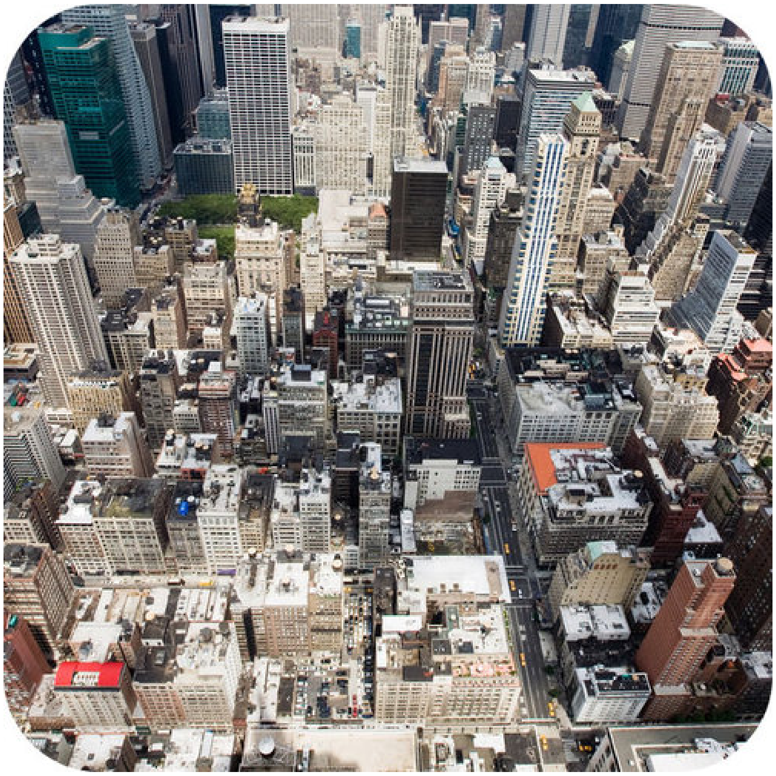


FIGURE 13.8
Manhattan is one of the most heavily populated regions in the world.

Vocabulary

- **Green Revolution**: Changes in the way food is produced since World War II that have resulted in enormous increases in production.
- **Industrial Revolution**: A time when mass production and fossil fuel use started to grow explosively.
- **overpopulation**: When the population of an area exceeds its carrying capacity or when long-term harm is done to resource availability or the environment.
- **pesticides**: A chemical that kills a certain pest that would otherwise eat or harm plants that humans want to grow.

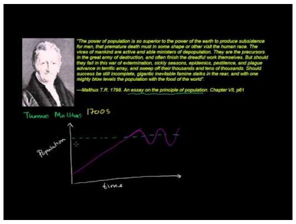
Summary

- Hunters and gatherers lived off the land, with no agriculture, and reached a total population of no more than around 10 million.
- Farming allowed people to settle down and allowed populations to grow.
- The Green Revolution and the Industrial Revolution are heavily dependent on fossil fuels.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=r1ywppAJ1xs



MEDIA

Click image to the left for more content.

1. Who was Thomas Malthus?
2. What did Malthus think would happen as population increased?
3. What did Malthus think would limit population?
4. What is the Malthusian limit?
5. What is happening to population growth in some developed countries today?
6. Malthus didn't account for what in his theory?
7. What country is close to the Malthusian limit today?

Review

1. Link major advances in agriculture and industry with changes in the human population.
2. What is carrying capacity? Has the human population exceeded Earth's carrying capacity for humans? If so, how could this have happened?
3. What is the Green Revolution? How has it affected human population?
4. What do you think of Thomas Malthus' prediction? Have we proven Malthus wrong or have we just not gotten to that point yet?

13.3 Overpopulation and Over-Consumption

- Describe the consequences of the Green Revolution on Earth's systems.
- Define over-consumption and explain its impact on Earth's systems.

How many people could live in this house?

The amount of space and resources used by each resident of this house far exceeds the average for a single person on Earth and even more for a person in a poor country in sub-Saharan Africa.

Consequences of the Green Revolution

The Green Revolution has brought enormous impacts to the planet.

Land Loss

Natural landscapes have been altered to create farmland and cities. Already, half of the ice-free lands have been converted to human uses. Estimates are that by 2030, that number will be more than 70%. Forests and other landscapes have been cleared for farming or urban areas. Rivers have been dammed and the water is transported by canals for irrigation and domestic uses. Ecologically sensitive areas have been altered: wetlands are now drained and coastlines are developed.

Pollution

Modern agricultural practices produce a lot of pollution (**Figure** 13.9). Some pesticides are toxic. Dead zones grow as fertilizers drain off farmland and introduce nutrients into lakes and coastal areas. Farm machines and vehicles used to transport crops produce air pollutants. Pollutants enter the air, water, or are spilled onto the land. Moreover, many types of pollution easily move between air, water, and land. As a result, no location or organism — not even polar bears in the remote Arctic — is free from pollution.

FIGURE 13.9
Pesticides are hazardous in large quantities and some are toxic in small quantities.

Consequences for Other Resources

The increased numbers of people have other impacts on the planet. Humans do not just need food. They also need clean water, secure shelter, and a safe place for their wastes. These needs are met to different degrees in different nations and among different socioeconomic classes of people. For example, about 1.2 billion of the world's people do not have enough clean water for drinking and washing each day (**Figure** 13.10).

Over-Consumption

The addition of more people has not just resulted in more poor people. A large percentage of people expect much more than to have their basic needs met. For about one-quarter of people there is an abundance of food, plenty of water, and a secure home. Comfortable temperatures are made possible by heating and cooling systems, rapid transportation is available by motor vehicles or a well-developed public transportation system, instant communication takes place by phones and email, and many other luxuries are available that were not even dreamed of only a few

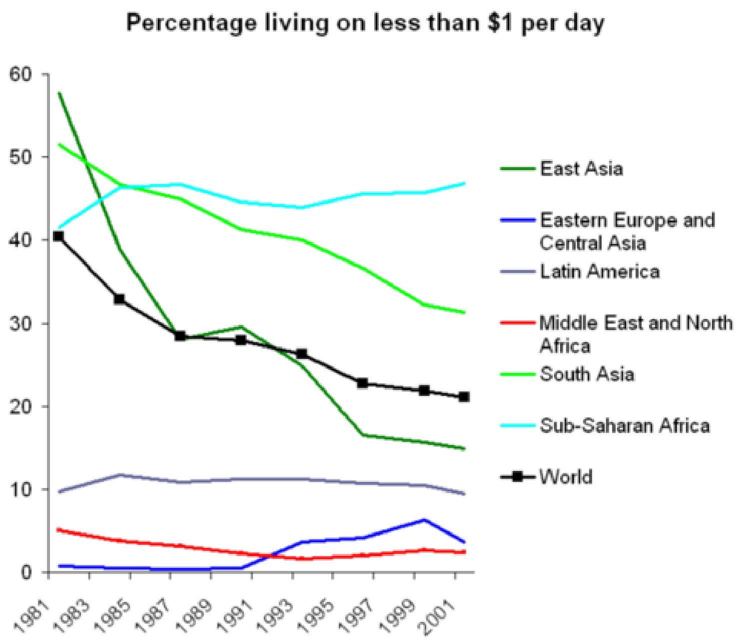


FIGURE 13.10

The percentage of people in the world that live in abject poverty is decreasing somewhat globally, but increasing in some regions, such as Sub-Saharan Africa.

decades ago. All of these require resources in order to be produced, and fossil fuels in order to be powered (**Figure** 13.11). Their production, use, and disposal all produce wastes.

Many people refer to the abundance of luxury items in these people's lives as **over-consumption**. People in developed nations use 32 times more resources than people in the developing countries of the world.

Vocabulary

- **over-consumption**: Resource use that is unsustainable in the long term; obtaining many more products than people need.

Summary

- The Green Revolution has allowed more people to be fed and the human population to increase. The consequences are land loss, pollution, and a tremendous use of fossil fuels.
- By keeping more people alive, the Green Revolution has put a strain on other needed resources like water and materials.
- Overpopulation is a big problem, but over-consumption is also depleting Earth's resources as some people in the world use far more materials than others.

Practice

Use these resources to answer the questions that follow.

http://www.nationalgeographic.com/eye/ozone/ozone.html

1. What happened in London in 1952?

2. What are the air pollutants?

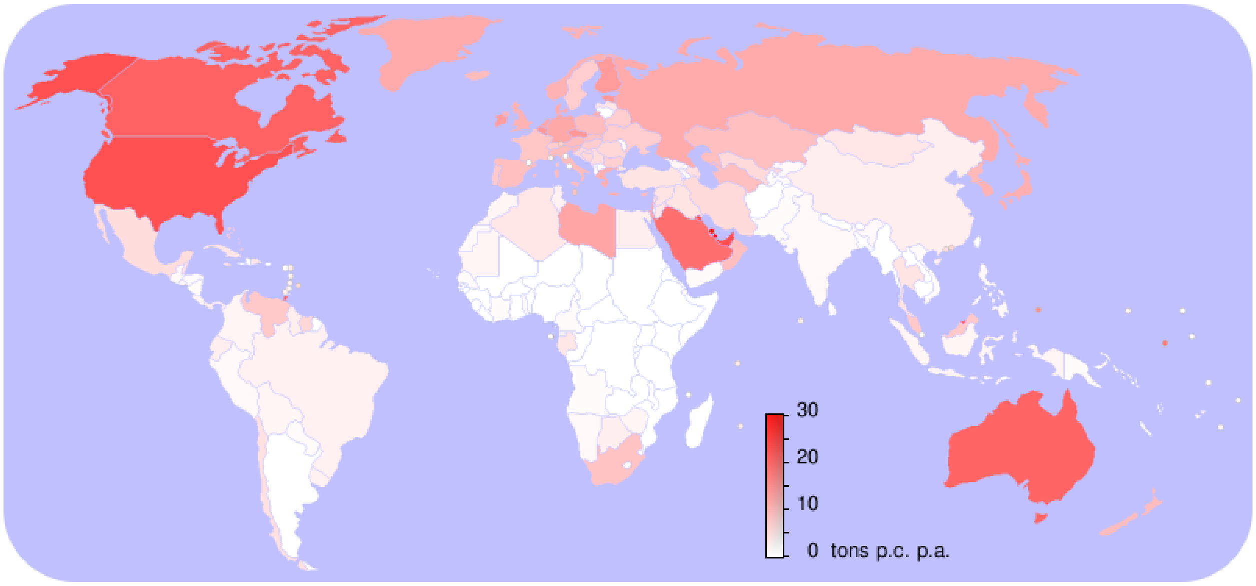


FIGURE 13.11

Since CO_2 is a waste product from fossil fuel burning, CO_2 emissions tell which countries are using the most fossil fuels, which means that the population has a high standard of living.

3. What problems does acid rain cause?
4. How much of the emissions come from transportation?
5. What is ozone?
6. What is affecting the ozone?

http://www.nationalgeographic.com/eye/deforestation/deforestation.html

7. How much of the Earth's forests have been destroyed?
8. Why might deforestation have devastating effects globally?
9. What is the Sahel and what happened to it?
10. Why is desertification called a runaway phenomenon?
11. What are the solutions for deforestation and desertification?

http://www.nationalgeographic.com/eye/overpopulation/overpopulation.html

12. Which areas have the highest population growth?
13. Why does the United States have positive population growth?
14. What has happened to population in Asia and Africa since 1960?
15. What can be done to help with the population growth?

Review

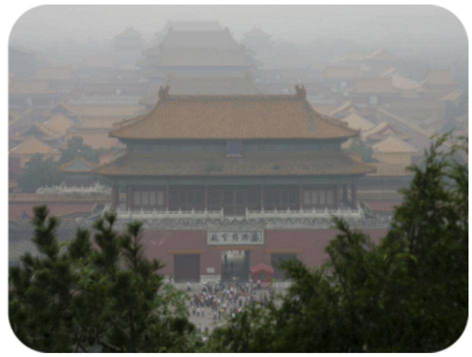
1. Why has so much natural land been converted to human uses? What happens to the ecosystems that are affected?

2. What causes pollution and why is it so widespread?

3. What do you use in your daily life that would be inconceivable for a poor teenager in sub-Saharan Africa? What about contrasting yourself with a poor teen living in an urban ghetto in the U.S.?

13.4 Sustainable Development

- Define sustainable development.
- Describe forms of sustainable development and explain how they conserve energy and natural resources.



Is there another way?

Visibility in Beijing is sometimes so bad that the airport must be closed due to smog. In their rush to develop, many nations are making the same mistakes that the developed nations have already made. Can everyone find a more sustainable path?

Sustainable Development

FIGURE 13.12

A topic generating a great deal of discussion these days is **sustainable development**. The goals of sustainable development are to:

- help people out of poverty.
- protect the environment.

- use resources no faster than the rate at which they are regenerated.

One of the most important steps to achieving a more sustainable future is to reduce human population growth. This has been happening in recent years. Studies have shown that the birth rate decreases as women become educated, because educated women tend to have fewer, and healthier, children.

Science can be an important part of sustainable development. When scientists understand how Earth's natural systems work, they can recognize how people are impacting them. Scientists can work to develop technologies that can be used to solve problems wisely. An example of a practice that can aid sustainable development is fish farming, as long as it is done in environmentally sound ways. Engineers can develop cleaner energy sources to reduce pollution and greenhouse gas emissions.

Citizens can change their behavior to reduce the impact they have on the planet by demanding products that are produced sustainably. When forests are logged, new trees should be planted. Mining should be done so that the landscape is not destroyed. People can consume less and think more about the impacts of what they do consume.

And what of the waste products of society? Will producing all that we need to keep the population growing result in a planet so polluted that the quality of life will be greatly diminished (**Figure ??**)? Will warming temperatures cause problems for human populations? The only answer to all of these questions is, time will tell.

Vocabulary

- **sustainable development**: Economic development that helps people out of poverty, use resources at a rate at which they can be replaced, and protects the environment.

Summary

- Sustainable development tries to bring people up to certain minimum living conditions without doing further damage to the environment.
- To develop sustainably, the human population must stabilize.
- Resources must be developed and used consciously and in environmentally sound ways.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=eEFwaQej_0E

MEDIA

Click image to the left for more content.

1. Explain sustainable development.
2. How can we achieve sustainable development?
3. What are renewable energy sources?
4. What are fossil fuels?
5. Why didn't the United States sign the Kyoto treaty?

6. List examples of renewable energy sources.

7. What can we do to reduce our carbon footprint?

8, How can we reduce the demand for fossil fuels?

Review

1. Why does the status of women help decrease population growth?

2. What is sustainable development? Do you think that it be achieved in your lifetime?

3. How can environmental protections be enacted and people be helped out of poverty at the same time? Are those goals conflicting?

13.5 Soil Pollution

- Explain how human activities cause soil erosion.

What would cause such a tremendous dust storm?

Farmers were forced off their lands during the Dust Bowl in the 1930s when the rains stopped and the topsoil blew off these former grasslands. A wind storm blew huge amounts of soil into the air in Texas on April 14, 1935. This scene was repeated throughout the central United States.

Causes of Soil Erosion

The agents of soil erosion are the same as the agents of all types of erosion: water, wind, ice, or gravity. Running water is the leading cause of soil erosion, because water is abundant and has a lot of power. Wind is also a leading cause of soil erosion because wind can pick up soil and blow it far away.

Activities that remove vegetation, disturb the ground, or allow the ground to dry are activities that increase erosion. What are some human activities that increase the likelihood that soil will be eroded?

Farming

Agriculture is probably the most significant activity that accelerates soil erosion because of the amount of land that is farmed and how much farming practices disturb the ground (**Figure** 13.13). Farmers remove native vegetation and then plow the land to plant new seeds. Because most crops grow only in spring and summer, the land lies fallow during the winter. Of course, winter is also the stormy season in many locations, so wind and rain are available to wash soil away. Tractor tires make deep grooves, which are natural pathways for water. Fine soil is blown away by wind.

The soil that is most likely to erode is the nutrient-rich topsoil, which degrades the farmland.

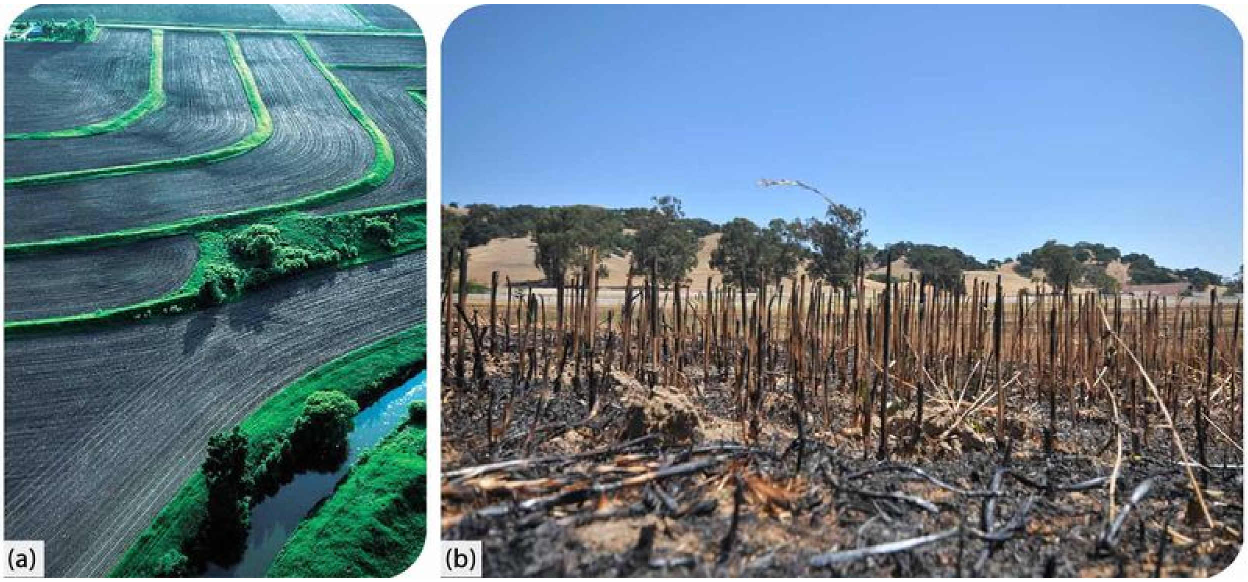


FIGURE 13.13

(a) The bare areas of farmland are especially vulnerable to erosion. (b) Slash-and-burn agriculture leaves land open for soil erosion and is one of the leading causes of soil erosion in the world.

Grazing

Grazing animals (**Figure** 13.14) wander over large areas of pasture or natural grasslands eating grasses and shrubs. Grazers expose soil by removing the plant cover for an area. They also churn up the ground with their hooves. If too many animals graze the same land area, the animals' hooves pull plants out by their roots. A land is overgrazed if too many animals are living there.

FIGURE 13.14

Grazing animals can cause erosion if they are allowed to overgraze and remove too much or all of the vegetation in a pasture.

Logging and Mining

Logging removes trees that protect the ground from soil erosion. The tree roots hold the soil together and the tree canopy protects the soil from hard falling rain. Logging results in the loss of **leaf litter**, or dead leaves, bark, and branches on the forest floor. Leaf litter plays an important role in protecting forest soils from erosion (**Figure** 13.15).

FIGURE 13.15
Logging exposes large areas of land to erosion.

Much of the world's original forests have been logged. Many of the tropical forests that remain are currently the site of logging because North America and Europe have already harvested many of their trees (**Figure** 13.16). Soils eroded from logged forests clog rivers and lakes, fill estuaries, and bury coral reefs.

Surface mining disturbs the land (**Figure** 13.17) and leaves the soil vulnerable to erosion.

Construction

Constructing buildings and roads churns up the ground and exposes soil to erosion. In some locations, native landscapes, such as forest and grassland, are cleared, exposing the surface to erosion (in some locations the land that will be built on is farmland). Near construction sites, dirt, picked up by the wind, is often in the air. Completed construction can also contribute to erosion (**Figure** 13.18).

Recreational Activities

Recreational activities may accelerate soil erosion. Off-road vehicles disturb the landscape and the area eventually develops bare spots where no plants can grow. In some delicate habitats, even hikers' boots can disturb the ground, so it's important to stay on the trail (**Figure** 13.19).

Soil erosion is as natural as any other type of erosion, but human activities have greatly accelerated soil erosion. In some locations soil erosion may occur about 10 times faster than its natural rate. Since Europeans settled in North America, about one-third of the topsoil in the area that is now the United States has eroded away.

FIGURE 13.16

Deforested swatches in Brazil show up as gray amid the bright red tropical rainforest.

FIGURE 13.17

(a) Disturbed land at a coal mine pit in Germany. (b) This coal mine in West Virginia covers more than 10,000 acres (15.6 square miles). Some of the exposed ground is being reclaimed by planting trees.

Vocabulary

- **leaf litter**: Dead leaves, branches, bark, and other plant parts that accumulate on the floor of a forest.

FIGURE 13.18
Urban areas and parking lots result in less water entering the ground. Water runs off the parking lot onto nearby lands and speeds up erosion in those areas.

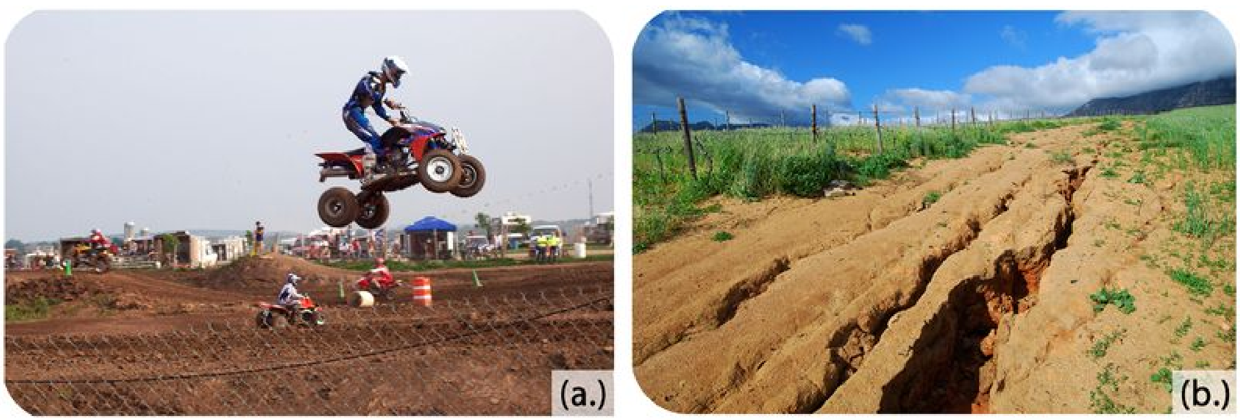


FIGURE 13.19
(a) ATV'S churn up the soil, accelerating erosion. (b) Hiking trails may become eroded.

Summary

- Although soil erosion is a natural process, human activities have greatly accelerated it.
- The agents of soil erosion are the same as of other types of erosion: water, ice, wind, and gravity.
- Soil erosion is more likely where the ground has been disturbed by agriculture, grazing animals, logging, mining, construction, and recreational activities.

Practice

Use this resource to answer the questions that follow.

http://www.scalloway.org.uk/phye6.htm

1. What is soil erosion?
2. Where is soil erosion common?
3. How can soil erosion be reduced?
4. What are good farming techniques?
5. What are some natural causes for soil erosion?

Review

1. What is soil erosion? Why did soil erosion accelerate so greatly during the Dust Bowl?
2. How do human activities accelerate soil erosion? Since soil erosion is a natural process, is this bad?
3. What is the consequence of the acceleration of soil erosion?

13.6 Avoiding Soil Loss

- Describe steps that can be taken to minimize soil loss.

How does the terracing shown in this photo prevent soil erosion?

Terracing keeps the soil from moving very far downhill since it will only get as far as the next terrace downhill. Water will also be slowed by the terraces and so will be less able to carry tremendous amounts of soil downhill. Terracing is a great way to preserve soil when farming is being done on hillsides.

Soil Erosion

Bad farming practices and a return to normal rainfall levels after an unusually wet period led to the Dust Bowl. In some regions more than 75% of the topsoil blew away. This is the most extreme example of soil erosion the United States has ever seen.

Still, in many areas of the world, the rate of soil erosion is many times greater than the rate at which it is forming. Drought, insect plagues, or outbreaks of disease are natural cycles of events that can negatively impact ecosystems and the soil, but there are also many ways in which humans neglect or abuse this important resource. Soils can also be contaminated if too much salt accumulates in the soil or where pollutants sink into the ground.

One harmful practice is removing the vegetation that helps to hold soil in place. Sometimes just walking or riding your bike over the same place will kill the grass that normally grows there. Land is also deliberately cleared or deforested for wood. The loose soils then may be carried away by wind or running water.

Soil Conservation

Soil is only a renewable resource if it is carefully managed. There are many practices that can protect and preserve soil resources.

FIGURE 13.20
A farmer and his sons walk through a dust storm in Cimarron County, Oklahoma in 1936.

Organic Material

Adding organic material to the soil in the form of plant or animal waste, such as compost or manure, increases the fertility of the soil and improves its ability to hold on to water and nutrients (**Figure** 13.21). Inorganic fertilizer can also temporarily increase the fertility of a soil and may be less expensive or time consuming, but it does not provide the same long-term improvements as organic materials.

Preventing Soil Erosion

Soil is a natural resource that is vitally important for sustaining natural habitats and for growing food. Although soil is a renewable resource, it is renewed slowly, taking hundreds or thousands of years for a good fertile soil to develop.

Most of the best land for farming is already being cultivated. With human populations continuing to grow, it is extremely important to protect our soil resources. Agricultural practices such as rotating crops, alternating the types of crops planted in each row, and planting nutrient-rich cover crops all help to keep soil more fertile as it is used season after season. Planting trees as windbreaks, plowing along contours of the field, or building terraces into steeper slopes will all help to hold soil in place (**Figure** 13.22). No-till or low-tillage farming helps to keep soil in place by disturbing the ground as little as possible when planting.

The rate of topsoil loss in the United States and other developed countries has decreased recently as better farming practices have been adopted. Unfortunately, in developing nations, soil is often not protected.

Table 13.1 shows some steps that we can take to prevent erosion. Some are things that can be done by farmers or developers. Others are things that individual homeowners or community members can implement locally.

TABLE 13.1: (continued)

Source of Erosion	Strategies for Prevention

TABLE 13.1: **Erosion**

Source of Erosion	Strategies for Prevention
Agriculture	Leave leaf litter on the ground in the winter. Grow cover crops, special crops grown in the winter to cover the soil. Plant tall trees around fields to buffer the effects of wind. Drive tractors as little as possible. Use drip irrigation that puts small amounts of water in the ground frequently. Avoid watering crops with sprinklers that make big water drops on the ground. Keep fields as flat as possible to avoid soil eroding down hill.
Grazing Animals	Move animals throughout the year, so they don't consume all the vegetation in one spot. Keep animals away from stream banks, where hills are especially prone to erosion.
Logging and Mining	Reduce the amount of land that is logged and mined. Reduce the number of roads that are built to access logging areas. Avoid logging and mining on steep lands. Cut only small areas at one time and quickly replant logged areas with new seedlings.
Development	Reduce the amount of land area that is developed into urban areas, parking lots, etc. Keep as much "green space" in cities as possible, such as parks or strips where plants can grow. Invest in and use new technologies for parking lots that make them permeable to water in order to reduce runoff of water.
Recreational Activities	Avoid using off-road vehicles on hilly lands. Stay on designated trails.
Building Construction	Avoid building on steep hills. Grade surrounding land to distribute water rather than collecting it in one place. Where water collects, drain to creeks and rivers. Landscape with plants that minimize erosion.

Summary

- Soil is a renewable resource, but sometimes it is lost faster than it can be replaced.
- Soil resources must be preserved because there are many more people on Earth who need to eat and a great deal of topsoil has already been lost in many regions.
- There are many techniques available for preventing soil loss in agriculture, grazing, logging, mining, and recreation.

FIGURE 13.21
Organic material can be added to soil to help increase its fertility.

FIGURE 13.22
Steep slopes can be terraced to make level planting areas and decrease surface water runoff and erosion.

- Soil conservation is extremely important. Some helpful practices include adding organic material, terracing, and no-till farming.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Erosion Control**

1. Describe contour farming.

2. What is terracing?
3. How does strip cropping work?
4. What is agroforestry?
5. How does tree litter help crops?

Review

1. Why is it so important for strategies that prevent soil erosion to be understood and used?
2. Which agricultural techniques are better that preserving soils?
3. How do recreational activities exacerbate soil erosion and how can this be lessened?
4. Why does the addition of organic material to soil help with its conservation?
5. What are a few agricultural practices that make conserving soil a priority?

13.7 Hazardous Waste

- Define hazardous waste.
- Explain how hazardous wastes negatively affect humans and the environment.

Are these hazardous wastes safely stored?

Hazardous wastes must be stored, used and disposed of properly. Some wastes are extremely corrosive and can get through steel drums over time. How can we be sure that hazardous wastes are actually stored safely for the time necessary?

What is Hazardous Waste?

Hazardous waste is any waste material that is dangerous to human health or that degrades the environment. Hazardous waste includes substances that are:

1. Toxic: causes serious harm or death, or is poisonous.

2. Chemically active: causes dangerous or unwanted chemical reactions, such as explosions.

3. Corrosive: destroys other things by chemical reactions.

4. Flammable: easily catches fire and may send dangerous smoke into the air.

All sorts of materials are hazardous wastes and there are many sources. Many people have substances that could become hazardous wastes in their homes. Several cleaning and gardening chemicals are hazardous if not used properly. These include chemicals like drain cleaners and pesticides that are toxic to humans and many other creatures. While these chemicals are fine if they are stored and used properly, if they are used or disposed of improperly, they may become hazardous wastes. Others sources of hazardous waste are shown in **Table** 13.2.

TABLE 13.2: Hazardous Waste

Type of Hazardous Waste	Example	Why it is Hazardous
Chemicals from the automobile industry	Gasoline, used motor oil, battery acid, brake fluid	Toxic to humans and other organisms; often chemically active; often flammable.
Batteries	Car batteries, household batteries	Contain toxic chemicals; are often corrosive.
Medical wastes	Surgical gloves, wastes contaminated with body fluids such as blood, x-ray equipment	Toxic to humans and other organisms; may be chemically active.
Paints	Paints, paint thinners, paint strippers, wood stains	Toxic; flammable.
Dry cleaning chemicals	Many various chemicals	Toxic; many cause cancer in humans.
Agricultural chemicals	Pesticides, herbicides, fertilizers	Toxic to humans; can harm other organism; pollute soils and water.

Summary

- Hazardous waste is material that is toxic, chemically active, corrosive, or flammable.
- Hazardous wastes are damaging to the environment or human health.
- Hazardous materials are found in a variety of settings, including industry, agriculture, and people's homes.

Practice

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/garbage/hazardous.html

1. What is hazardous waste?
2. How many hazardous wastes does the EPA recognize?
3. What household products can be recycled?
4. What household items should be disposed of as hazardous waste?
5. What household items can be put in the trash?
6. Can anything be washed down the drain?

Review

1. If pesticides are toxic, why do we spray them on food crops?
2. Why are some medical wastes hazardous?
3. What is hazardous waste? Is it always clear whether something is hazardous or not?

13.8 Impacts of Hazardous Waste

- Describe the impacts of hazardous waste on humans and the environment.
- Trace how these impacts led to the Superfund Act.

What role do citizens play in protecting their environment?

Sometimes it's up to the residents in an area to recognize the effects of hazardous waste and to get the government to find the responsible party and initiate cleanup. Here, a resident of Love Canal protests the hazardous waste contamination in her neighborhood.

Love Canal

The story of Love Canal, New York, begins in the 1950s, when a local chemical company placed hazardous wastes in 55-gallon steel drums and buried them. Love Canal was an abandoned waterway near Niagara Falls and was thought to be a safe site for hazardous waste disposal because the ground was fairly impermeable (**Figure** 13.23). After burial, the company covered the containers with soil and sold the land to the local school system for $1. The company warned the school district that the site had been used for toxic waste disposal.

FIGURE 13.23
Steel drums were used to contain 21,000 tons of hazardous chemicals at Love Canal.

Soon a school, a playground, and 100 homes were built on the site. The impermeable ground was breached when sewer systems were dug into the rock layer. Over time, the steel drums rusted and the chemicals were released into the ground. In the 1960s people began to notice bad odors. Children developed burns after playing in the soil, and they were often sick. In 1977 a swamp created by heavy rains was found to contain 82 toxic chemicals, including 11 suspected cancer-causing chemicals.

A Love Canal resident, Lois Gibbs, organized a group of citizens called the Love Canal Homeowners Association to try to find out what was causing the problems (See opening image). When they discovered that toxic chemicals were buried beneath their homes and school, they demanded that the government take action to clean up the area and remove the chemicals.

A video of Lois Gibbs describing the origin of the Love Canal problem: http://www.youtube.com/watch?v=PrzqFPego4A.

Superfund Act

In 1978, people were relocated to safe areas. The problem of Love Canal was instrumental in the passage of the the **Superfund Act** in 1980. This law requires companies to be responsible for hazardous chemicals that they put into the environment and to pay to clean up polluted sites, which can often cost hundreds of millions of dollars. Love Canal became a **Superfund site** in 1983 and as a result, several measures were taken to secure the toxic wastes. The land was capped so that water could not reach the waste, debris was cleaned from the nearby area, and contaminated soils were removed.

Impacts of Hazardous Waste

The pollution at Love Canal was not initially visible, but it became visible. The health effects from the waste were also not initially visible, but they became clearly visible. The effects of the contamination that were seen in human health included sickness in children and a higher than normal number of miscarriages in pregnant women. Toxic chemicals may cause cancer and birth defects. Why do you think children and fetuses are more susceptible? Because young organisms grow more rapidly, they take in more of the toxic chemicals and are more affected.

Cancer Clusters

Sometimes the chemicals are not so easily seen as they were at Love Canal. But the impacts can be seen statistically. For example, contaminated drinking water may cause an increase in some types of cancer in a community.

Why is one person with cancer not enough to suspect contamination by toxic waste? One is not a statistically valid number. A certain number of people get cancer all the time. To identify contamination, a number of cancers above the normal rate, called a cancer cluster, must be discovered. A case that was made into a book and movie called *A Civil Action* involved the community of Woburn, Massachusetts. Groundwater contamination was initially suspected because of an increase in childhood leukemia and other illnesses. As a result of concern by parents, the well water was analyzed and shown to have high levels of TCE (trichloroethylene).

Toxic Metals

Lead and mercury are two chemicals that are especially toxic to humans. Lead was once a common ingredient in gasoline and paint, but it was shown to damage human brains and nervous systems. Since young children are growing rapidly, lead is especially harmful in children under the age of six (**Figure** 13.24). In the 1970s and 1980s, the United States government passed laws completely banning lead in gasoline and paint. Homes built before the 1970s may contain lead paint. Paint so old is likely to be peeling and poses a great threat to human health. About 200 children die every year from lead poisoning.

FIGURE 13.24

(a) Leaded gasoline. (b) Leaded paint.

Mercury is a pollutant that can easily spread around the world. Sources of mercury include volcanic eruptions, coal burning, and wastes such as batteries, electronic switches, and electronic appliances such as television sets. Like lead, mercury damages the brain and impairs nervous system function. More about the hazards of mercury pollution can be found later in this concept.

Vocabulary

- **Superfund Act**: A law passed by the U.S. Congress in 1980 that held companies responsible for any hazardous chemicals that they might create.
- **Superfund site**: A site where hazardous waste has been spilled. Under the Superfund Act, the company that created the hazardous waste is responsible for cleaning up the waste.

Summary

- The Superfund Act of 1980 requires that companies safely dispose of hazardous chemicals they generate and clean up sites they pollute.
- The effects of hazardous wastes on human populations include miscarriages, birth defects, brain damage, and cancer, particularly in children.
- An individual may develop a disease, like cancer, but when the number of cases of the disease exceeds what is found in other areas, it is cause for concern.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=vKIM9sE0t6I

MEDIA

Click image to the left for more content.

1. Where is the Love Canal?
2. What disaster occurred there?
3. What was the Love Canal supposed to do? Why wasn't it completed?
4. What chemical company acquired the canal? How did they use the area?
5. How much waste was dumped into the canal?
6. Who purchased the canal from the chemical company? What was built on top of the canal?
7. What did the residents living adjacent to the canal notice?

http://www.youtube.com/watch?v=MXSE9kcBQCI

MEDIA

Click image to the left for more content.

8. What problems did the winter of 1977 cause?
9. What is dioxin?
10. What was the Love Canal declared?
11. What health problems could the chemicals found in the Love Canal cause?
12. How was the Love Canal cleaned up?

Review

1. If waste is to remain hazardous for a long period of time, how can society protect itself from problems as occurred at Love Canal?
2. What is the Superfund Act and how did Love Canal lead to it?
3. What is a cancer cluster? What should be done if one is found?

13.9 Preventing Hazardous Waste Problems

- Explain how to prevent pollution by hazardous wastes.

What should be done about hazardous waste sites?

Cleaning up toxic wastes has incredible costs in time and money. Laws now protect lands from contamination, but many sites were damaged before those laws were passed. No other organization is big enough, so it is the government's job to clean up a toxic site if the company that caused the damage no longer exists or cannot afford cleanup.

Preventing Hazardous Waste Pollution

Nations that have more industry produce more hazardous waste. Currently, the United States is the world's largest producer of hazardous wastes, but China, which produces so many products for the developed world, may soon take over the number-one spot.

Countries with more industry produce more hazardous wastes than those with little industry. Problems with hazardous wastes and their disposal became obvious sooner in the developed world than in the developing world. As a result, many developed nations, including the United States, have laws to help control hazardous waste disposal and to clean toxic sites.

As mentioned in the "Impacts of Hazardous Waste" lesson, the Superfund Act requires companies to clean up contaminated sites that are designated as Superfund sites (**Figure** 13.25). If a responsible party cannot be identified, because the company has gone out of business or its culpability cannot be proven, the federal government pays for the cleanup out of a trust fund with money put aside by the petroleum and chemical industries. As a result of the Superfund Act, companies today are more careful about how they deal with hazardous substances.

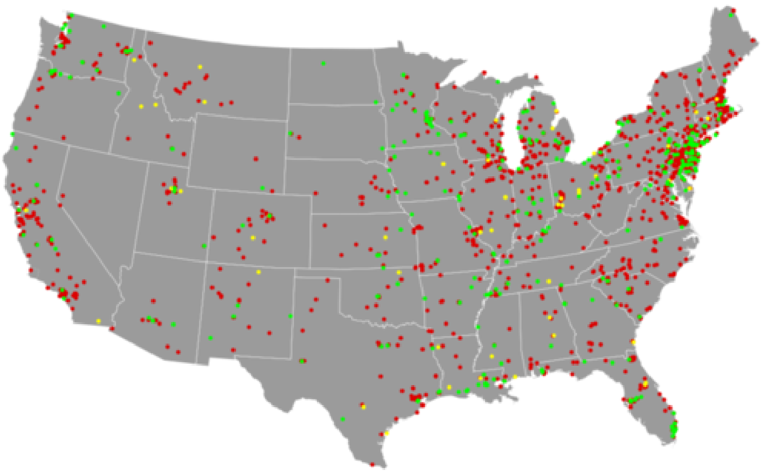


FIGURE 13.25
Superfund sites are located all over the nation and many are waiting to be cleaned up.

The Resource Conservation and Recovery Act of 1976 requires that companies keep track of any hazardous materials they produce. These materials must be disposed of using government guidelines and records must be kept to show the government that the wastes were disposed of safely. Workers must be protected from the hazardous materials.

To some extent, individuals can control the production and disposal of hazardous wastes. We can choose to use materials that are not hazardous, such as using vinegar as a cleanser. At home, people can control the amount of pesticides that they use (or they can use organic methods of pest control). It is also necessary to dispose of hazardous materials properly by not pouring them over the land, down the drain or toilet, or into a sewer or trashcan.

Summary

- Government regulations, like the Superfund Act, hold companies accountable for the hazardous materials they produce.
- Developed nations have seen the consequences of hazardous waste and are more likely to have protections in place than developing countries.
- People can lessen the hazardous waste problem by using materials that are not hazardous or by disposing of wastes properly.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is the Los Angeles South Bay region known for?
2. What are superfunds?
3. Who stored the oil underground in this region?
4. What is the problem at the site?

5. What do citizens need to do?
6. What has occurred at the Del Amo Facility recently?
7. What happened in March 2011?

Review

1. How do the Superfund Act and other government regulations prevent lands from being contaminated?
2. What can you do to prevent or lessen the generation of hazardous wastes?
3. Why does the United States have so many Superfund sites compared with other nations?

13.10 Environmental Impacts of Mining

- Describe the environmental costs of mining.

How much does your mp3 player really cost?

Many of the things we want come partly from minerals. But making minerals useful often causes environmental damage.

Mining and the Environment

Although mining provides people with many needed resources, the environmental costs can be high. Surface mining clears the landscape of trees and soil, and nearby streams and lakes are inundated with sediment. Pollutants from the mined rock, such as heavy metals, enter the sediment and water system. Acids flow from some mine sites, changing the composition of nearby waterways (**Figure** 13.26).

U.S. law has changed in recent decades so that a mine region must be restored to its natural state, a process called **reclamation**. This is not true of older mines. Pits may be refilled or reshaped and vegetation planted. Pits may be

FIGURE 13.26
Acid drainage from a surface coal mine in Missouri.

allowed to fill with water and become lakes or may be turned into landfills. Underground mines may be sealed off or left open as homes for bats.

Vocabulary

- **reclamation**: Restoring an altered property, such as one that has been mined, to its previous state.

Summary

- Surface mining clears the land, completely destroying the ecosystems that were found there.
- Mining releases pollutants, which affect the immediate area and may travel downstream or downwind to cause problems elsewhere.
- Reclamation occurs when people attempt to return the mined land to its original state.

Practice

Use this resource to answer the questions that follow.

http://news.discovery.com/videos/earth-scientists-seek-ban-on-mountaintop-mining.html

MEDIA
Click image to the left for more content.

1. What is mountaintop mining?
2. What are the advantages to mountaintop mining?
3. What damage does this type of mining do to the environment?
4. What are companies required to do about the damage?
5. What is the government's current position on mountaintop mining?

Review

1. What damage may be caused by mining?
2. Why is sediment considered a problem in mined areas?
3. If lands altered by mining in recent decades must be reclaimed, what happens to lands that were mined prior to that law?

13.11 Uses of Water

- Describe how humans use water in a variety of ways.

What do you use water for?

Drinking, of course. Bathing, naturally. But what else? Growing food, producing goods, recreation, maintaining healthy ecosystems: all require lots and lots of water.

Water Consumption

Humans use six times as much water today as they did 100 years ago. People living in developed countries use a far greater proportion of the world's water than people in less developed countries. What do people use all of that water for?

Human Uses of Water

Besides drinking and washing, people need water for agriculture, industry, household uses, and recreation (**Figure** 13.27). Recreational use and environmental use average 1% each.

Water use can be consumptive or non-consumptive, depending on whether the water is lost to the ecosystem.

- **Non-consumptive** water use includes water that can be recycled and reused. For example, the water that goes down the drain and enters the sewer system is purified and then redistributed for reuse. By recycling water, the overall water consumption is reduced.
- **Consumptive** water use takes the water out of the ecosystem. Can you name some examples of consumptive water use?

Agriculture

Some of the world's farmers still farm without irrigation by choosing crops that match the amount of rain that falls in their area. But some years are wet and others are dry. For farmers to avoid years in which they produce little or

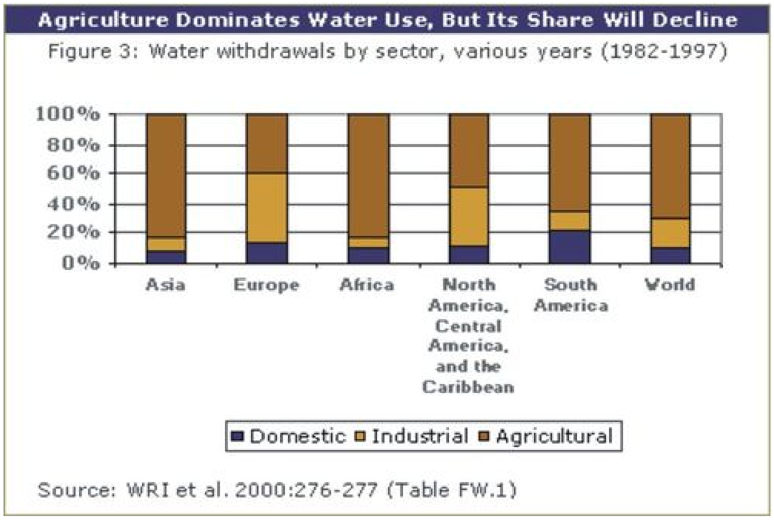


FIGURE 13.27
Water used for home, industrial, and agricultural purposes in different regions. Globally more than two-thirds of water is for agriculture.

no food, many of the world's crops are produced using irrigation.

Wasteful Methods

Three popular irrigation methods are:

- Overhead sprinklers.
- Trench irrigation: canals carry water from a water source to the fields.
- Flood irrigation: fields are flooded with water.

All of these methods waste water. Between 15% and 36% percent of the water never reaches the crops because it evaporates or leaves the fields as runoff. Water that runs off a field often takes valuable soil with it.

Non-wasteful Methods

A much more efficient way to water crops is **drip irrigation** (**Figure** 13.28). With drip irrigation, pipes and tubes deliver small amounts of water directly to the soil at the roots of each plant or tree. The water is not sprayed into the air or over the ground, so nearly all of it goes directly into the soil and plant roots.

Why Not Change?

Why do farmers use wasteful irrigation methods when water-efficient methods are available? Many farmers and farming corporations have not switched to more efficient irrigation methods for two reasons:

1. Drip irrigation and other more efficient irrigation methods are more expensive than sprinklers, trenches, and flooding.

2. In the United States and some other countries, the government pays for much of the cost of the water that is used for agriculture. Because farmers do not pay the full cost of their water use, they do not have any financial incentive to use less water.

What ideas can you come up with to encourage farmers to use more efficient irrigation systems?

FIGURE 13.28
Drip irrigation delivers water to the base of each plant so little is lost to evaporation and runoff.

Aquaculture

Aquaculture is a different type of agriculture. Aquaculture is farming to raise fish, shellfish, algae, or aquatic plants (**Figure** 13.29). As the supplies of fish from lakes, rivers, and the oceans dwindle, people are getting more fish from aquaculture. Raising fish increases our food resources and is especially valuable where protein sources are limited. Farmed fish are becoming increasingly common in grocery stores all over the world.

Growing fish in a large scale requires that the fish stocks are healthy and protected from predators. The species raised must be hearty, inexpensive to feed, and able to reproduce in captivity. Wastes must be flushed out to keep animals healthy. Raising shellfish at farms can also be successful.

Aquaculture Problems

For some species, aquaculture is very successful and environmental harm is minimal. But for other species, aquaculture can cause problems. Natural landscapes, such as mangroves, which are rich ecosystems and also protect coastlines from storm damage, may be lost to fish farms (**Figure** 13.30). For fish farmers, keeping costs down may be a problem since coastal land may be expensive and labor costs may be high. Large predatory fish at the 4th or 5th trophic level must eat a lot, so feeding large numbers of these fish is expensive and environmentally costly. Farmed fish are genetically different from wild stocks, and if they escape into the wild they may cause problems for native fish. Because the organisms live so close together, parasites are common and may also escape into the wild.

Industrial Water Use

Industrial water use accounts for an estimated 15% of worldwide water use, with a much greater percentage in developed nations. Industrial uses of water include power plants that use water to cool their equipment and oil refineries that use water for chemical processes. Manufacturing is also water intensive.

Household Use

Think about all the ways you use water in a day. You need to count the water you drink, cook with, bathe in, garden with, let run down the drain, or flush down the toilet. In developed countries, people use a lot of water, while in less

FIGURE 13.29
Workers at a fish farm harvest fish they will sell to stores.

March 6, 2006 (Terra ASTER)

FIGURE 13.30
Shrimp farms on the coast of Ecuador are shown as blue rectangles. Mangrove forests, salt flats, and salt marshes have been converted to shrimp farms.

developed countries people use much less. Globally, household or personal water use is estimated to account for 15% of world-wide water use.

Some household water uses are non-consumptive, because water is recaptured in sewer systems, treated, and returned to surface water supplies for reuse. Many things can be done to lower water consumption at home.

- Convert lawns and gardens to drip-irrigation systems.
- Install low-flow shower heads and low-flow toilets.

In what other ways can you use less water at home?

Recreational Use

People love water for swimming, fishing, boating, river rafting, and other activates. Even activities such as golf, where there may not be any standing water, require plenty of water to make the grass on the course green. Despite its value, the amount of water that most recreational activities use is low: less than 1% of all the water we use.

Many recreational water uses are non-consumptive including swimming, fishing, and boating. Golf courses are the biggest recreational water consumer since they require large amounts for irrigation, especially because many courses are located in warm, sunny, desert regions where water is scarce and evaporation is high.

This National Geographic video chronicles the conflict between conserving the Yangtze River for recreational uses versus damming it for the clean energy China needs so badly: http://video.nationalgeographic.com/video/player/environment/energy-environment/energy-conservation.html.

Environmental Use

Environmental use of water includes creating wildlife habitat. Lakes are built to create places for fish and water birds (**Figure** 13.31). Most environmental uses are non-consumptive and account for an even smaller percentage of water use than recreational uses. A shortage of this water is a leading cause of global biodiversity loss.

FIGURE 13.31
Wetlands and other environments depend on clean water to survive.

Vocabulary

- **aquaculture**: Agriculture of the sea; farmed fish, seafood and aquatic plants.

- **consumptive water use**: Water use in which the water is lost to the ecosystem.
- **drip irrigation**: Pipes and tubes that deliver small amounts of water directly to the soil at the roots of plants.
- **non-consumptive water use**: Water use that recycles and does not use up the water supply.

Summary

- Consumptive water use takes water out of the ecosystem; non-consumptive water use includes water that can be recycled and reused.
- People can use less water by having efficient systems for water use and by reusing and recycling water where possible.
- Some water must remain in the environment for recreational use for humans and to support ecosystems.

Practice

Use these resources to answer the questions that follow.

http://ga.water.usgs.gov/edu/sq3.html

1. How much water is used in an average bath?

2. How much water is used in a 10 minute shower?

3. How much water is used to flush the toilet?

http://ga.water.usgs.gov/edu/sq2.html

4. What is the water distribution for your state?

http://ga.water.usgs.gov/edu/sc1.html

5. How much water does it take to produce bread?

6. How much water does it take to make a hamburger?

Review

1. Why do people use so much more water than they used to?

2. Why don't localities and people use water in the most efficient way, rather than sometimes in wasteful ways?

3. What is aquaculture and why is it going to be increasingly important in the future?

13.12 Water Distribution

- Describe how water is distributed across the globe.
- Explain the causes and consequences of water scarcity.

Will water cause the next war?

Wars have been fought over oil, but many people predict that the next war will be fought over water. Certainly, water is becoming scarcer.

Water Distribution

Water is unevenly distributed around the world. Large portions of the world, such as much of northern Africa, receive very little water relative to their population (**Figure** 13.32). The map shows the relationship between water supply and population by river basin.

Over time, there will be less water per person within many river basins as the population grows and global temperatures increase so that some water sources are lost. In 2025, many nations, even developed nations, are projected to have less water per person than now (**Figure** 13.33).

Water Shortages

Water scarcity is a problem now and will become an even larger problem in the future as water sources are reduced or polluted and population grows. In 1995, about 40% of the world's population faced water scarcity (**Figure** 13.34). Scientists estimate that by the year 2025, nearly half of the world's people won't have enough water to meet their daily needs. Nearly one-quarter of the world's people will have less than 500 m^3 of water to use in an entire year. That amount is less water in a year than some people in the United States use in one day.

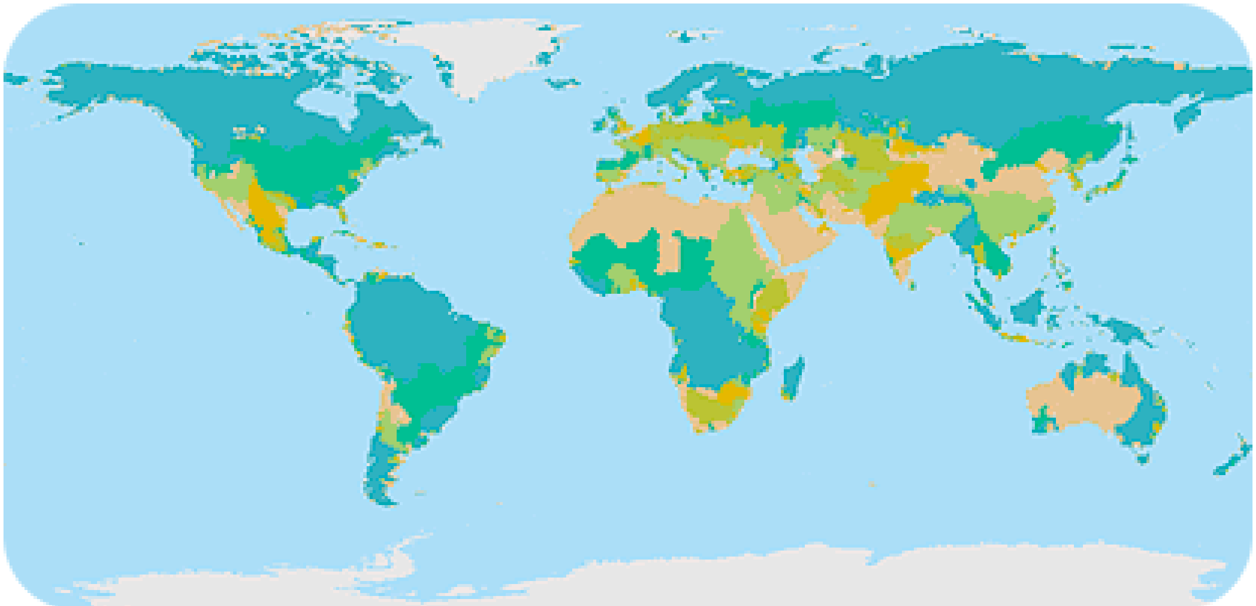


FIGURE 13.32

Blue means there is a lot of river water for each person who lives in the river basin. Salmon pink means there is very little river water for each person who lives in the river basin.

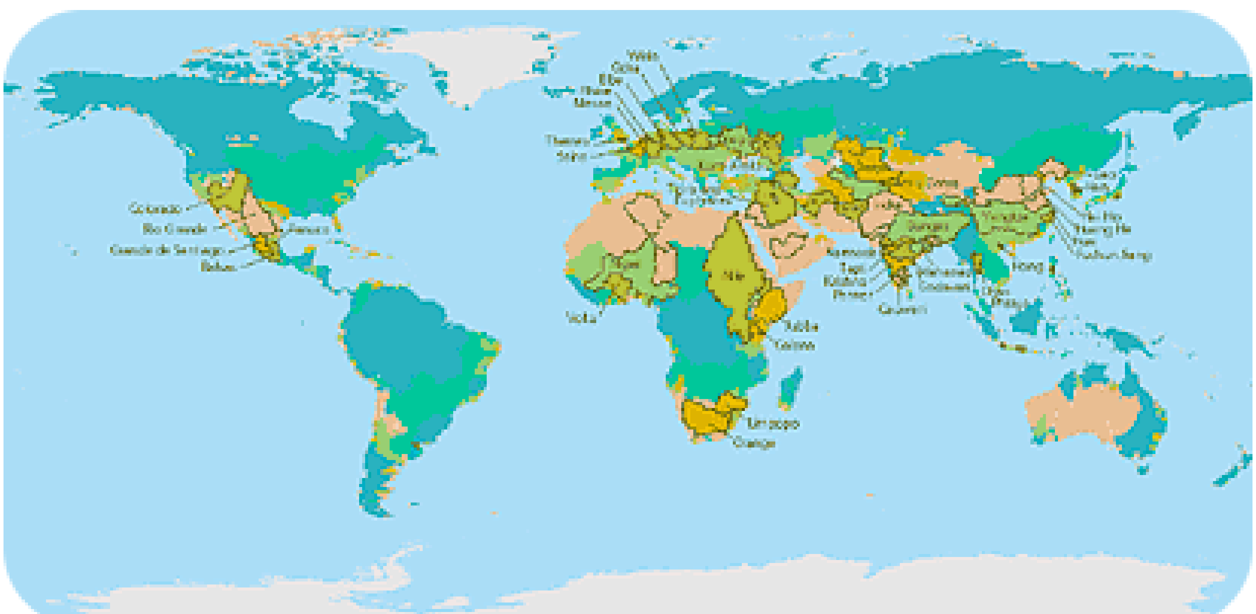


FIGURE 13.33

The same map but projected into 2025.

Nearly Half the World Will Live With Water Scarcity by 2025

Figure 2: Global Renewable Water Supply per Person, 1995 and 2025 (projected)

Water Supply (m3/person /year)	1995 Population (millions)	1995 Percent of Total	2025 Population (millions)	2025 Percent of Total
<500	1,077	19.0	1,783	24.5
500-1,000	587	10.4	624	8.6
1,000-1,700	669	11.8	1,077	14.8
Subtotal	2,333	41.2	3,484	47.9
>1,700	3,091	54.6	3,494	48.0
Unallocated	241	4.2	296	4.0
Total	5,665	100.0	7,274	100.0

Source: WRI. The 2025 estimates are considered conservative because they are based on the United Nations' low-range projections for population growth, which has population peaking at 7.3 billion in 2025 (UNDP 1999:3). In addition, a slight mismatch between the water runoff and population data sets leaves 4 percent of the global population unaccounted in this analysis.

FIGURE 13.34
Water supply compared to population.

Droughts

Droughts occur when a region experiences unusually low precipitation for months or years (**Figure** 13.35). Periods of drought may create or worsen water shortages.

Human activities can contribute to the frequency and duration of droughts. For example, deforestation keeps trees from returning water to the atmosphere by transpiration; part of the water cycle becomes broken. Because it is difficult to predict when droughts will happen, it is difficult for countries to predict how serious water shortages will be each year.

Effect of Changing Climate

Global warming will change patterns of rainfall and water distribution. As the Earth warms, regions that currently receive an adequate supply of rain may shift. Regions that rely on snowmelt may find that there is less snow and the melt comes earlier and faster in the spring, causing the water to run off and not be available through the dry summers. A change in temperature and precipitation would completely change the types of plants and animals that can live successfully in that region.

Water Scarcity

Water scarcity can have dire consequences for the people, the economy, and the environment. Without adequate water, crops and livestock dwindle and people go hungry. Industry, construction, and economic development is halted, causing a nation to sink further into poverty. The risk of regional conflicts over scarce water resources rises. People die from diseases, thirst, or even in war over scarce resources.

California's population is growing by hundreds of thousands of people a year, but much of the state receives as

FIGURE 13.35
Extended periods with lower than normal rainfall cause droughts.

much annual rainfall as Morocco. With fish populations crashing, global warming, and the demands of the country's largest agricultural industry, the pressures on our water supply are increasing.

Find out more at http://science.kqed.org/quest/video/state-of-thirst-californias-water-future/.

MEDIA
Click image to the left for more content.

Conflicts Over Water

As water supplies become scarce, conflicts will arise between the individuals or nations that have enough clean water and those that do not (**Figure ??**). Some of today's greatest tensions are happening in places where water is scarce. Water disputes may add to tensions between countries where differing national interests and withdrawal rights have been in conflict. Just as with energy resources today, wars may erupt over water.

Water disputes are happening along 260 different river systems that cross national boundaries. Some of these disputes are potentially very serious. International water laws, such as the Helsinki Rules, help interpret water rights among countries.

Vocabulary

- **drought**: A long period of lower than normal rainfall for a particular region.

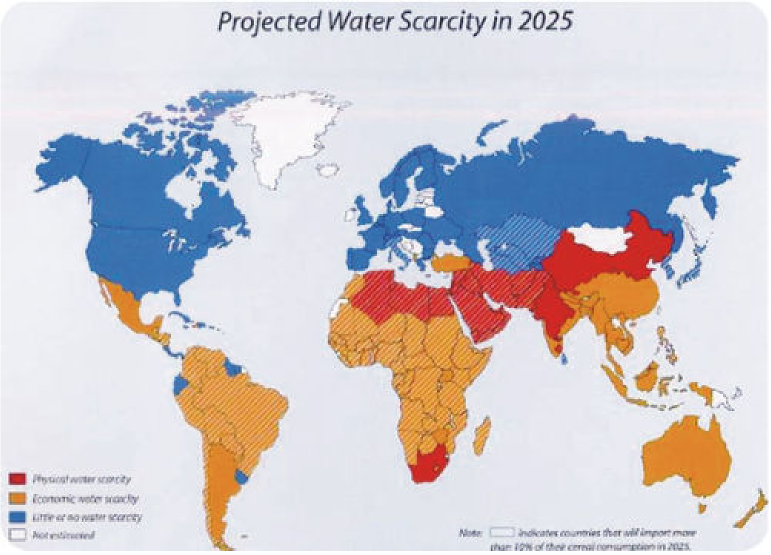


FIGURE 13.36
By 2025, many nations will face water scarcity. For the nations in red, there will simply not be enough fresh water; the nations in brown may not be able to afford to supply their citizens with fresh water.

Summary

- A lot of the problem with water is that it is not evenly distributed across the planet.
- Many of the world's people live with water scarcity, and that percentage will increase as populations increase and climate changes.
- Some people predict that, just as wars are fought over energy now, future wars will be fought over water.

Practice

Use this resource to answer the questions that follow.

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

MEDIA
Click image to the left for more content.

1. What is water scarcity?
2. Why do people take water for granted?
3. How much freshwater is there on Earth?
4. How many people do not have access to clean water?
5. What will occur by 2025?
6. What is physical water scarcity? Where does this occur?
7. What is economic water scarcity? Where does this occur?

Review

1. How will changing climate affect the availability and distribution of water?
2. How do human activities affect the occurrence of droughts?
3. How do so many people live with so little water?

13.13 Safety of Water

- Describe the causes and consequences of unsafe water.

What do you see in this photo?

The Ganges River is sacred to the people of India. It is also a major source of water for drinking and bathing for millions of people. An estimated 400 million people are affected by pollution in the Ganges. What can be done to protect a water body that has so much pressure placed on it?

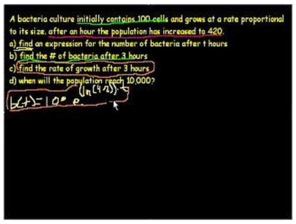
Scarcity of Safe Drinking Water

The water that comes out of our faucets is safe because it has gone through a series of treatment and purification processes to remove contaminants. Those of us who are fortunate enough to always be able to get clean water from a tap in our home may have trouble imagining life in a country that cannot afford the technology to treat and purify water.

Pollution

Many people in the world have no choice but to drink from the same polluted river where sewage is dumped. One-fifth of all people in the world, more than 1.1 billion people, do not have access to safe water for drinking, personal cleanliness, and domestic use. Unsafe drinking water carries many **pathogens**, or disease-causing agents such as infectious bacteria, toxic chemicals, radiological hazards, and parasites.

Exponential growth of bacteria is explained in this video giving the viewer a good idea of how a small number of bacteria can cause a major toxic problem **(1e - I&E Stand.)**: http://www.youtube.com/watch?v=JWfTckls59k#38;f eature=player_embedded (16:00).



MEDIA

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Waterborne Disease

Waterborne disease caused by unsafe drinking water is the leading cause of death for children under the age of five in many nations and a cause of death and illness for many adults. About 88% of all diseases are caused by drinking unsafe water (**Figure** 13.37). Throughout the world, more than 14,000 people die every day from waterborne diseases, such as cholera, and many of the world's hospital beds are occupied by patients suffering from a waterborne disease.

FIGURE 13.37

Dracunculiasis, commonly known as Guinea Worm, is contracted when a person drinks the guinea worm larvae.

International aid can sometimes help to provide safe drinking water to people in regions where none is available (**Figure** 13.38). Sometimes wells are drilled to avoid contaminated surface waters.

Vocabulary

- **pathogen**: Disease causing organisms.

Summary

- More than 1 billion people do not have access to water that is safe for drinking and washing.
- Waterborne diseases cause death and illness to people in many parts of the world.
- Government programs and international aid help to provide safe drinking water for some people.

FIGURE 13.38
Boys avoid guinea worm disease by drinking through a specially designed straw.

Practice

Use this resource to answer the questions that follow.

http://www.pbs.org/newshour/bb/asia/july-dec10/pakistan2_08-26.html

1. What waterborne diseases have they seen in Pakistan?
2. What is AWD?
3. What is the number-one killer of children under age five in Pakistan?
4. How many people have contracted waterborne diseases in Pakistan?
5. What caused the epidemic in Pakistan?

Review

1. Would you go thirsty or would you drink from a water source that was visibly polluted?
2. Why do nations fail to provide safe drinking water for their people?
3. Why do waterborne diseases rarely strike in the developed world?

13.14 Water Pollution

- Describe the sources of water pollution.

Is polluted water like this only seen in developing nations?

There is certainly polluted water in developed nations, but that water is cleaned and purified before it is put in taps and sent to people's homes. Pollutants come from a variety of sources.

Introduction

Freshwater and ocean pollution are serious global problems that affect the availability of safe drinking water, human health, and the environment. Waterborne diseases from water pollution kill millions of people in underdeveloped countries every year.

Sources of Water Pollution

Water pollution contributes to water shortages by making some water sources unavailable for use. In underdeveloped countries, raw sewage is dumped into the same water that people drink and bathe in. Even in developed countries, water pollution affects human and environmental health.

Water pollution includes any contaminant that gets into lakes, streams, and oceans. The most widespread source of water contamination in developing countries is raw sewage. In developed countries, the three main sources of water pollution are described below.

Municipal Pollution

Wastewater from cities and towns contains many different contaminants from many different homes, businesses, and industries (**Figure** 13.39). Contaminants come from:

- Sewage disposal (some sewage is inadequately treated or untreated).
- Storm drains.
- Septic tanks (sewage from homes).
- Boats that dump sewage.
- Yard runoff (fertilizer and herbicide waste).

FIGURE 13.39
Municipal and agricultural pollution.

Large numbers of sewage spills into San Francisco Bay are forcing cities, water agencies and the public to take a closer look at wastewater and its impacts on the health of the bay. QUEST investigates the causes of the spills and what's being done to prevent them.

Watch the investigation at http://science.kqed.org/quest/video/wastewater-woes-sewage-spills-in-sf-bay/.

Adobe Flash

MEDIA
Click image to the left for more content.

Industrial Pollution

Factories and hospitals spew pollutants into the air and waterways (**Figure** 13.40). Some of the most hazardous industrial pollutants include:

- Radioactive substances from nuclear power plants and medical and scientific sources.

- Heavy metals, organic toxins, oils, and solids in industrial waste.
- Chemicals, such as sulfur, from burning fossil fuels.
- Oil and other petroleum products from supertanker spills and offshore drilling accidents.
- Heated water from industrial processes, such as power stations.

FIGURE 13.40
Industrial Waste Water: Polluted water coming from a factory in Mexico. The different colors of foam indicate various chemicals in the water and industrial pollution.

Agricultural Pollution

Runoff from crops, livestock, and poultry farming carries contaminants such as fertilizers, pesticides, and animal waste into nearby waterways (**Figure** 13.41). Soil and silt also run off farms. Animal wastes may carry harmful diseases, particularly in the developing world.

FIGURE 13.41
The high density of animals in a factory farm means that runoff from the area is full of pollutants.

Fertilizers that run off of lawns and farm fields are extremely harmful to the environment. Nutrients, such as nitrates, in the fertilizer promote algae growth in the water they flow into. With the excess nutrients, lakes, rivers, and bays become clogged with algae and aquatic plants. Eventually these organisms die and decompose. Decomposition uses up all the dissolved oxygen in the water. Without oxygen, large numbers of plants, fish, and bottom-dwelling animals die.

Summary

- Municipal pollution comes from sewage, storm drains, septic tanks, boats, and runoff from yards.
- Industrial pollution, from factories and hospitals, includes radioactive substances; heavy metals and other pollutants in industrial waste; by-products of fossil fuel burning; oil and other petroleum products; and heat from factories and power plants.
- Agricultural pollutants include wastes from animals, pesticides, herbicides, fertilizers, and soil.

Practice

Use this resource to answer the questions that follow.

http://www.watersheds.org/earth/karstmovie.htm

Click on non point pollution and the various pushpins.

1. What type of pollutants do houses create?
2. How do pollutants from cars enter the groundwater?
3. How does farming cause pollution?
4. How do towns contribute to water pollution?
5. How do sinkholes contribute to water pollution?

Review

1. How can fertilizers, which help things grow, be pollutants?
2. Why is raw sewage a major pollutant in some countries but not in developed countries?
3. How could heat be a pollutant? What damage could it cause?

13.15 Protecting Water From Pollution

- Explain how to reduce water pollution and clean up polluted water.

How do municipalities clean water?

We take clean water for granted because we have advanced wastewater treatment facilities that remove impurities with settling containers, filters, chemicals, and biological agents.

Reducing Water Pollution

Water pollution can be reduced in two ways:

- Keep the water from becoming polluted.
- Clean water that is already polluted.

Clean Water Act

Keeping water from becoming polluted often requires laws to be sure that people and companies behave responsibly. In the United States, the Clean Water Act gives the Environmental Protection Agency (EPA) the authority to set standards for water quality for industry, agriculture, and domestic uses. The law gives the EPA the authority to reduce the discharge of pollution into waterways, finance wastewater treatment plants, and manage runoff. Since its passage in 1972, more wastewater treatment plants have been constructed and the release of industrial waste into the water supply is better controlled.

The United Nations and other international groups are working to improve global water quality standards by providing the technology for treating water. These organizations also educate people in how to protect and improve the quality of the water they use (**Figure** 13.42).

FIGURE 13.42

Scientists control water pollution by sampling the water and studying the pollutants that are in the water.

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking, medicine, agriculture, and industrial processes.

People living in developed countries suffer from few waterborne diseases and illness, because they have extensive water treatment systems to collect, treat, and redeliver clean water. Many underdeveloped nations have few or no water treatment facilities.

Wastewater contains hundreds of contaminants, such as suspended solids, oxygen-demanding materials, dissolved inorganic compounds, and harmful bacteria. In a wastewater treatment plant, multiple processes must be used to produce usable water:

- **Sewage treatment** removes contaminants, such as solids and particles, from sewage.
- **Water purification** produces drinking water by removing bacteria, algae, viruses, fungi, unpleasant elements such as iron and sulfur, and man-made chemical pollutants.

The treatment method used depends on the kind of wastewater being treated and the desired end result. Wastewater is treated using a series of steps, each of which produces water with fewer contaminants.

What Can You Do?

What can individuals do to protect water quality?

- Find approved recycling or disposal facilities for motor oil and household chemicals.
- Use lawn, garden, and farm chemicals sparingly and wisely.
- Repair automobile or boat engine leaks immediately.
- Keep litter, pet waste, leaves, and grass clippings out of street gutters and storm drains.

Vocabulary

- **sewage treatment**: Any process that removes contaminants from sewage or wastewater.
- **water purification**: Any process used to produce safe drinking water by removing contaminants.

Summary

- Keeping water from becoming polluted is easier, less expensive, and safer than cleaning it once it is polluted.
- Since the passage of the Clean Water Act, many wastewater treatment plants have been constructed and utilized.
- There are multiple levels of water treatment: some water is cleaned enough for use on lawns, while other water is cleaned enough to be safe for drinking.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Fbmc3L9j4Os

MEDIA

Click image to the left for more content.

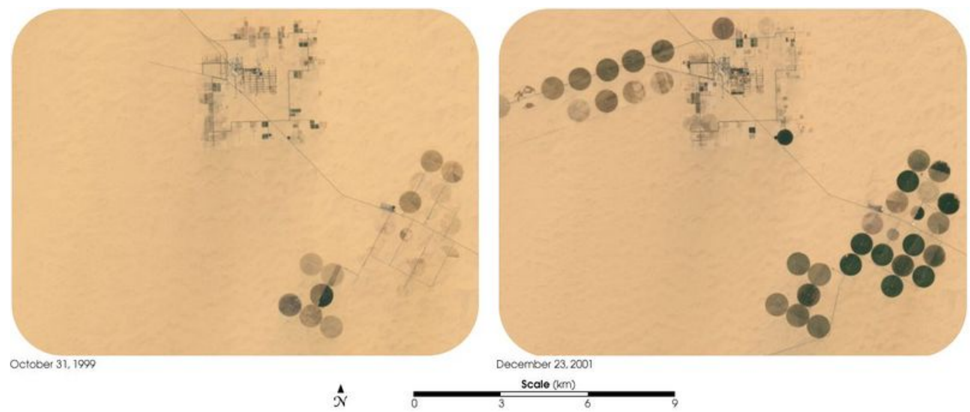
1. What caused people to demand action?
2. When did people protest? How many people were involved?
3. What agency was created by Nixon in response to public demand?
4. What did Nixon do to the Clean Water Act?
5. How did Congress respond?
6. What was banned during this same time?

Review

1. What is the purpose of the Clean Water Act?
2. How is wastewater treated?
3. What can the members of your household do to protect water quality?

13.16 Groundwater Depletion

- Explain the causes and consequences of groundwater depletion.



Is it good to make the desert bloom?

Many sunny, arid regions are good for growing crops as long as water can be added. Some of the increase in productivity is due to farming in regions that are technically too dry. Groundwater can be used to make the desert bloom, but at what cost? And for how long? Eventually the wells will run dry.

Groundwater Overuse

Some aquifers are overused; people pump out more water than is replaced. As the water is pumped out, the water table slowly falls, requiring wells to be dug deeper, which takes more money and energy. Wells may go completely dry if they are not deep enough to reach into the lowered water table.

Other problems may stem from groundwater overuse. Subsidence and saltwater intrusion are two of them.

Ogallala Aquifer

The Ogallala Aquifer supplies about one-third of the irrigation water in the United States. The Ogallala Aquifer is widely used by people for municipal and agricultural needs. (**Figure** 13.44). The aquifer is found from 30 to 100 meters deep over an area of about 440,000 square kilometers!

The water in the aquifer is mostly from the last ice age. About eight times more water is taken from the Ogallala Aquifer each year than is replenished. Much of the water is used for irrigation (**Figure** 13.45).

Subsidence

Lowering the water table may cause the ground surface to sink. **Subsidence** may occur beneath houses and other structures (**Figure** 13.46).

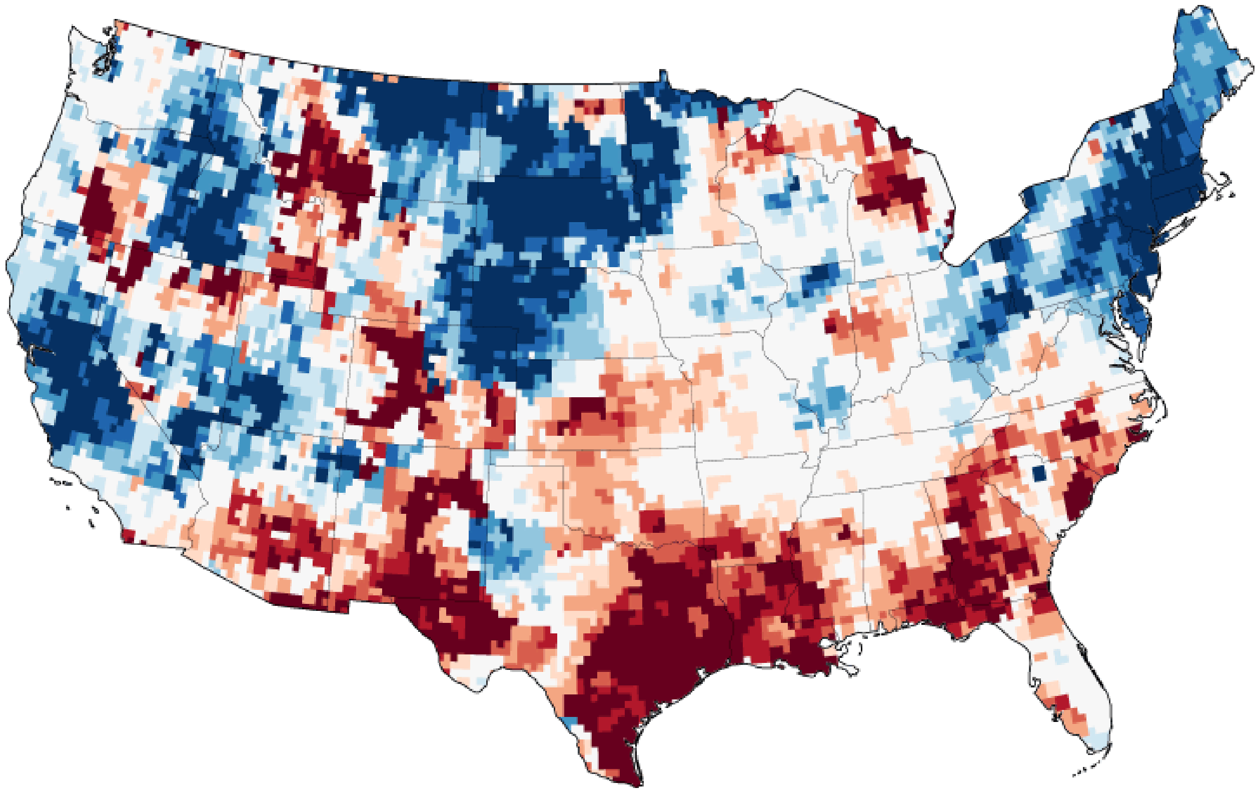


FIGURE 13.43

Intense drought has reduced groundwater levels in the southern U.S., particularly in Texas and New Mexico.

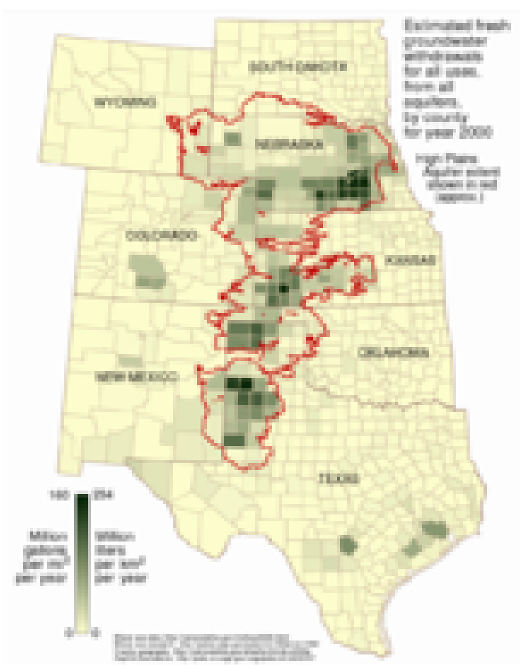


FIGURE 13.44

The Ogallala Aquifer is found beneath eight states and is heavily used.

FIGURE 13.45
Farms in Kansas use central pivot irrigation, which is more efficient since water falls directly on the crops instead of being shot in the air. These fields are between 800 and 1600 meters (0.5 and 1 mile) in diameter.

FIGURE 13.46
The San Joaquin Valley of California is one of the world's major agricultural areas. So much groundwater has been pumped that the land has subsided many tens of feet.

Salt Water Intrusion

When coastal aquifers are overused, salt water from the ocean may enter the aquifer, contaminating the aquifer and making it less useful for drinking and irrigation. Salt water incursion is a problem in developed coastal regions, such as on Hawaii.

Vocabulary

- **subsidence**: Sinking of the land surface because of the extraction of ground water.

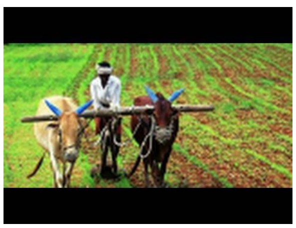
Summary

- When water is pumped from an aquifer, the water table declines and wells must be drilled deeper.
- The Ogallala Aquifer was filled in the ice age but is being used to irrigate the farms of the Midwestern U.S. at a rate far greater than it is being replenished.
- Ground subsidence and saltwater intrusion are two possible consequences of groundwater overuse.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=o1QsCa7RmmU



MEDIA

Click image to the left for more content.

1. How has irrigation changed farming?

2. What is leading to people's demands for additional water?

3. What is the GRACE satellite doing?

4. How does GRACE find groundwater aquifers?

5. How people know the aquifers are being depleted?

6. What is the future of water?

Review

1. What are some of the problems that come from overuse of groundwater?

2. How does salt water enter an aquifer?

3. In a location where the ground has subsided due to the extraction of groundwater from an aquifer, what do you think would happen if people tried to pump water back into the aquifer?

13.17 Groundwater Pollution

- Describe how pollutants enter groundwater.

How could the water in this well be polluted?

Such an idyllic scene. The water from the well must taste as fresh as the springtime air. Of course, the water may be contaminated. Industrial waste from a factory down the road, or any number of other things, could have polluted the aquifer.

How Pollutants Enter Groundwater

Groundwater pollutants are the same as surface water pollutants: municipal, agricultural, and industrial. Groundwater is more susceptible to some sources of pollution. For example, irrigation water infiltrates into the ground, bringing with it the pesticides, fertilizers, and herbicides that were sprayed on the fields. Water that seeps through landfills also carries toxins into the ground. Toxic substances and things like gasoline are kept in underground storage tanks; more than 100,000 of the tanks are currently leaking and many more may develop leaks.

Filtered Water

Groundwater is a bit safer from pollution than surface water from some types of pollution because some pollutants are filtered out by the rock and soil that water travels through as it travels through the ground or once it is in the aquifer. But rock and soil can't get out everything, depending on the type of rock and soil and on the types of pollutants. As it is, about 25% of the usable groundwater and 45% of the municipal groundwater supplies in the United States are polluted.

FIGURE 13.47
Tanks may break and leak whatever toxins they contain into the ground.

Pollutant Plume

When the pollutant enters the aquifer, contamination spreads in the water outward from the source and travels in the direction that the water is moving. This pollutant plume may travel very slowly, only a few inches a day, but over time can contaminate a large portion of the aquifer. Many wells that are currently in use are contaminated. In Florida, for example, more than 90% of wells have detectible contaminants and thousands have been closed.

Summary

- Groundwater is susceptible to pollutants that infiltrate into the ground from underground storage tanks or agricultural fields.
- Rock and soil filters some pollutants as water travels down to and through an aquifer.
- A plume containing pollutants travels outward from the source and through the aquifer in the direction the water is moving.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=5xs1jLlbztE

MEDIA
Click image to the left for more content.

1. How does rock dissolve?
2. How does groundwater get contaminated?
3. What happens in karst aquifers?

4. What are the three types of contaminants?
5. What are sediments?

Review

1. Is groundwater always cleaner than surface water?
2. Is water that is advertised as spring water necessarily free of contaminants? Why or why not?
3. How does groundwater move into and through an aquifer?

13.18 Cleaning Up Groundwater

- Describe how to clean up groundwater and explain why it is difficult and expensive.

Would you drink this water?

This water is obviously dirty, but some of the worst contaminants that can be in water are invisible. Those contaminants, especially when they are in groundwater, are extremely difficult to remove.

Cleaning Groundwater

Preventing groundwater contamination is much easier and cheaper than cleaning it. To clean groundwater, the water, as well as the rock and soil through which it travels, must be cleansed. Thoroughly cleaning an aquifer would require cleansing each pore within the soil or rock unit. For this reason, cleaning polluted groundwater is very costly, takes years, and is sometimes not technically feasible. If the toxic materials can be removed from the aquifer, disposing of them is another challenge.

Stages of Groundwater Cleaning

Elimination of the Pollution Source

If the source is an underground tank, the tank will be pumped dry and then dug out from the ground. If the source is a factory that is releasing toxic chemicals that are ending up in the groundwater, the factory may be required to stop the discharge.

Monitoring the Extent of the Pollutant

Hydrologists must determine how far, in what direction, and how rapidly the plume is moving. They must determine the concentration of the contaminant to determine how much it is being diluted. The scientists will use existing wells and may drill test wells to check for concentrations and monitor the movement of the plume.

Modeling the Contaminant Plume

Using the well data, the hydrologist uses a computer program with information on the permeability of the aquifer and the direction and rate of groundwater flow, then models the plume to predict the dispersal of the contaminant through the aquifer. Drilling test wells to monitor pollution is expensive.

Remediation

First, an underground barrier is constructed to isolate the contaminated groundwater from the rest of the aquifer. Next, the contaminated groundwater may be treated in place.

Bioremediation is relatively inexpensive. Bioengineered microorganisms are injected into the contaminant plume and allowed to consume the pollutant. Air may be pumped into the polluted region to encourage the growth and reproduction of the microbes. With **chemical remediation**, a chemical is pumped into the aquifer so the contaminant is destroyed. Acids or bases can neutralize contaminants or cause pollutants to precipitate from the water.

The most difficult and expensive option is for reclamation teams to pump the water to the surface, cleanse it using chemical or biological methods, then re-inject it into the aquifer. The contaminated portions of the aquifer must be dug up and the pollutant destroyed by incinerating or chemically processing the soil, which is then returned to the ground. This technique is often prohibitively expensive and is done only in extreme cases.

Vocabulary

- **bioremediation**: Microorganisms engineered to consume a contaminant are injected into a pollutant plume to neutralize the toxins.
- **chemical remediation**: A chemical that will react with the pollutant is pumped into the plume to neutralize it.

FIGURE 13.48
Test wells are drilled to monitor groundwater pollution.

Summary

- There are four stages needed to clean groundwater: remove the pollutant source, monitor the pollutant, model the contaminant plume, and perform remediation.
- By testing the water in many wells for a contaminant, scientists can model the contaminant plume in an aquifer.
- Cleaning groundwater in an aquifer usually requires bioremediation, the use of microorganisms that are bioengineered to consume a pollutant, or chemical remediation, which causes neutralizing chemical reactions.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=p9vJqAPzvwA

MEDIA

Click image to the left for more content.

1. What was the Hanford site used for?
2. What river needs to be protected?
3. How much contamination was released into the soil?
4. How much has the contamination decreased?
5. What is the goal at Hanford?
6. What is being done to clean up the water?
7. How much of the groundwater has been treated?

Review

1. Why does cleaning groundwater in an aquifer also require cleaning the soil or rock that the water travels through?
2. Describe how bioremediation works. Why is this a good way to clean an aquifer without removing the water?
3. How do scientists monitor and model a contaminant plume?

13.19 Conserving Water

- Describe ways to conserve water.

You can help to use less water by conserving in your own home. One way is to install a low-flow shower head to reduce the amount water used during showers.

How Society Can Conserve Water

Water consumption per person has been going down for the past few decades. There are many ways that water conservation can be encouraged. Charging more for water gives a financial incentive for careful water use. Water use may be restricted by time of day, season, or activity. Good behavior can be encouraged; for example, people can be given an incentive to replace grass with desert plants in arid regions.

FIGURE 13.49
This colorful adobe house in Tucson, Arizona is surrounded by native cactus, which needs little water to thrive.

How You Can Conserve Water

As human population growth continues, water conservation will become increasingly important globally (**Figure ??**), especially in developed countries where people use an enormous amount of water. What are some of the ways you can conserve water in and around your home?

- Avoid polluting water so that less is needed.
- Convert to more efficient irrigation methods on farms and in gardens.
- Reduce household demand by installing water-saving devices such as low-flow shower heads and toilets.
- Reduce personal demand by turning off the tap when water is not being used and taking shorter showers.
- Engage in water-saving practices: for instance, water lawns less and sweep rather than hose down sidewalks.

How you can conserve water at home is the subject of this National Geographic video, "Conserve Water": http://video.nationalgeographic.com/video/environment/going-green-environment/green-home-makeover/conserve-water-greenguide/. Other videos for making your home greener are found on that page as well.

At Earth Summit 2002, many governments approved a Plan of Action to address the scarcity of water and safe drinking water in developing countries. One goal of this plan is to cut in half the number of people without access to safe drinking water by 2015. This is a very important goal and one made more difficult as population continues to grow.

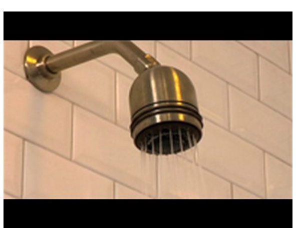
Summary

- Society can reduce water consumption by making policies that encourage or require conservation.
- People can reduce water consumption by taking shorter showers, installing water-saving devices, and many other methods.
- Financial incentives can work to encourage people to conserve water and other resources.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=4MDLpVHY8LE



MEDIA

Click image to the left for more content.

1. What percentage of water is used in the bathroom?
2. How do low-flow toilets conserve water?
3. What does an aerator do?
4. List 3 additional tips for saving water.
5. How much water does a professional car war wash use?
6. Why shouldn't you use the garden hose to wash a car?

Review

1. Why does your choice of garden plants affect the water consumption of your household?
2. How does water pollution reduce the amount of water that is available for people to use?
3. Why is providing clean water to all people so difficult? Why is it so important?

13.20 Coastal Pollution

- Explain the relationship between coastal pollution and marine dead zones.

Fertilizer makes things grow. How could it cause a dead zone?

Fertilizer from farms and yards carried from the Mississippi River into the Gulf of Mexico creates an enormous dead zone, where algae use up all the oxygen and nothing else can live. The largest, in 2002, was about 22,000 square kilometers (8,400 mi^2).

Ocean Pollution

Most ocean pollution comes as runoff from land and originates as agricultural, industrial, and municipal wastes (**Figure** 13.50). The remaining 20% of water pollution enters the ocean directly from oil spills and people dumping wastes directly into the water. Ships at sea empty their wastes directly into the ocean, for example.

Coastal pollution can make coastal water unsafe for humans and wildlife. After rainfall, there can be enough runoff pollution that beaches must be closed to prevent the spread of disease from pollutants. A surprising number of beaches are closed because of possible health hazards each year.

A large proportion of the fish we rely on for food live in the coastal wetlands or lay their eggs there. Coastal runoff from farm waste often carries water-borne organisms that cause lesions that kill fish. Humans who come in

FIGURE 13.50

In some areas of the world, ocean pollution is all too obvious.

contact with polluted waters and affected fish can also experience harmful symptoms. More than one-third of the shellfish-growing waters of the United States are adversely affected by coastal pollution.

A National Geographic video, "Why the Ocean Matters," has beautiful footage and a brief introduction to some of the problems facing the seas: http://video.nationalgeographic.com/video/environment/habitats-environment/habitats-oceans-env/why-ocean-matters/.

Dead Zones

Fertilizers that run off of lawns and farm fields are extremely harmful to the environment. Nutrients, such as nitrates, in the fertilizer promote algae growth in the water they flow into. With the excess nutrients, lakes, rivers, and bays become clogged with algae and aquatic plants. Eventually these organisms die and decompose. Decomposition uses up all the dissolved oxygen in the water. Without oxygen, large numbers of plants, fish, and bottom-dwelling animals die.

Every year dead zones appear in lakes and nearshore waters. A dead zone is an area of hundreds of kilometers of ocean without fish or plant life.

The Mississippi is not the only river that carries the nutrients necessary to cause a dead zone. Rivers that drain regions where human population density is high and where crops are grown create dead zones all over the world (**Figure** 13.51).

Summary

- Most ocean pollution comes from land and much congregates in the coastal regions.
- Excess fertilizer travels in rivers to the sea and causes algae to bloom. These algae die and decomposition uses

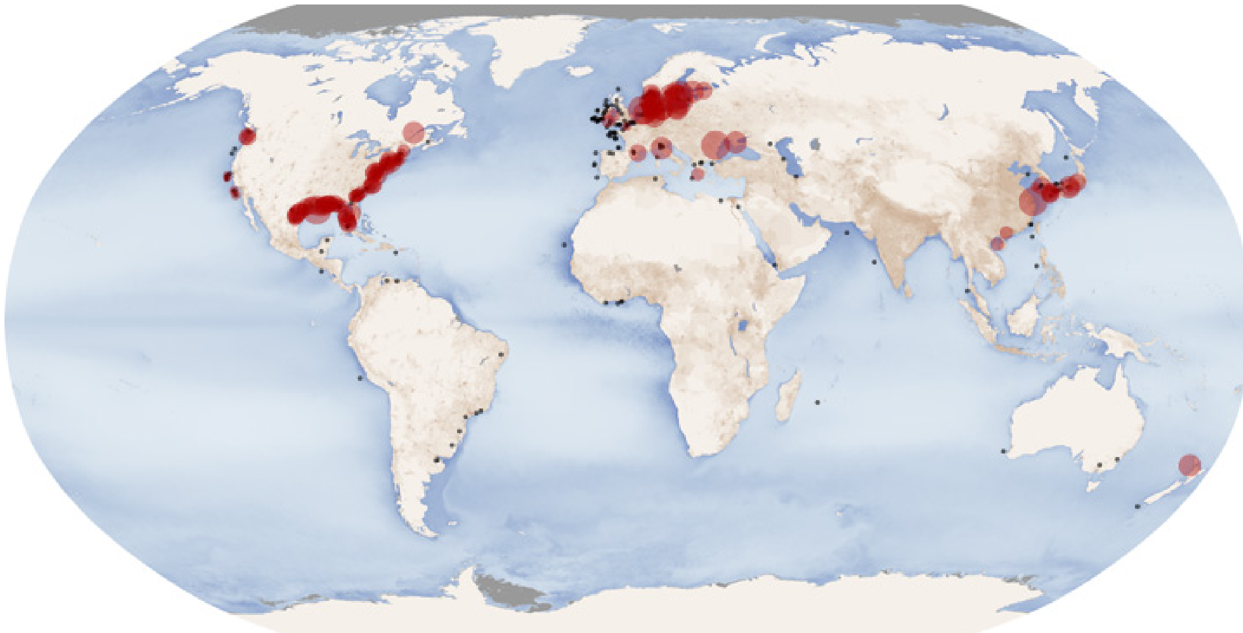


FIGURE 13.51

Dead zones off the coasts. Red dots show the location and size of the dead zone; black circles show the location but the size is unknown. Darker blue regions of the oceans indicate that organic particulates are high and may lead to a dead zone.

up the oxygen in an area, causing a dead zone.

- The dead zone in the Gulf of Mexico from Mississippi River runoff is getting larger each year.

Practice

Use these resources to answer the questions that follow

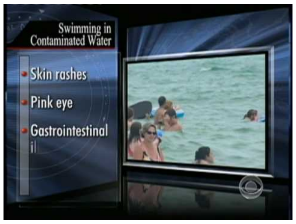
http://www.youtube.com/watch?v=xLv1vPEQyM0

MEDIA

Click image to the left for more content.

1. Why does the US Coast Guard do vehicle patrols?
2. Why are storm drains under US Coast Guard jurisdiction?
3. What is the purpose of the pollution fines?

http://www.youtube.com/watch?v=MBpnuYul7B8



MEDIA

Click image to the left for more content.

4. Where are the best beaches?

5. Where are the dirtiest beaches?

6, What is the danger of swimming in contaminated water?

7. What is the danger of digging in the sand?

Review

1. What are the consequences of coastal pollution?
2. What are the sources of coastal pollution?
3. What sequence of events causes a dead zone?

13.21 Ocean Garbage Patch

- Explain how trash ends up as ocean debris.
- Trace the path of trash to the ocean garbage patch.

How could these balloons kill a sea turtle?

Balloons flying off into the sky symbolize freedom and happiness. Eventually those balloons pop and the plastic falls to the surface. Much of this plastic will end up in the sea where it may be accidentally ingested by a marine organism — with dire results.

Marine Trash

Trash from land may end up as trash in the ocean, sometimes extremely far from land. Some of it will eventually wash ashore, possibly far from where it originated.

Sources of Trash

Although people had once thought that the trash found everywhere at sea was from ships, it turns out that 80% is from land. Some of that is from runoff, some is blown from nearshore landfills, and some is dumped directly into the sea.

The 20% that comes from ships at sea includes trash thrown overboard by large cruise ships and many other vessels. It also includes lines and nets from fishing vessels. Ghost nets, nets abandoned by fishermen intentionally or not, float the seas and entangle animals so that they cannot escape. Containers sometimes go overboard in storms. Some noteworthy events, like a container of rubber ducks that entered the sea in 1992, are used to better understand ocean currents. The ducks went everywhere!

FIGURE 13.52
Trash has washed up on this beach.

Makeup of Trash

About 80% of the trash that ends up in the oceans is plastic. This is because a large amount of the trash produced since World War II is plastic. Also many types of plastic do not biodegrade, so they simply accumulate. While many types of plastic photodegrade — that is, they break up in sunlight — this process only works when the plastics are dry. Plastic trash in the water does break down into smaller pieces, eventually becoming molecule-sized polymers. Other trash in the oceans includes chemical sludge and materials that do biodegrade, like wood.

Toxic chemicals

Some plastics contain toxic chemicals, such as bisphenol A. Plastics can also absorb organic pollutants that may be floating in the water, such as the pesticide DDT (which is banned in the U.S. but not in other nations) and some endocrine disruptors.

Effect on Organisms

Marine birds, such as albatross, or animals like sea turtles, live most of their lives at sea and just come ashore to mate. These organisms can't break down the plastic and they may eventually die. Boats may be affected. Plastic waste is estimated to kill 100,000 sea turtles and marine mammals annually, but exact numbers are unknown.

Plastic shopping bags are extremely abundant in the oceans. If an organism accidentally ingests one, it may clog digestion and cause starvation by stopping food from moving through or making the animal not feel hungry.

The Great Pacific Garbage Patch

Trash from the lands all around the North Pacific is caught up in currents. The currents bring the trash into the center of the North Pacific Gyre. Scientists estimate that it takes about six years for trash to move from west coast of North America to the center of the gyre. The concentration of trash increases toward the center of the gyre.

While recognizable pieces of garbage are visible, much of the trash is tiny plastic polymers that are invisible but can be detected in water samples. The particles are at or just below the surface within the gyre. Plastic confetti-like pieces are visible beneath the surface at the gyre's center.

FIGURE 13.53
This albatross likely died from the plastic it had ingested.

FIGURE 13.54
Plastic bags in the ocean can be mistaken for food by an unsuspecting marine predator.

The size of the garbage patch is unknown, since it can't be seen from above. Some people estimate that it's twice the size of continental U.S, with a mass of 100 million tons.

Effect on Organisms

In some areas, plastics have seven times the concentration of zooplankton. This means that filter feeders are ingesting a lot of plastics. This may kill the organisms or the plastics may remain in their bodies. They are then eaten by larger organisms that store the plastics and may eventually die. Fish may eat organisms that have eaten plastic and then be eaten by people. This also exposes humans to toxic chemicals that the fish may have ingested with the plastic.

There are similar patches of trash in the gyres of the North Atlantic and Indian oceans. The Southern Hemisphere has less trash buildup because less of the region is continent.

Summary

- Trash from land (80%) or human activities at sea (20%) ends up in the oceans; about 80% of this trash is plastic.
- Plastic trash does not usually biodegrade in the ocean but just forms tiny polymers that resemble plankton.
- Plastic pieces of trash and plastic molecules can kill marine organisms by becoming lodged in their digestive systems or by trapping them so they can't swim.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=8a4S23uXIcM

MEDIA

Click image to the left for more content.

1. What created the garbage patch?

2. How much stuff does it contain?

3. What makes up 80% of the patch?

4. What is the problem with plastic?

5. Where does the garbage come from?

6. What is the solution to stop adding to the patch?

Review

1. How can plastic kill marine organisms?

2. Since plastic doesn't biodegrade in the oceans, what does the future hold? What can be done to make the future better?

3. Some people say that the Great Pacific Garbage Patch is a hoax. What can scientists do to show people that it is real?

13.22 Oil Spills

- Describe the damage that occurs from oil spills.

Will this oil spill victim live?

After every oil spill, photos are released of marine organisms covered with oil. Sometimes people are trying to clean them. Seabirds are especially vulnerable; they dive into a slick because the surface looks like calmer water. Oil-coated birds cannot regulate their body temperatures and will die. After cleanup, some birds will live and some will not.

Oil Spills

Large oil spills, like the Exxon Valdez in Alaska in 1989, get a lot of attention, as they should. Besides these large spills, though, much more oil enters the oceans from small leaks that are only a problem locally. In this lesson, we'll take a look at a large recent oil spill in the Gulf of Mexico.

The Gulf of Mexico Oil Spill

New drilling techniques have allowed oil companies to drill in deeper waters than ever before. This allows us to access oil deposits that were never before accessible, but only with great technological difficulty. The risks from deepwater drilling and the consequences when something goes wrong are greater than those associated with shallower wells.

Explosion

Working on oil platforms is dangerous. Workers are exposed to harsh ocean conditions and gas explosions. The danger was never more obvious than on April 20, 2010, when 11 workers were killed and 17 injured in an explosion on a deepwater oil rig in the Gulf of Mexico (**Figure** 13.55). The drilling rig, operated by BP, was 77 km (48 miles) offshore and the depth to the well was more than 5,000 feet.

FIGURE 13.55
The U.S. Coast Guard tries to put out the fire and search for missing workers after the explosion on the Deepwater Horizon drilling rig. Eleven workers were killed.

Spill

Two days after the explosion, the drill rig sank. The 5,000-foot pipe that connected the wellhead to the drilling platform bent. Oil was free to gush into the Gulf of Mexico from nearly a mile deep (**Figure** 13.56). Initial efforts to cap or contain the spill at or near its source all failed to stop the vast oil spill. It was not until July 15, nearly three months after the accident, that the well was successfully capped.

Estimating the flow of oil into the Gulf from the well was extremely difficult because the leak was so far below the surface. The U.S. government estimates that about 4.9 million barrels entered the Gulf at a rate of 35,000 to 60,000 barrels a day. The largest previous oil spill in the United States was of 300,000 barrels by the Exxon Valdez in 1989 in Prince William Sound, Alaska.

Cleanup

Once the oil is in the water, there are three types of methods for dealing with it:

1. Removal: Oil is corralled and then burned; natural gas is flared off (**Figure** 13.57). Machines that can separate oil from the water are placed aboard ships stationed in the area. These ships cleaned tens of thousands of barrels of contaminated seawater each day.

2. Containment: Floating containment booms are placed on the surface offshore of the most sensitive coastal areas in an attempt to attempt to trap the oil. But the seas must be calm for the booms to be effective, and so were not very useful in the Gulf (**Figure** 13.58). Sand berms have been constructed off of the Louisiana coast to keep the oil from reaching shore.

3. Dispersal: Oil disperses naturally over time because it mixes with the water. However, such large amounts of oil will take decades to disperse. To speed the process up, BP has sprayed unprecedented amounts of chemical dispersants on the spill. That action did not receive support from the scientific community since no one knows the risks to people and the environment from such a large amount of these harmful chemicals. Some workers may have

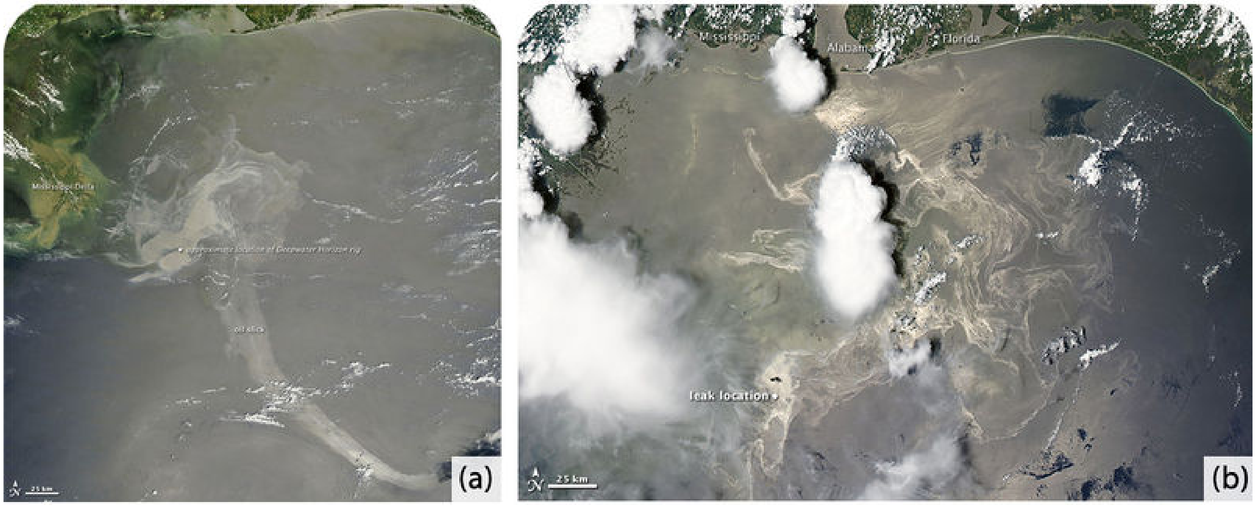


FIGURE 13.56

(a) On May 17, 2010, oil had been leaking into the Gulf for nearly one month. On that date government estimates put the maximum total oil leak at 1,600,000 barrels, according to the New York Times. (b) The BP oil spill on June 19, 2010. The government estimates for total oil leaked by this date was 3,200,000 barrels.

FIGURE 13.57

Burning the oil can reduce the amount in the water.

become ill from exposure to the chemicals.

Plugging the Well

BP drilled two relief wells into the original well. When the relief wells entered the original borehole, specialized liquids were pumped into the original well to stop the flow. Operation of the relief wells began in August 2010. The

FIGURE 13.58
A containment boom holds back oil, but it is only effective in calm water.

original well was declared effectively dead on September 19, 2010.

Impact

The economic and environmental impact of this spill will be felt for many years. Many people rely on the Gulf for their livelihoods or for recreation. Commercial fishing, tourism, and oil-related jobs are the economic engines of the region. Fearing contamination, NOAA imposed a fishing ban on approximately one-third of the Gulf (**Figure** 13.59). Tourism is down in the region as beach goers find other ways to spend their time. Real estate prices along the Gulf have declined precipitously.

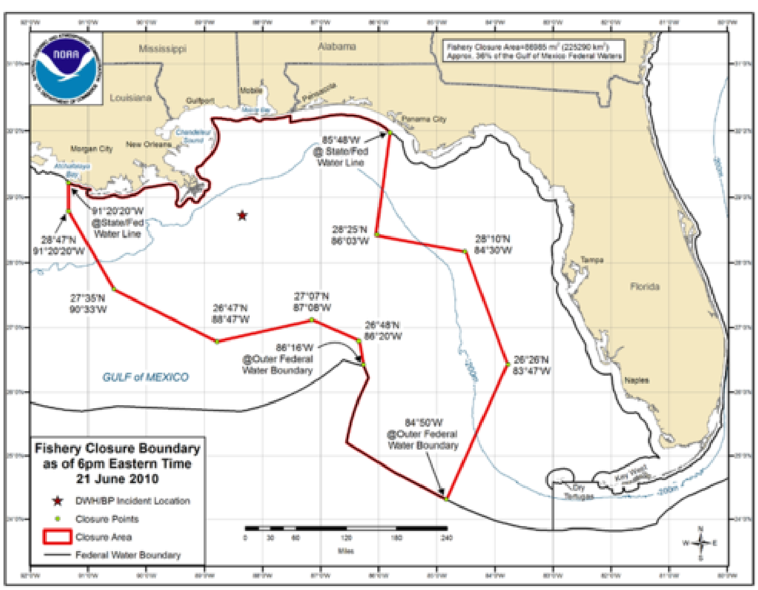


FIGURE 13.59
This was the extent of the banned area on June 21, 2010.

The toll on wildlife is felt throughout the Gulf. Plankton, which form the base of the food chain, are killed by the oil, leaving other organisms without food. Islands and marshlands around the Gulf have many species that are already at risk, including four endangered species of sea turtles. With such low numbers, rebuilding their populations after the spill will be difficult.

The Gulf of Mexico is one of only two places in the world where bluefin tuna spawn and they are also already endangered. Marine mammals in the Gulf may come up into the slick as they come to the surface to breathe.

Eight national parks and seashores are found along the Gulf shores. Other locations may be ecologically sensitive habitats such as mangroves or marshlands.

Long-Term Effects

There is still oil on beaches and in sediment on the seafloor in the region. Chemicals from the oil dispersants are still in the water. In October 2011 a report was issued that showed that whales and dolphins are dying in the Gulf at twice their normal rate. The long-term effects will be with us for a long time.

Summary

- As oil becomes scarcer, there are economic incentives to drill in deeper water, but this is a technologically difficult undertaking.
- There are still chemicals in the water that cause damage to wildlife.
- Massive amounts of oil that have been spilled into a water body can be removed, contained, or dispersed. These actions are difficult and may have negative consequences.
- Birds or beaches coated with oil are the most visible evidence of a spill, but there are many consequences that we can't see, like oil on the seabed or chemical dispersants in the water.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=mCSnD3KfjmM

MEDIA

Click image to the left for more content.

1. What happened on April 20, 2010?
2. What is our experience with most oils spills?
3. Why is this spill dangerous?
4. How are scientists trying to clean up the oil?
5. Why is oil usually lethal for plankton?
6. What species important to commercial fishing are found in the Gulf?
7. What is in danger in the deep water of the Gulf?

Review

1. Petroleum provides a great deal of money and a tremendous number of jobs to the U.S. What precautions should be made to be sure that there is little chance of negative consequences?

2. How do chemical dispersants work? Should they always be used?
3. What are the long-term effects of a major oil spill?

13.23 Air Quality

- Explain how air pollution affects air quality.

What is this in the air?

People have euphemisms for smog; sometimes it's fog, sometimes it's haze. It's hard to know sometimes whether the air is full of something natural, like water vapor, or something man-made, like ozone. But in cities like this the air is often being marred by air pollution.

Air Quality

Pollutants include materials that are naturally occurring but are added to the atmosphere so that they are there in larger quantities than normal. Pollutants may also be human-made compounds that have never before been found in the atmosphere. Pollutants dirty the air, change natural processes in the atmosphere, and harm living things.

Problems with Air Quality

Air pollution started to be a problem when early people burned wood for heat and cooking fires in enclosed spaces such as caves and small tents or houses. But the problems became more widespread as fossil fuels such as coal began to be burned during the Industrial Revolution.

Smog

Air pollution became a crisis in the developed nations in the mid-20th century. Coal smoke and auto exhaust combined to create toxic smog that in some places caused lung damage and sometimes death (**Figure** 13.60). In

Donora, Pennsylvania, in October 1948, 20 people died and 4,000 became ill when coal smoke was trapped by an inversion.

FIGURE 13.60
In London in December 1952, the "Big Smog" killed 4,000 people over five days. Many thousands more likely died of health complications from the event in the next several months.

Photochemical Smog

Photochemical smog, a different type of air pollution, first became a problem in Southern California after World War II. The abundance of cars and sunshine provided the perfect setting for a chemical reaction between some of the molecules in auto exhaust or oil refinery emissions and sunshine (**Figure** 13.61). Photochemical smog consists of more than 100 compounds, most importantly ozone.

The Clean Air Act

The terrible events in Pennsylvania and London, plus the recognition of the hazards of photochemical smog, led to the passage of the Clean Air Act in 1970 in the United States. The act now regulates 189 pollutants. The six most important pollutants regulated by the Act are ozone, particulate matter, sulfur dioxide, nitrogen dioxide, carbon monoxide, and the heavy metal lead. Other important regulated pollutants include benzene, perchloroethylene, methylene chloride, dioxin, asbestos, toluene, and metals such as cadmium, mercury, chromium, and lead compounds.

What is the result of the Clean Air Act? In short, the air in the United States is much cleaner. Visibility is better and people are no longer incapacitated by industrial smog. However, despite the Act, industry, power plants, and vehicles put 160 million tons of pollutants into the air each year. Some of this smog is invisible and some contributes to the orange or blue haze that affects many cities.

FIGURE 13.61
Smog over Los Angeles as viewed from the Hollywood Hills.

Regional Air Quality

Air quality in a region is not just affected by the amount of pollutants released into the atmosphere in that location but by other geographical and atmospheric factors. Winds can move pollutants into or out of a region and a mountain range can trap pollutants on its leeward side. Inversions commonly trap pollutants within a cool air mass. If the inversion lasts long enough, pollution can reach dangerous levels.

Pollutants remain over a region until they are transported out of the area by wind, diluted by air blown in from another region, transformed into other compounds, or carried to the ground when mixed with rain or snow.

Table 13.3 lists the smoggiest cities in 2011: eight of the 10 are in California. Why do you think California cities are among those with the worst air pollution?

The state has the right conditions for collecting pollutants including mountain ranges that trap smoggy air, arid and sometimes windless conditions, agriculture, industry, and lots and lots of cars.

TABLE 13.3: Smoggiest U.S. Cities, 2011

Rank	City, State
1	Los Angeles, California
2	Bakersfield, California
3	Visalia-Porterville, California
4	Fresno, California
5	Sacramento, California
6	Hanford, California
7	San Diego, California
8	Houston, Texas
9	Merced, California
10	Charlotte, North Carolina

Vocabulary

- **photochemical smog**: This type of air pollution results from a chemical reaction between pollutants in the presence of sunshine.

Summary

- Air is polluted by natural compounds in unnatural quantities or by unnatural compounds.

MEDIA
Click image to the left for more content.

1. What causes air quality problems on the East Coast?
2. What is NASA trying to do with this mission?
3. What problems do satellites have?
4. What 5 pollutants can be seen from space?
5. Why does the airplane spiral up and down?
6. What is the goal of the research?

Review

1. How does photochemical smog differ from other types of air pollution?
2. What does the Clean Air Act regulate?
3. Why do parts of California have such bad air pollution?

13.24 Types of Air Pollution

- Distinguish between primary and secondary pollutants and identify examples of each.

Why is there a lid over that smoke?

The smoke pictured above is stuck between two layers of air. The bottom layer is more dense than the top layer, so there is no mixing between the two layers. In winter, an inversion traps all of the pollutants that are emitted into the air over a region.

Types of Air Pollution

The two types of air pollutants are primary pollutants, which enter the atmosphere directly, and secondary pollutants, which form from a chemical reaction.

Primary Pollutants

Some primary pollutants are natural, such as volcanic ash. Dust is natural but exacerbated by human activities; for example, when the ground is torn up for agriculture or development. Most primary pollutants are the result of human activities, the direct emissions from vehicles and smokestacks. Primary pollutants include:

- Carbon oxides include carbon monoxide (CO) and carbon dioxide (CO_2) (**Figure** 13.62). Both are colorless, odorless gases. CO is toxic to both plants and animals. CO and CO_2 are both greenhouse gases.

- Nitrogen oxides are produced when nitrogen and oxygen from the atmosphere come together at high temperatures. This occurs in hot exhaust gas from vehicles, power plants, or factories. Nitrogen oxide (NO) and nitrogen dioxide (NO_2) are greenhouse gases. Nitrogen oxides contribute to acid rain.

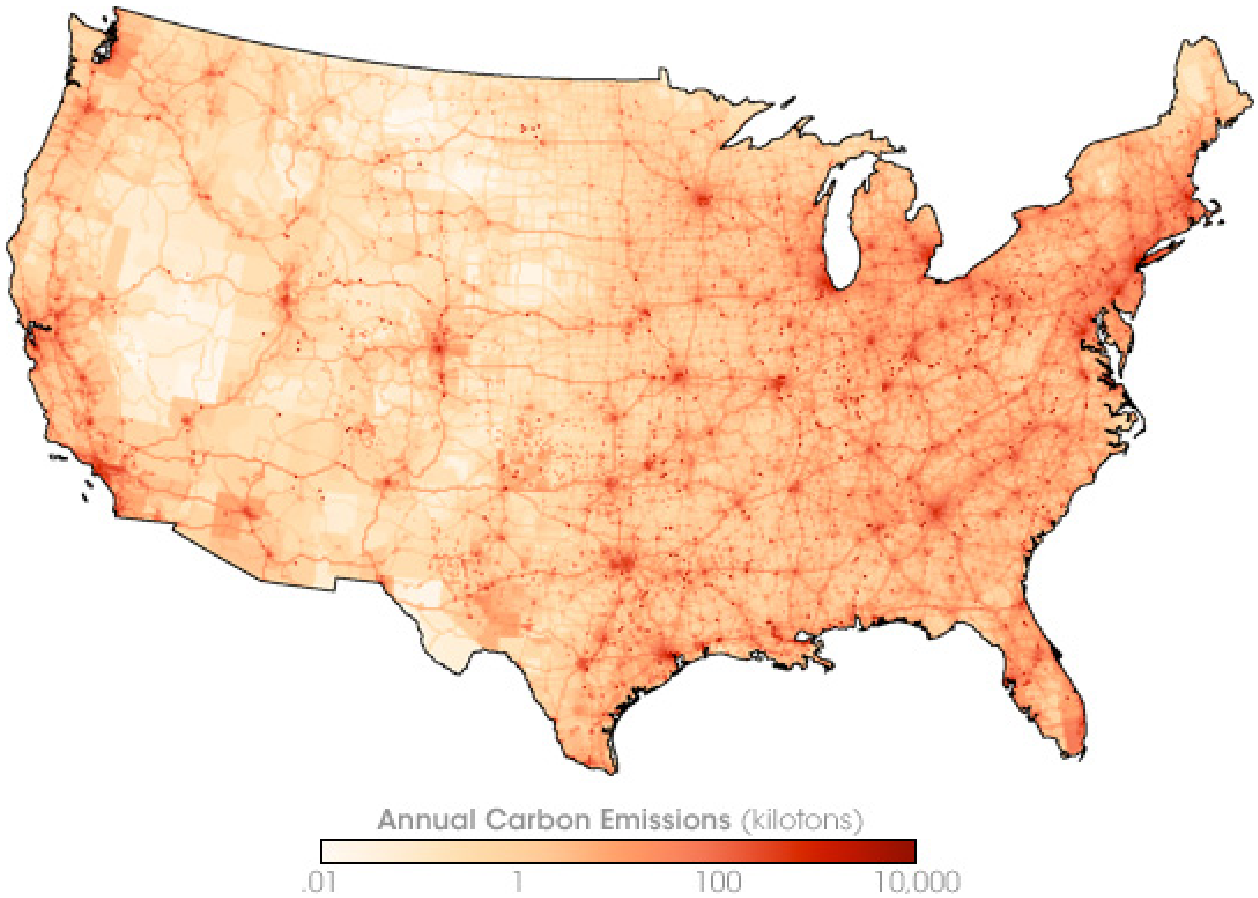


FIGURE 13.62
High CO_2 levels are found in major metropolitan areas and along the major interstate highways.

- Sulfur oxides include sulfur dioxide (SO_2) and sulfur trioxide (SO_3). These form when sulfur from burning coal reaches the air. Sulfur oxides are components of acid rain.
- Particulates are solid particles, such as ash, dust, and fecal matter (**Figure** 13.63). They are commonly formed from combustion of fossil fuels, and can produce smog. Particulates can contribute to asthma, heart disease, and some types of cancers.

- Lead was once widely used in automobile fuels, paint, and pipes. This heavy metal can cause brain damage or blood poisoning.
- Volatile organic compounds (VOCs) are mostly hydrocarbons. Important VOCs include methane (a naturally occurring greenhouse gas that is increasing because of human activities), chlorofluorocarbons (human-made compounds that are being phased out because of their effect on the ozone layer), and dioxin (a byproduct of chemical production that serves no useful purpose, but is harmful to humans and other organisms).

Secondary Pollutants

Any city can have photochemical smog, but it is most common in sunny, dry locations. A rise in the number of vehicles in cities worldwide has increased photochemical smog. Nitrogen oxides, ozone, and several other

FIGURE 13.63
Particulates from a brush fire give the sky a strange glow in Arizona.

compounds are some of the components of this type of air pollution.

Photochemical smog forms when car exhaust is exposed to sunlight. Nitrogen oxide is created by gas combustion in cars and then into the air (**Figure** 13.64). In the presence of sunshine, the NO_2 splits and releases an oxygen ion (O). The O then combines with an oxygen molecule (O_2) to form ozone (O_3). This reaction can also go in reverse: Nitric oxide (NO) removes an oxygen atom from ozone to make it O_2. The direction the reaction goes depends on how much NO_2 and NO there is. If NO_2 is three times more abundant than NO, ozone will be produced. If nitric oxide levels are high, ozone will not be created.

FIGURE 13.64
The brown color of the air behind the Golden Gate Bridge is typical of California cities, because of nitrogen oxides.

Ozone is one of the major secondary pollutants. It is created by a chemical reaction that takes place in exhaust and in the presence of sunlight. The gas is acrid-smelling and whitish. Warm, dry cities surrounded by mountains, such as Los Angeles, Phoenix, and Denver, are especially prone to photochemical smog. Photochemical smog peaks at midday on the hottest days of summer. Ozone is also a greenhouse gas.

Vocabulary

- **ozone**: Three oxygen atoms bonded together in an O_3 molecule. Ozone in the lower atmosphere is a pollutant.

Summary

- There are many types of primary pollutants, including carbon oxides, nitrogen oxides, sulfur oxides, particulates, lead, and volatile organic compounds.
- Secondary pollutants form from chemical reactions that occur when pollution is exposed to sunlight.
- Ozone is a secondary pollutant that is also a greenhouse gas.

Practice

Use this resource to answer the questions that follow.

http://science.howstuffworks.com/environmental/green-science/air-pollution-info1.htm

1. List the most significant air pollutants.
2. What makes up the largest group of pollutants?
3. What is carbon monoxide? What produces it?
4. What are the most dangerous of the air pollutants? How are they produced?
5. How are nitrogen oxides produced?
6. What produces hydrocarbons?

Review

1. How are primary and secondary pollutants different?
2. Explain how nitrogen oxide pollutants form.
3. What is ozone and how does it form?

13.25 Causes Of Air Pollution

- Describe the sources of air pollution.

How come we don't see emissions like this too often any more?

This photo of a power plant was taken before emission control equipment was added. Emissions are down since laws have been enacted to protect the air.

Causes of Air Pollution

Most air pollutants come from burning fossil fuels or plant material. Some are the result of evaporation from human-made materials. Nearly half (49%) of air pollution comes from transportation, 28% from factories and power plants, and the remaining pollution from a variety of other sources.

Fossil Fuels

Fossil fuels are burned in most motor vehicles and power plants. These nonrenewable resources are the power for nearly all manufacturing and other industries. Pure coal and petroleum can burn cleanly and emit only carbon dioxide and water, but most of the time these fossil fuels do not burn completely and the incomplete chemical reactions produce pollutants. Few sources of these fossil fuels are pure, so other pollutants are usually released. These pollutants include carbon monoxide, nitrogen dioxide, sulfur dioxide, and hydrocarbons.

In large car-dependent cities such as Los Angeles and Mexico City, 80% to 85% of air pollution is from motor vehicles (**Figure** 13.65). Ozone, carbon monoxide, and nitrous oxides come from vehicle exhaust.

See the relative amounts of CO_2 released by different fossil fuels in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CO2BTU_3.MPG.

FIGURE 13.65
Auto exhaust like this means that the fuels is not burning efficiently.

A few pollutants come primarily from power plants or industrial plants that burn coal or oil. Sulfur dioxide (SO_2) is a major component of industrial air pollution that is released whenever coal and petroleum are burned. SO_2 mixes with H_2O in the air to produce sulfuric acid (H_2SO_4).

Mercury is released when coal and some types of wastes are burned. Mercury is emitted as a gas, but as it cools, it becomes a droplet. Mercury droplets eventually fall to the ground. If they fall into sediments, bacteria convert them to the most dangerous form of mercury: methyl mercury. Highly toxic, methyl mercury is one of the metal's organic forms.

Biomass Burning

Fossil fuels are ancient plants and animals that have been converted into usable hydrocarbons. Burning plant and animal material directly also produces pollutants. Biomass is the total amount of living material found in an environment. The biomass of a rainforest is the amount of living material found in that rainforest.

The primary way biomass is burned is for **slash-and-burn agriculture** (**Figure** 13.66). The rainforest is slashed down and then the waste is burned to clear the land for farming. Biomass from other biomes, such as the savannah, is also burned to clear farmland. The pollutants are much the same as from burning fossil fuels: CO_2, carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon. Burning forests increases greenhouse gases in the atmosphere by releasing the CO_2 stored in the biomass and also by removing the forest so that it cannot store CO_2 in the future. As with all forms of air pollution, the smoke from biomass burning often spreads far and pollutants can plague neighboring states or countries.

Particulates result when anything is burned. About 40% of the particulates that enter the atmosphere above the United States are from industry and about 17% are from vehicles. Particulates also occur naturally from volcanic eruptions or windblown dust. Like other pollutants, they travel all around the world on atmospheric currents.

FIGURE 13.66
A forest that has been slash-and-burned to make new farmland.

Evaporation

Volatile organic compounds (VOCs) enter the atmosphere by evaporation. VOCs evaporate from human-made substances, such as paint thinners, dry cleaning solvents, petroleum, wood preservatives, and other liquids. Naturally occurring VOCs evaporate off of pine and citrus trees. The atmosphere contains tens of thousands of different VOCs, nearly 100 of which are monitored. The most common is methane, a greenhouse gas (**Figure** 13.67). Methane occurs naturally, but human agriculture is increasing the amount of methane in the atmosphere.

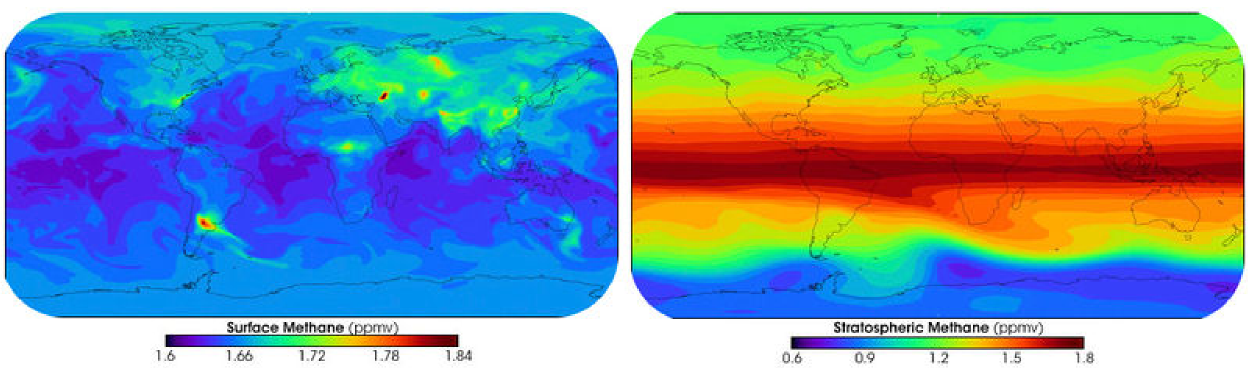


FIGURE 13.67
Methane forms when organic material decomposes in an oxygen-poor environment. In the top image, surface methane production is shown. Stratospheric methane concentrations in the bottom image show that methane is carried up into the stratosphere by the upward flow of air in the tropics.

Vocabulary

- **slash-and-burn agriculture**: A method of clearing land for farming that involves cutting trees and then burning the leftover debris. This is common in rainforests.

Summary

- Most fossil fuels are dirty and release pollutants such as carbon monoxide, nitrogen dioxide, sulfur dioxide, and hydrocarbons.
- Burning plants and other biomass releases pollutants including carbon monoxide, methane, particulates, nitrous oxide, hydrocarbons, and organic and elemental carbon.
- Volatile organic compounds evaporate into the air and become pollutants.

Practice

Use this resource to answer the questions that follow.

http://www.universetoday.com/81977/causes-of-air-pollution/

1. What is air pollution?

2. What are the results of air pollution?

3. How does manufacturing cause pollution?

4. What does the burning of fossil fuels contribute to air pollution?

5. How does the Earth contribute to air pollution?

Review

1. What is slash-and-burn agriculture and what pollutants does it release?

2. Why does burning biomass release pollutants?

3. Name a compound that occurs in the atmosphere naturally but is a pollutant in excess amounts due to human activities.

13.26 Effects of Air Pollution on the Environment

- Explain how air pollution damages the environment.

Did you ever see a sky without contrails?

In the three days after the terrorists attacks on September 11, 2001, jet airplanes did not fly over the United States. Without the gases from jet contrails blocking sunlight, air temperature increased 1°C (1.8°F) across the United States. This is just one of the effects air pollution has on the environment.

Smog Effects on the Environment

All air pollutants cause some damage to living creatures and the environment. Different types of pollutants cause different types of harm.

Particulates

Particulates reduce visibility. In the western United States, people can now ordinarily see only about 100 to 150 kilometers (60 to 90 miles), which is one-half to two-thirds the natural (pre-pollution) range on a clear day. In the East, people can only see about 40 to 60 kilometers (25-35 miles), about one-fifth the distance they could see without any air pollution (**Figure** 13.68).

Particulates reduce the amount of sunshine that reaches the ground, which may reduce photosynthesis. Since particulates form the nucleus for raindrops, snowflakes, or other forms of precipitation, precipitation may increase when particulates are high. An increase in particles in the air seems to increase the number of raindrops, but often decreases their size.

FIGURE 13.68
Smog in New York City.

By reducing sunshine, particulates can also alter air temperature as mentioned above. Imagine how much all of the sources of particulates combine to reduce temperatures. What affect might this have on global warming?

Ozone

Ozone damages some plants. Since ozone effects accumulate, plants that live a long time show the most damage. Some species of trees appear to be the most susceptible. If a forest contains ozone-sensitive trees, they may die out and be replaced by species that are not as easily harmed. This can change an entire ecosystem, because animals and plants may not be able to survive without the habitats created by the native trees.

Some crop plants show ozone damage (**Figure** 13.69). When exposed to ozone, spinach leaves become spotted. Soybeans and other crops have reduced productivity. In developing nations, where getting every last bit of food energy out of the agricultural system is critical, any loss is keenly felt.

FIGURE 13.69
The spots on this leaf are caused by ozone damage.

Oxides

Oxide air pollutants also damage the environment. NO_2 is a toxic, orange-brown colored gas that gives air a distinctive orange color and an unpleasant odor. Nitrogen and sulfur-oxides in the atmosphere create acids that fall as acid rain.

Lichen get a lot of their nutrients from the air so they may be good indicators of changes in the atmosphere such as increased nitrogen. In Yosemite National Park, this could change the ecosystem of the region and lead to fires and other problems.

Find out more at http://science.kqed.org/quest/audio/lichen-point-to-pollution/.

MEDIA

Click image to the left for more content.

Summary

- An increase in particulates may reduce photosynthesis, increase precipitation, and reduce temperatures.
- Ozone may damage native plants and some crop plants by slowing growth or damaging leaves.
- Nitrogen and sulfur-oxides are pollutants. They also create acids in the atmosphere that fall as acid rain.

Practice

Use this resource to answer the questions that follow.

http://www.mass.gov/dep/air/aq/env_effects.htm

1. What is haze?
2. What effects has air pollution had on animals?
3. Why is persistent air pollution a problem in aquatic ecosystems?
4. How can UV radiation damage crops?
5. How have forests been damaged by air pollution?

Review

1. What is the effect of an increase in particulates on the environment?
2. What is the effect of ozone on native and crop plants?
3. What colors do different pollutants have and how could you recognize them on a smoggy day?

13.27 Effects of Air Pollution on Human Health

- Describe the affects of air pollution on are on the rise.

How is breathing on a smoggy day like breathing trash?

On a smoggy day, you're breathing garbage. No different from tossing trash out of a car window with no intention of picking it up, we spew trash into the air as we drive, as we heat our homes, and as we manufacture goods. Would we tolerate all this trash if it were in our houses laying on the ground?

Smog Effects on Human Health

Human health suffers in locations with high levels of air pollution.

Pollutants and their Effects

Different pollutants have different health effects:

- Lead is the most common toxic material and is responsible for lead poisoning.
- Carbon monoxide can kill people in poorly ventilated spaces, such as tunnels.
- Nitrogen and sulfur-oxides cause lung disease and increased rates of asthma, emphysema, and viral infections such as the flu.
- Ozone damages the human respiratory system, causing lung disease. High ozone levels are also associated with increased heart disease and cancer.
- Particulates enter the lungs and cause heart or lung disease. When particulate levels are high, asthma attacks are more common. By some estimates, 30,000 deaths a year in the United States are caused by fine particle pollution.

Human Illnesses from Air Pollution

Many but not all cases of asthma can be linked to air pollution. During the 1996 Olympic Games, Atlanta, Georgia, closed off their downtown to private vehicles. This action decreased ozone levels by 28%. At the same time, there were 40% fewer hospital visits for asthma. Can scientists conclude without a shadow of a doubt that the reduction in ozone caused the reduction in hospital visits? What could they do to make that determination?

Lung cancer among people who have never smoked is around 15% and is increasing. One study showed that the risk of being afflicted with lung cancer increases directly with a person's exposure to air pollution (**Figure** 13.70). The study concluded that no level of air pollution should be considered safe. Exposure to smog also increased the risk of dying from any cause, including heart disease.

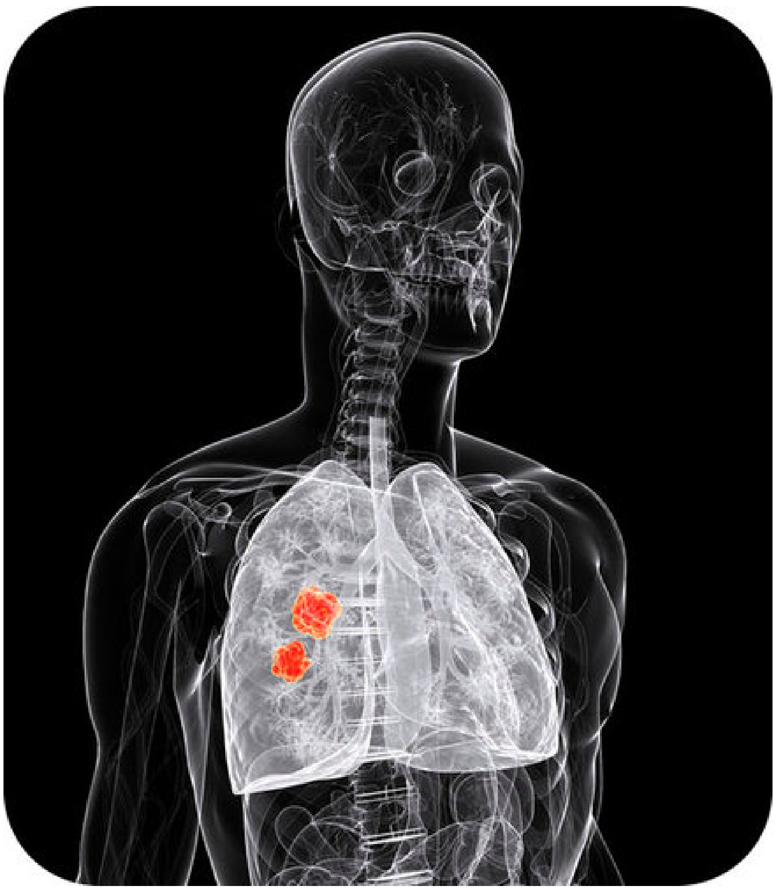


FIGURE 13.70
A lung tumor is highlighted in this chest x-ray.

One study found that in the United States, children develop asthma at more than twice the rate of two decades ago and at four times the rate of children in Canada. Adults also suffer from air pollution-related illnesses that include lung disease, heart disease, lung cancer, and weakened immune systems. The asthma rate worldwide is rising 20% to 50% every decade.

Summary

- Pollutants emitted into the air cause lung and other diseases in humans.
- Asthma, lung cancer, and other lung diseases are linked to air pollution.
- Disease rates for air pollutant related diseases are rising.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=IjpKnoHOu8M

MEDIA

Click image to the left for more content.

1. What is the your body's first line of defense against air pollutants?
2. What happens when people breath in air pollutants?
3. Which populations are most effected by air pollution?
4. Why is air population especially dangerous for infants and toddlers?
5. How much does poor air cost Washington state each year?

Review

1. Lung cancer is on the rise in people who've never smoked. To what might you attribute this fact?
2. What experiments have been done, deliberately or inadvertently, to test the effects of air pollution on asthma?
3. How might the increase in asthma be related to air pollution?

13.28 Mercury Pollution

- Explain the health hazards posed by mercury pollution.

How much fish should you eat?

On the one hand, you hear fish is good for you. On the other, you hear that you're not supposed to eat too much of some types of fish, like tuna. How can something that's supposed to be good for you be harmful to your health?

Mercury Pollution

Mercury is released into the atmosphere when coal is burned (**Figure** 13.71). But breathing the mercury is not harmful. In the atmosphere, the mercury forms small droplets that are deposited in water or sediments.

Bioaccumulation

Do you know why you are supposed to eat large predatory fish like tuna infrequently? It is because of the **bioaccumulation** of mercury in those species.

Some pollutants remain in an organism throughout its life, a phenomenon called bioaccumulation. In this process, an organism accumulates the entire amount of a toxic compound that it consumes over its lifetime. Not all substances bioaccumulate. Can you name one that does not? Aspirin does not bioaccumulate; if it did, a person would quickly accumulate a toxic amount in her body. Compounds that bioaccumulate are usually stored in the organism's fat.

In the sediments, bacteria convert the droplets to the hazardous compound methyl mercury. Bacteria and plankton store all of the mercury from all of the seawater they ingest (**Figure** 13.72). A small fish that eats bacteria and plankton accumulates all of the mercury from all of the tiny creatures it eats over its lifetime. A big fish accumulates all of the mercury from all of the small fish it eats over its lifetime. For a tuna at the top of the food chain, that's a lot of mercury.

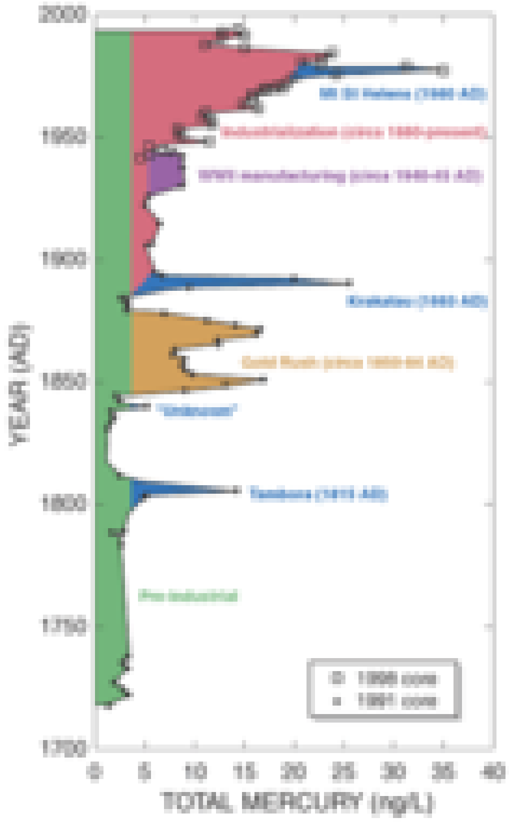


FIGURE 13.71
Historic increases of mercury in the atmosphere: blue is volcanic eruptions; brown, purple, and pink are human-caused. The red region shows the effect of industrialization on atmospheric mercury.

So tuna pose a health hazard to anything that eats them because their bodies are so high in mercury. This is why the government recommends limits on the amount of tuna that people eat. Limiting intake of large predatory fish is especially important for children and pregnant women. If the mercury just stayed in a person's fat, it would not be harmful, but that fat is used when a woman is pregnant or nursing a baby. A person will also get the mercury into her system when she (or he) burns the fat while losing weight.

Mad As a Hatter

Methyl mercury poisoning can cause nervous system or brain damage, especially in infants and children. Children may experience brain damage or developmental delays. The phrase "mad as a hatter" was common when Lewis Carroll wrote his Alice in Wonderland stories. It was based on symptoms suffered by hatters who were exposed to mercury and experienced mercury poisoning while using the metal to make hats (**Figure** 13.73). Like mercury, other metals and VOCS can bioaccumulate, causing harm to animals and people high on the food chain.

Mercury, a potent neurotoxin, has been flowing into the San Francisco Bay since the Gold Rush Era. It has settled in the bay's mud and made its way up the food chain, endangering wildlife and making many fish unsafe to eat. Now a multi-billion-dollar plan aims to clean it up.

Find out more at http://science.kqed.org/quest/video/mercury-in-san-francisco-bay/.

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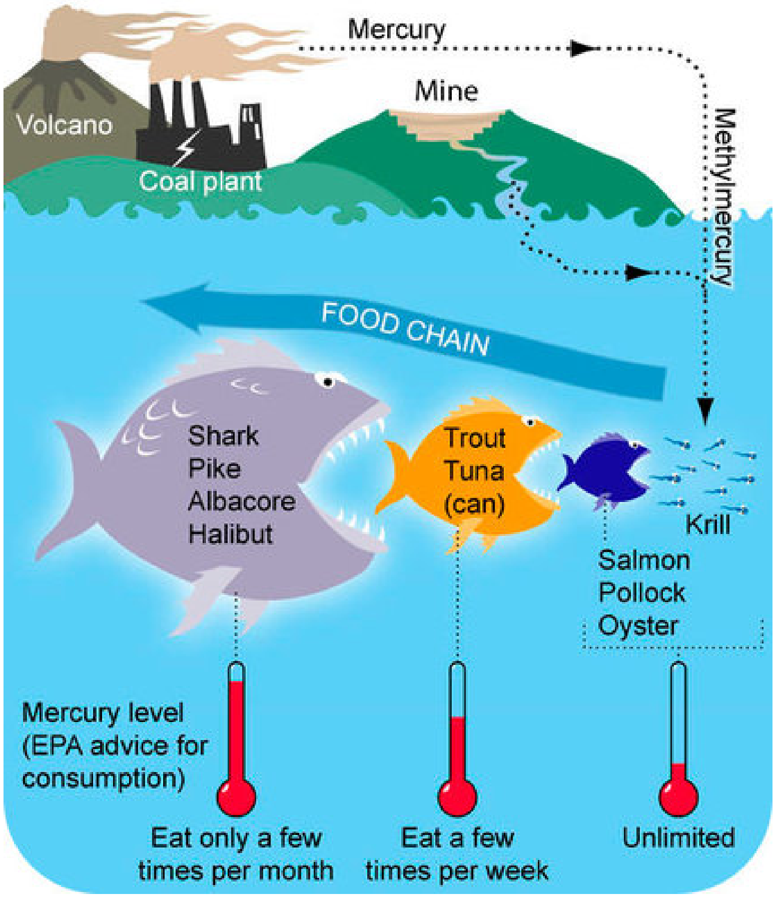


FIGURE 13.72
Methyl mercury bioaccumulates up the food chain.

Vocabulary

- **bioaccumulation**: The accumulation of toxic substances within organisms so that the concentrations increase up the food web.

Summary

- Burning coal releases mercury into the atmosphere. It falls into sediments and is converted into methyl mercury by bacteria.
- Creatures ingest the methyl mercury and store it. Then, larger creatures eat them and store all of that methyl mercury, on up the food chain.
- Mercury poisoning causes nervous system damage.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=xRqAS4Eow-c

FIGURE 13.73
The Mad Hatter.

MEDIA
Click image to the left for more content.

1. What is a natural source of mercury in the air?
2. What the are the human-made sources of mercury?
3. Why is Acadia National Park concerned about mercury?
4. What is biomagnification?
5. What are the toxic effects of mercury?
6. Explain what people can do to reduce mercury in the environment.

Review

1. What is bioaccumulation?
2. How does mercury change from something benign to something harmful?
3. Why should you restrict your intake of tuna and other large predatory fish but continue to eat or even increase your consumption of small fish that are low on the food chain, like anchovies?

13.29 Acid Rain

- Describe the causes and consequences of acid rain.

What made the pits in this gargoyle?

This gargoyle, on Notre Dame Cathedral in Paris, has pits and rounded edges, which are the results of acid rain. Acid rain damages statues and architecture in developed nations.

Acid Rain

Acid rain is caused by sulfur and nitrogen oxides emanating from power plants or metal refineries. The smokestacks have been built tall so that pollutants don't sit over cities (**Figure** 13.74).

FIGURE 13.74
Tall smokestacks allow the emissions to rise high into the atmosphere and travel up to 1,000 km (600 miles) downwind.

As they move, these pollutants combine with water vapor to form sulfuric and nitric acids. The acid droplets form acid fog, rain, snow, or they may be deposited dry. Most typical is acid rain (**Figure** 13.75).

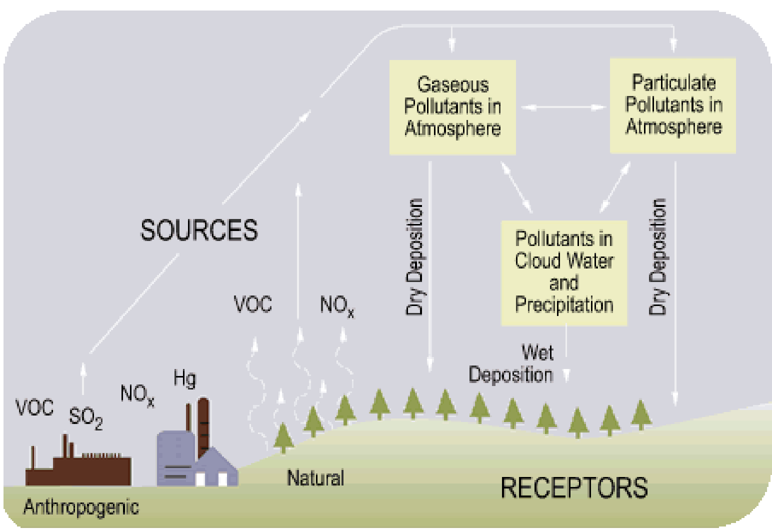


FIGURE 13.75
Pollutants are deposited dry or in precipitation.

pH and Acid Rain

Acid rain water is more acidic than normal rain water. Acidity is measured on the **pH scale**. Lower numbers are more acidic and higher numbers are less acidic (also called more **alkaline**) (**Figure** 13.76). Natural rain is somewhat acidic, with a pH of 5.6; acid rain must have a pH of less than 5.0. A small change in pH represents a large change in acidity: rain with a pH of 4.6 is 10 times more acidic than normal rain (with a pH of 5.6). Rain with a pH of 3.6 is 100 times more acidic.

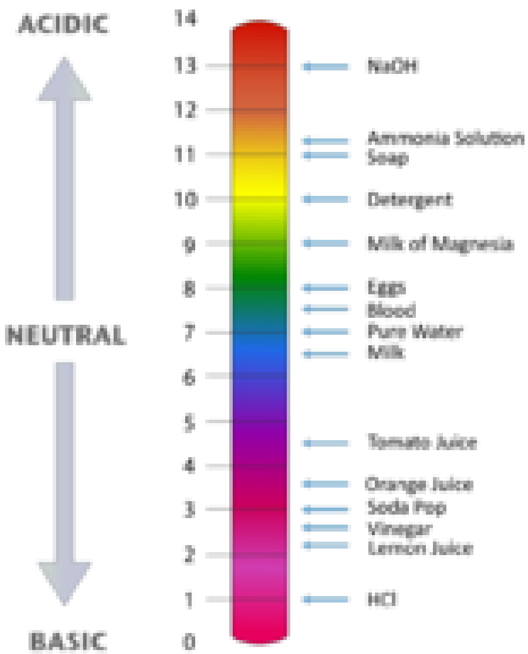


FIGURE 13.76
A pH scale goes from 1 to 14; numbers are shown with the pH of some common substances. A value of 7 is neutral. The strongest acids are at the low end of the scale and the strongest bases are at the high end.

Regions with a lot of coal-burning power plants have the most acidic rain. The acidity of average rainwater in the northeastern United States has fallen to between 4.0 and 4.6. Acid fog has even lower pH with an average of around 3.4. One fog in Southern California in 1986 had a pH of 1.7, equal to toilet-bowl cleaner.

In arid climates, such as in Southern California, acids deposit on the ground dry. Acid precipitation ends up on the land surface and in water bodies. Some forest soils in the northeast are five to ten times more acidic than they were two or three decades ago. Acid droplets move down through acidic soils to lower the pH of streams and lakes even more. Acids strip soil of metals and nutrients, which collect in streams and lakes. As a result, stripped soils may no longer provide the nutrients that native plants need.

Effects of Acid Rain

Acid rain takes a toll on ecosystems (**Figure** 13.77). Plants that are exposed to acids become weak and are more likely to be damaged by bad weather, insect pests, or disease. Snails die in acid soils, so songbirds do not have as much food to eat. Young birds and mammals do not build bones as well and may not be as strong. Eggshells may also be weak and break more easily.

As lakes become acidic, organisms die off. No fish can live if the pH drops below 4.5. Organic material cannot decay, and mosses take over the lake. Wildlife that depend on the lake for drinking water suffer population declines.

Crops are damaged by acid rain. This is most noticeable in poor nations where people can't afford to fix the problems with fertilizers or other technology.

Acid rain damages cultural monuments like buildings and statues. These include the U.S. Capitol and many buildings in Europe, such as Westminster Abbey.

Carbonate rocks neutralize acids and so some regions do not suffer the effects of acid rain nearly as much. Limestone in the midwestern United States protects the area. One reason that the northeastern United States is so vulnerable to

FIGURE 13.77
Acid rain has killed trees in this forest in the Czech Republic.

acid rain damage is that the rocks are not carbonates.

Because pollutants can travel so far, much of the acid rain that falls hurts states or nations other than ones where the pollutants were released. All the rain that falls in Sweden is acidic and fish in lakes all over the country are dying. The pollutants come from the United Kingdom and Western Europe, which are now working to decrease their emissions. Canada also suffers from acid rain that originates in the United States, a problem that is also improving. Southeast Asia is experiencing more acid rain between nations as the region industrializes.

Vocabulary

- **acid rain**: Rain that has a pH of less than 5.0.
- **alkaline**: Also called basic. Substances that have a pH of greater than 7.0.
- **pH scale**: A scale that measures the acidity of a solution. A pH of 7 is neutral. Smaller numbers are more acidic and larger numbers are more alkaline.

Summary

- Nitrogen and sulfur compounds emitted high into the atmosphere create acids that later fall as acid rain.
- Acidity is measured on a pH scale. Rain that is 5.0 or less on that scale is considered acid rain.
- Acid rain weakens plants and animals and damages cultural treasures.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=HE6Y0iEuXMQ

MEDIA

Click image to the left for more content.

1. What causes acid rain?
2. What two gases react with water to make acid rain?
3. What damage can acid rain cause?
4. How can we reduce acid rain?
5. What are scrubbers?
6. What is slurry?
7. How effective are scrubbers?

Review

1. Where does much of the acid rain fall and where does acid rain do the most damage?
2. What damage does acid rain do to organisms and cultural structures?
3. One problem with acid rain is that the pollutants that cause it may be emitted far upwind from where it falls in a different country. How can nations deal with this problem?

13.30 Ozone Depletion

- Explain how a hole in the ozone layer forms, and describe the effects that follow.

Why can't the children in Punta Arenas go outside in the spring?

Children in Punta Arenas, Chile, the world's most southern city, look forward to spring as much as anyone who lives through a frigid, dark winter. But some years, the children are instructed not to go outside because the ozone hole has moved north and the UV radiation is too high.

Ozone Depletion

At this point you might be asking yourself, "Is ozone bad or is ozone good?" There is no simple answer to that question: It depends on where the ozone is located (**Figure** 13.78).

- In the troposphere, ozone is a pollutant.
- In the ozone layer in the stratosphere, ozone screens out high energy ultraviolet radiation and makes Earth habitable.

How Ozone is Destroyed

Human-made chemicals are breaking ozone molecules in the ozone layer. Chlorofluorocarbons (CFCs) are the most common, but there are others, including halons, methyl bromide, carbon tetrachloride, and methyl chloroform. CFCs were once widely used because they are cheap, nontoxic, nonflammable, and non-reactive. They were used as spray-can propellants, refrigerants, and in many other products.

Once they are released into the air, CFCs float up to the stratosphere. Air currents move them toward the poles. In the winter, they freeze onto nitric acid molecules in **polar stratospheric clouds (PSC)** (**Figure** 13.79). In the spring,

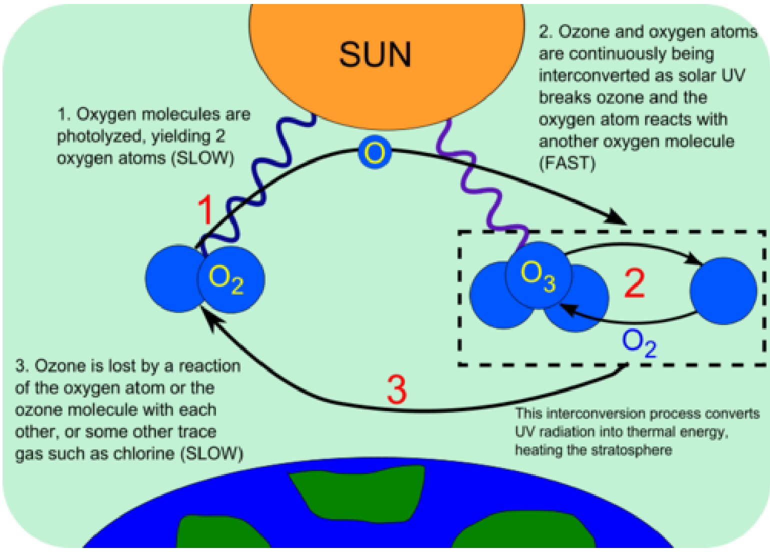


FIGURE 13.78

(1) Solar energy breaks apart oxygen molecules into two oxygen atoms. (2) Ozone forms when oxygen atoms bond together as O_3. UV rays break apart the ozone molecules into one oxygen molecule (O_2) and one oxygen atom (O). These processes convert UV radiation into heat, which is how the Sun heats the stratosphere. (3) Under natural circumstances, the amount of ozone created equals the amount destroyed. When O_3 interacts with chlorine or some other gases the O_3 breaks down into O_2 and O and so the ozone layer loses its ability to filter out UV.

the sun's warmth starts the air moving, and ultraviolet light breaks the CFCs apart. The chlorine atom floats away and attaches to one of the oxygen atoms on an ozone molecule. The chlorine pulls the oxygen atom away, leaving behind an O_2 molecule, which provides no UV protection. The chlorine then releases the oxygen atom and moves on to destroy another ozone molecule. One CFC molecule can destroy as many as 100,000 ozone molecules.

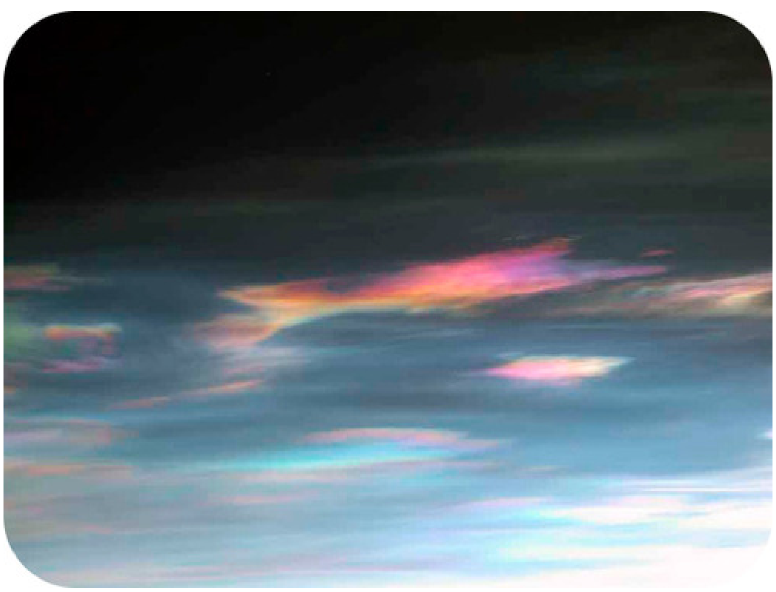


FIGURE 13.79

PSCs form only where the stratosphere is coldest, and are most common above Antarctica in the wintertime. PSCs are needed for stratospheric ozone to be destroyed.

The Ozone Hole

Ozone destruction creates the **ozone hole** where the layer is dangerously thin (**Figure** 13.80). As air circulates over Antarctica in the spring, the ozone hole expands northward over the southern continents, including Australia, New Zealand, southern South America, and southern Africa. UV levels may rise as much as 20% beneath the ozone hole.

The hole was first measured in 1981 when it was 2 million square km (900,000 square miles). The 2006 hole was the largest ever observed at 28 million square km (11.4 million square miles). The size of the ozone hole each year depends on many factors, including whether conditions are right for the formation of PSCs.

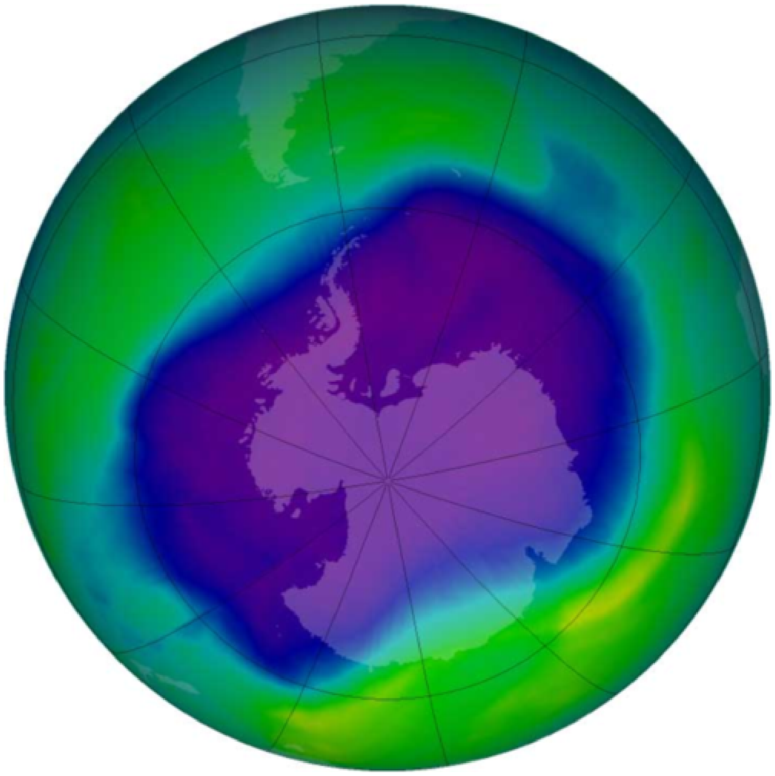


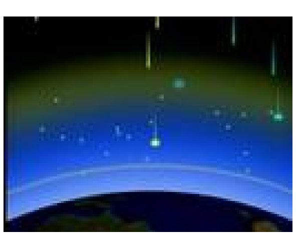
FIGURE 13.80
The September 2006 ozone hole, the largest observed (through 2011). Blue and purple colors show particularly low levels of ozone.

Find out how the ozone hole forms and view the hole over time on this National Geographic video: http://news.nationalgeographic.com/news/2008/11/081103-ozone-video-vin.html.

Ozone Loss in the North

Ozone loss also occurs over the North Polar Region, but it is not enough for scientists to call it a hole. Why do you think there is less ozone loss over the North Pole area? The region of low ozone levels is small because the atmosphere is not as cold and PSCs do not form as readily. Still, springtime ozone levels are relatively low. This low moves south over some of the world's most populated areas in Europe, North America, and Asia. At 40^oN, the latitude of New York City, UV-B has increased about 4% per decade since 1978. At 55^oN, the approximate latitude of Moscow and Copenhagen, the increase has been 6.8% per decade since 1978.

This video explains an importance of the stratospheric ozone layer to life on Earth **(8c)**: http://www.youtube.com/watch?v=I1wrEvc2URE#38;feature=related (1:52).



MEDIA
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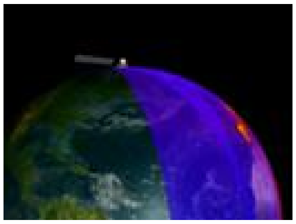
This NASA video discusses the ingredients of ozone depletion of Antarctica and the future of the ozone hole, including the effect of climate change **(8c)**: http://www.youtube.com/watch?v=qUfVMogIdr8#38;feature=related (2:20).



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Effects of Ozone Loss

Ozone losses on human health and environment include:

- Increases in sunburns, cataracts (clouding of the lens of the eye), and skin cancers. A loss of ozone of only 1% is estimated to increase skin cancer cases by 5% to 6%.
- Decreases in the human immune system's ability to fight off infectious diseases.
- Reduction in crop yields because many plants are sensitive to ultraviolet light.
- Decreases in phytoplankton productivity. A decrease of 6% to 12% has been measured around Antarctica, which may be at least partly related to the ozone hole. The effects of excess UV on other organisms is not known.
- Whales in the Gulf of California have been found to have sunburned cells in their lowest skin layers, indicating very severe sunburns. The problem is greatest with light colored species or species that spend more time near the sea surface.

When the problem with ozone depletion was recognized, world leaders took action. CFCs were banned in spray cans in some nations in 1978. The greatest production of CFCs was in 1986, but it has declined since then. This will be discussed more in the next lesson.

Vocabulary

- **ozone hole**: A region around Antarctica in which ozone levels are reduced in springtime because of the action of ozone-destroying chemicals.
- **polar stratospheric clouds (PSC)**: Clouds that form in the stratosphere when it is especially cold; PSCs are necessary for the breakup of chlorofluorocarbons (CFCs).

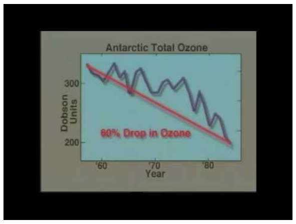
Summary

- CFCs float up into the stratosphere where they break apart. The chlorine pulls an oxygen ion off of an ozone molecule and destroys it.
- The ozone hole is where there is less ozone than normal at that altitude. It forms in the spring.
- Ozone loss increases the amount of high-energy ultraviolet radiation that can strike Earth, causing ecological and health problems.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=xDOFJ5xoGmw

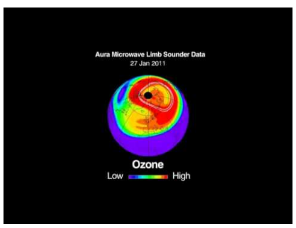


MEDIA

Click image to the left for more content.

1. What is the purpose of the ozone?
2. Why is the ozone layer so fragile?
3. How much did ozone decrease between 1979 and 1993?
4. Which satellite was launched to study the ozone? When?

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



MEDIA

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5. What caused this ozone loss?

Review

1. How do CFCs destroy ozone?
2. What is the ozone hole and where is it found? Is there an equivalent hole in the Northern Hemisphere?
3. What are some of the consequences of ozone loss that have been identified?

13.31 Reducing Air Pollution

- Describe ways to reduce air pollution.

What does a catalytic converter do anyway?

In the days before catalytic converters, cars spewed lots of smoke. Laws governing emissions have helped to clean up the air.

The Clean Air Act

The Clean Air Act of 1970 and the amendments since then have done a great job in requiring people to clean up the air over the United States. Emissions of the six major pollutants regulated by the Clean Air Act — carbon monoxide, lead, nitrous oxides, ozone, sulfur dioxide, and particulates — have decreased by more than 50%. Cars, power plants, and factories individually release less pollution than they did in the mid-20th century. But there are many more cars, power plants, and factories. Many pollutants are still being released and some substances have been found to be pollutants that were not known to be pollutants in the past. There is still much work to be done to continue to clean up the air.

Reducing Air Pollution from Vehicles

Reducing air pollution from vehicles can be done in a number of ways.

- Breaking down pollutants before they are released into the atmosphere. Motor vehicles emit less pollution than they once did because of **catalytic converters** (**Figure** 13.81). Catalytic converters contain a **catalyst** that speeds up chemical reactions and breaks down nitrous oxides, carbon monoxide, and VOCs. Catalytic converters only work when they are hot, so a lot of exhaust escapes as the car is warming up.

FIGURE 13.81
Catalytic converters are placed on modern cars in the United States.

- Making a vehicle more fuel efficient. Lighter, more streamlined vehicles need less energy. **Hybrid vehicles** have an electric motor and a rechargeable battery. The energy that would be lost during braking is funneled into charging the battery, which then can power the car. The internal combustion engine only takes over when power in the battery has run out. Hybrids can reduce auto emissions by 90% or more, but many models do not maximize the possible fuel efficiency of the vehicle.

A plug-in hybrid is plugged into an electricity source when it is not in use, perhaps in a garage, to make sure that the battery is charged. Plug-in hybrids run for a longer time on electricity and so are less polluting than regular hybrids. Plug-in hybrids began to become available in 2010.

- Developing new technologies that do not use fossil fuels. Fueling a car with something other than a liquid organic-based fuel is difficult. A **fuel cell** converts chemical energy into electrical energy. Hydrogen fuel cells harness the energy released when hydrogen and oxygen come together to create water (**Figure** 13.82). Fuel cells are extremely efficient and they produce no pollutants. But developing fuel-cell technology has had many problems and no one knows when or if they will become practical.

Reducing Industrial Air Pollution

Pollutants are removed from the exhaust streams of power plants and industrial plants before they enter the atmosphere. Particulates can be filtered out, and sulfur and nitric oxides can be broken down by catalysts. Removing these oxides reduces the pollutants that cause acid rain.

Particles are relatively easy to remove from emissions by using motion or electricity to separate particles from the gases. Scrubbers remove particles and waste gases from exhaust using liquids or neutralizing materials (**Figure** 13.83). Gases, such as nitrogen oxides, can be broken down at very high temperatures.

FIGURE 13.82

A hydrogen fuel-cell car looks like a gasoline-powered car.

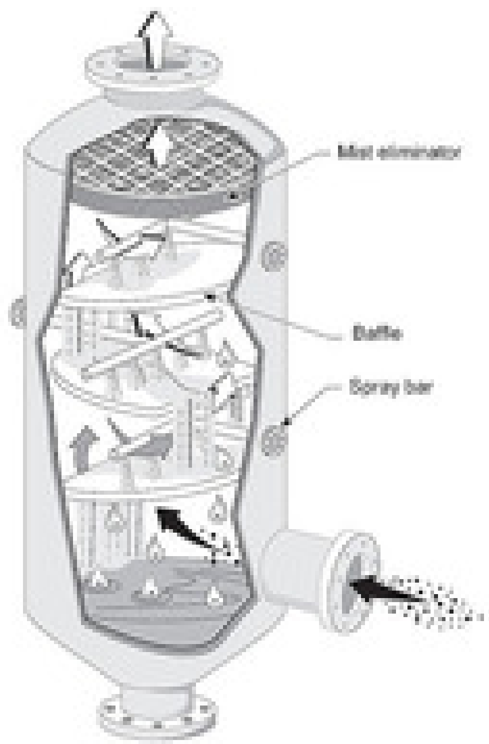


FIGURE 13.83

Scrubbers remove particles and waste gases from exhaust.

Gasification

Gasification is a developing technology. In gasification, coal (rarely is another organic material used) is heated to extremely high temperatures to create syngas, which is then filtered. The energy goes on to drive a generator. Syngas releases about 80% less pollution than regular coal plants, and greenhouse gases are also lower. Clean coal plants do not need scrubbers or other pollution control devices. Although the technology is ready, clean coal plants are more expensive to construct and operate. Also, heating the coal to high enough temperatures uses a great deal of energy, so the technology is not energy efficient. In addition, large amounts of the greenhouse gas CO_2 are still released with clean coal technology. Nonetheless, a few of these plants are operating in the United States and around the world.

Ways You Can Reduce Air Pollution

How can air pollution be reduced? Using less fossil fuel is one way to lessen pollution. Some examples of ways to conserve fossil fuels are:

- Riding a bike or walking instead of driving.
- Taking a bus or carpooling.
- Buying a car that has greater fuel efficiency.
- Turning off lights and appliances when they are not in use.
- Using energy efficient light bulbs and appliances.
- Buying fewer things that are manufactured using fossil fuels.

All these actions reduce the amount of energy that power plants need to produce.

Developing alternative energy sources is important. What are some of the problems facing wider adoption of alternative energy sources?

- The technologies for several sources of alternative energy, including solar and wind, are still being developed.
- Solar and wind are still expensive relative to using fossil fuels. The technology needs to advance so that the price falls.
- Some areas get low amounts of sunlight and are not suited for solar. Others do not have much wind. It is important that regions develop what best suits them. While the desert Southwest will need to develop solar, the Great Plains can use wind energy as its energy source. Perhaps some locations will rely on nuclear power plants, although current nuclear power plants have major problems with safety and waste disposal.

Sometimes technological approaches are what is needed.

National Geographic videos exploring energy conservation are found in Environment Videos, Energy: http://video.nationalgeographic.com/video/environment/energy-environment.

- Alternative Energy
- Fuel Cells
- Solar Power

What you can do to your home to help reduce energy use: http://www.youtube.com/watch?v=6h8QjZvcp0I#38;feature=related.

A very simple thing you can do to conserve energy is discussed in "This Bulb": http://www.youtube.com/watch?v=FvOBHMb6Cqc.

Vocabulary

- **catalyst**: A substance that increases (or decreases) the rate of a chemical reaction but is not used up in the reaction.
- **catalytic converter**: Found on modern motor vehicles, these devices use a catalyst to break apart pollutants.
- **fuel cell**: An energy cell in which chemical energy is converted into electrical energy.
- **gasification**: A technology that cleans coal before it is burned, which increases efficiency and reduces emissions.
- **hybrid vehicle**: A very efficient vehicle that is powered by an internal combustion engine, an electric motor and a rechargeable battery.

Summary

- Catalytic converters break down some pollutants, but only when they are hot.
- Hybrid vehicles use the energy that is usually wasted as a car slows to charge a battery that then powers the car.
- Different types of clean energy can be developed for different locations, such as solar for the desert southwest and wind for coastal regions.

Practice

Use this resource to answer the questions that follow.

http://www.epa.gov/air/caa/40th_highlights.html

1. How have lead levels changed in ambient air?
2. How has reducing acid rain helped the environment?
3. How much has acid deposition been reduced?
4. How much have toxic emissions from industry been reduced?
5. Explain the technologies that have improved vehicle emissions.

Review

1. How do fuel cells work, what are their advantages, and why are they not used in every vehicle?
2. What is gasification technology and what role could it play in reducing air pollution?
3. What can you do to reduce the amount of air pollution you produce?

13.32 Reducing Ozone Destruction

- Describe efforts to reduce ozone destruction.

What would have happened if CFCs had not been phased out?

Had CFCs not been phased out, by 2050 there would have been 10 times more skin cancer cases than in 1980. The result would have been about 20 million more cases of skin cancer in the United States and 130 million cases globally.

Reducing Ozone Destruction

One success story in reducing pollutants that harm the atmosphere concerns ozone-destroying chemicals. In 1973, scientists calculated that CFCs could reach the stratosphere and break apart. This would release chlorine atoms, which would then destroy ozone. Based only on their calculations, the United States and most Scandinavian countries banned CFCs in spray cans in 1978.

More confirmation that CFCs break down ozone was needed before more was done to reduce production of ozone-destroying chemicals. In 1985, members of the British Antarctic Survey reported that a 50% reduction in the ozone layer had been found over Antarctica in the previous three springs.

The Montreal Protocol

Two years after the British Antarctic Survey report, the "Montreal Protocol on Substances that Deplete the Ozone Layer" was ratified by nations all over the world.

The Montreal Protocol controls the production and consumption of 96 chemicals that damage the ozone layer (**Figure** 13.84). Hazardous substances are phased out first by developed nations and one decade later by developing nations. More hazardous substances are phased out more quickly. CFCs have been mostly phased out since 1995, although were used in developing nations until 2010. Some of the less hazardous substances will not be phased out until 2030. The Protocol also requires that wealthier nations donate money to develop technologies that will replace these chemicals.

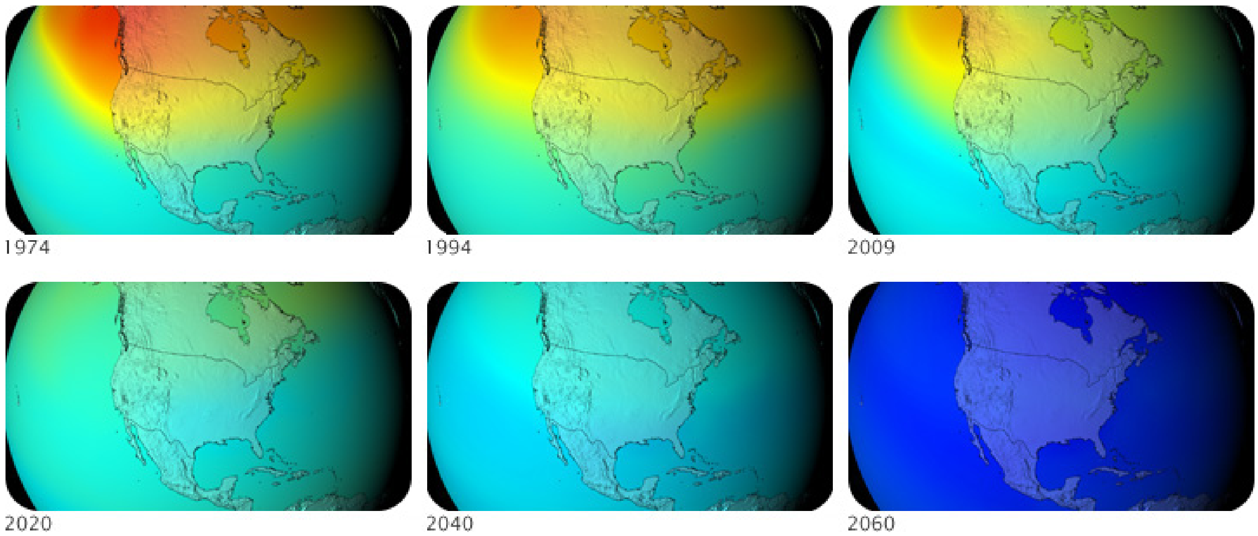


FIGURE 13.84
Ozone levels over North America decreased between 1974 and 2009. Models of the future predict what ozone levels would have been if CFCs were not being phased out. Warmer colors indicate more ozone.

Since CFCs take many years to reach the stratosphere and can survive there a long time before they break down, the ozone hole will probably continue to grow for some time before it begins to shrink. The ozone layer will reach the same levels it had before 1980 around 2068 and 1950 levels in one or two centuries.

Summary

- Calculations of ozone destruction prompted governments to ban some CFCs in 1978.
- The Montreal Protocol protects the ozone layer by regulating the production and consumption of ozone-destroying chemicals.
- Ozone levels continue to decrease, but the ozone hole will eventually begin to get smaller.

Practice

Use this resource to answer the questions that follow:

http://www.youtube.com/watch?v=tnp0YU3u1r4

MEDIA

Click image to the left for more content.

1. What problems can overexposure to UV light cause?
2. When was the Montreal Protocol signed?
3. What has been phased out due to the Montreal Protocol?
4. How long will it take the ozone to recover?
5. When will HCFCs be phased out?
6. Explain why the Montreal Protocol has been successful.
7. What company has spent $40 million researching clean cooling technology?

Review

1. How did mathematical calculations and observations of depletion of ozone over Antarctica prompt society to act to protect the ozone layer?
2. What is the Montreal Protocol?
3. Why doesn't the ozone hole repair itself now that CFCs are banned?

13.33 Climate Change in Earth History

- Explain how Earth's climate has changed in the past.

How important is climate in the history of life?

Dinosaurs lived a long time, geologically speaking, in part because the weather was favorable to them. Giant mammals lived during the ice ages because conditions were favorable. Earth's climate has been warmer and colder in Earth history, but mostly it's been warmer.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago (**Figure** 13.85). Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

For the past 2,000 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5^{o}C (10^{o}F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1^{o}C (2.0^{o}F) higher than today (**Figure** 13.86).

Since the end of the Pleistocene, the global average temperature has risen about 4^{o}C (7^{o}F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

FIGURE 13.85
The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

Summary

- Earth's climate has been warmer and colder, but mostly warmer, through Earth history.
- For the past 2,000 years, when human society has really blossomed, climate has been relatively stable.
- An increase in glaciers lowers sea level and a decrease in glaciers raises sea level.

Practice

Use this resource to answer the questions that follow.

http://climate.nasa.gov/evidence/

1. When did the last ice age end?
2. What is most historical climate variation attributed to?
3. What has occurred in the last 1,300 years?
4. What have ice cores shown?

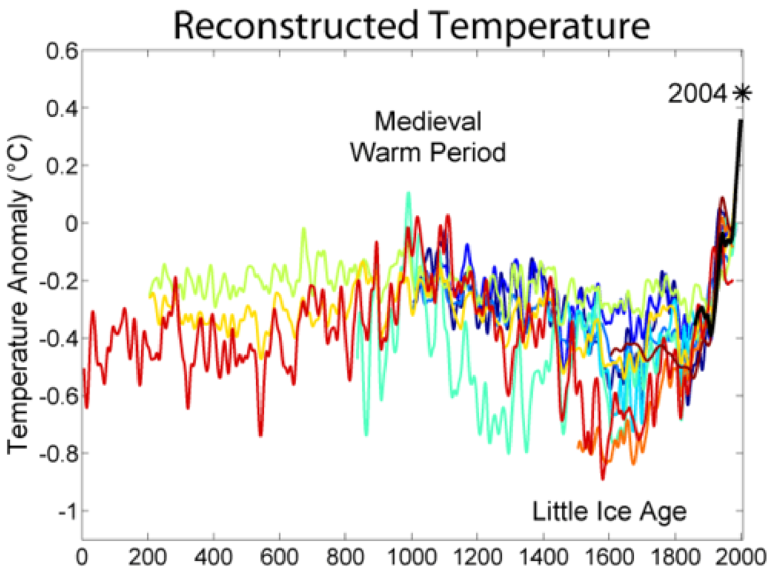


FIGURE 13.86

The graph is a compilation of 10 reconstructions (the colored lines) of mean temperature changes and one graph of instrumentally recorded data of mean temperature changes (black). This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

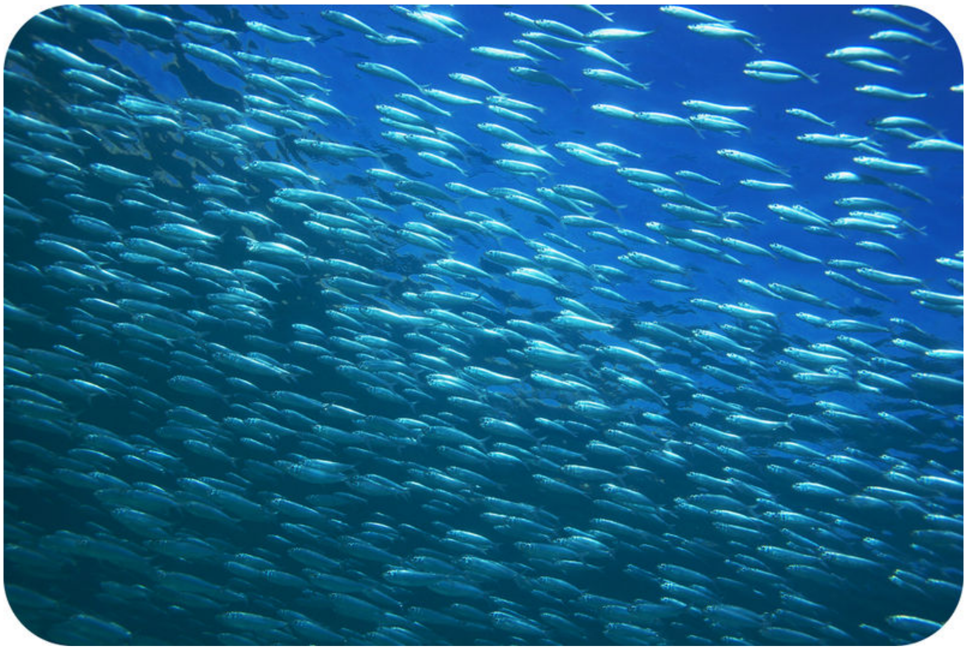
5. List the effects of global climate change.

Review

1. How has climate changed in the past 1,100 years?
2. What were the temperatures of the glacial and interglacial periods of the Pleistocene ice ages?
3. Why is the fact that climate has changed a lot during Earth history important to a discussion of climate change today?

13.34 Short-Term Climate Change

- Describe common short-term climate variations.



Why is El Niño important to a discussion on climate change?

In 1973 a severe El Niño shut off upwelling off of South America, resulting in the collapse of the anchovetta fishery. Without small fish to eat, larger marine organisms died off. Since then, severe El Niño events have become more frequent.

El Niño Southern Oscillation

Short-term changes in climate are common and they have many causes (**Figure** 13.87). The largest and most important of these is the oscillation between El Niño and La Niña conditions. This cycle is called the ENSO (El Niño Southern Oscillation). The ENSO drives changes in climate that are felt around the world about every two to seven years.

Normal Conditions

In a normal year, the trade winds blow across the Pacific Ocean near the equator from east to west (toward Asia). A low pressure cell rises above the western equatorial Pacific. Warm water in the western Pacific Ocean raises sea levels by half a meter. Along the western coast of South America, the Peru Current carries cold water northward, and then westward along the equator with the trade winds. Upwelling brings cold, nutrient-rich waters from the deep sea.

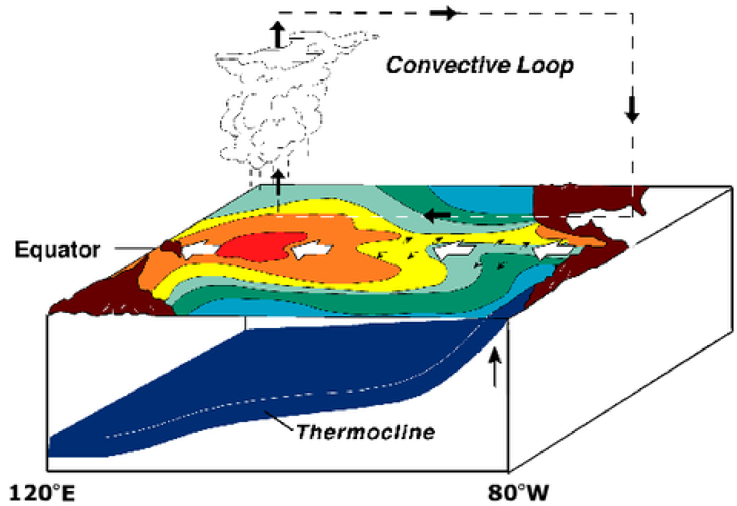


FIGURE 13.87
Under normal conditions, low pressure and warm water (shown in red) build up in the western Pacific Ocean. Notice that continents are shown in brown in the image. North and South America are on the right in this image.

El Niño

In an **El Niño** year, when water temperature reaches around 28^{o}C (82^{o}F), the trade winds weaken or reverse direction and blow east (toward South America) (**Figure** 13.88). Warm water is dragged back across the Pacific Ocean and piles up off the west coast of South America. With warm, low-density water at the surface, upwelling stops. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans, are affected by the decline in fish.

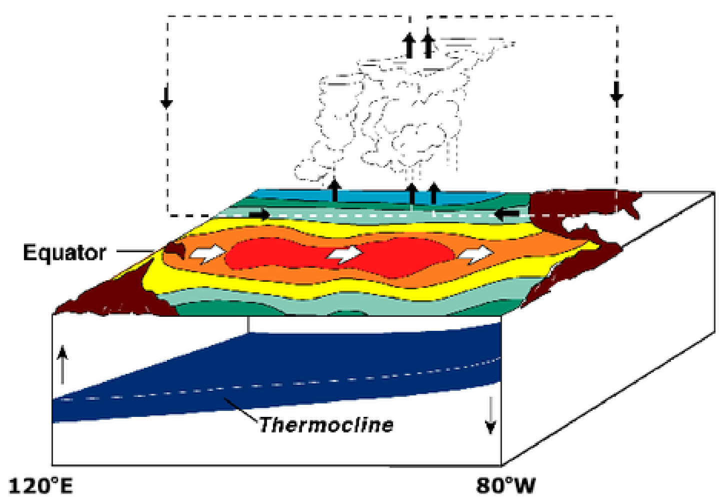


FIGURE 13.88
In El Niño conditions, the trade winds weaken or reverse directions. Warm water moves eastward across the Pacific Ocean and piles up against South America.

By altering atmospheric and oceanic circulation, El Niño events change global climate patterns.

- Some regions receive more than average rainfall, including the west coast of North and South America, the southern United States, and Western Europe.
- Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and

southern Europe.

An El Niño cycle lasts one to two years. Often, normal circulation patterns resume. Sometimes circulation patterns bounce back quickly and extremely (**Figure** 13.89). This is a **La Niña**.

La Niña

In a La Niña year, as in a normal year, trade winds moves from east to west and warm water piles up in the western Pacific Ocean. Ocean temperatures along coastal South America are colder than normal (instead of warmer, as in El Niño). Cold water reaches farther into the western Pacific than normal.

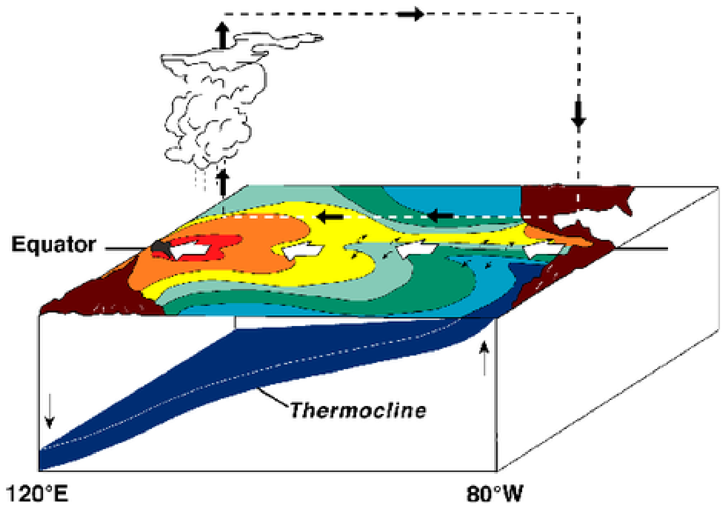


FIGURE 13.89
A La Niña year is like a normal year but the circulation patters are more extreme.

An online guide to El Niño and La Niña events from the University of Illinois is found here: http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/eln/home.rxml.

Other important oscillations are smaller and have a local, rather than global, effect. The North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times and warm and wet at others.

This ABC News video explores the relationship of El Niño to global warming. El Niño is named as the cause of strange weather across the United States in the winter of 2007 in this video **(5g)**: http://www.youtube.com/watch?v=5uk9nwtAOio#38;feature=related (3:33).

MEDIA
Click image to the left for more content.

Vocabulary

- **El Niño**: A natural climate variation in which the trade winds weaken or reverse directions, and warm water accumulates on the ocean surface off of South America.

- **La Niña**: A natural climate variation in which the trade winds are stronger than normal and surface water off of South America is cold.

Summary

- El Niño and La Niña are two examples of short-term climate changes lasting one to a few years.
- In an El Niño, the trade winds reverse direction, as do the equatorial surface currents, causing warm water to pool off of South America and stop upwelling.
- A La Niña is like normal conditions only more so.

Practice

Use this resource to answer the questions that follow.

http://video.nationalgeographic.com/video/player/environment/environment-natural-disasters/landslides-and-more/el-nino.html

MEDIA
Click image to the left for more content.

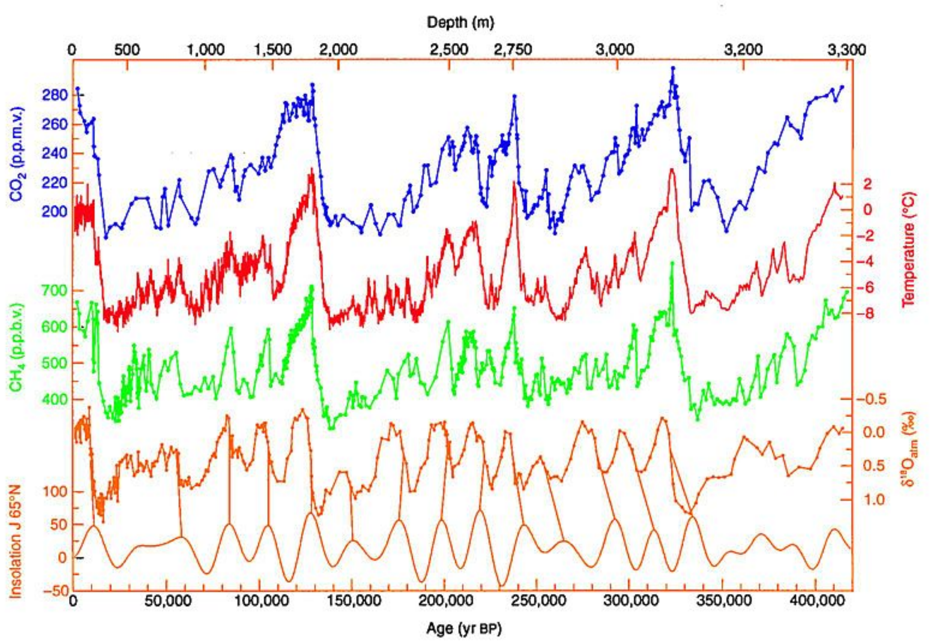
1. What happened in 1998?
2. What is El Niño?
3. Where does the warm water gather?
4. What are the effects of El Niño?
5. What is La Niña?
6. What specific effects were seen due to the El Niño of 1997-1998 in North America?
7. What happened in the ocean?
8. How was animal life effected by the El Niño phenomenon?

Review

1. Describe what happens with wind and current directions during an El Niño event.
2. Why does an El Niño cause a collapse of the food chain off of South America?
3. How does a La Niña event compare with an El Niño event?

13.35 Long-Term Climate Change

- Explain mechanisms that can change climate over the long term.



Why do the blue, green and red lines go in the same direction at the same time?

This is a complicated graph, but extremely interesting. The data are from the 3600 meter-long Vostok ice core, which gave climate scientists an unprecedented look into the history of Earth's climate. The red line is temperature. You can see that carbon dioxide and methane are correlated with temperature. When these greenhouse gases are high, temperature is high. This holds true for the 440,000 years revealed in the core.

Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes:

- In the amount of energy the Sun produces over years.
- In the positions of the continents over millions of years.
- In the tilt of Earth's axis and orbit over thousands of years.
- That are sudden and dramatic because of random catastrophic events, such as a large asteroid impact.
- In greenhouse gases in the atmosphere, caused naturally or by human activities.

Solar Variation

The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle (**Figure** 13.90). When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is, and there is no known 11-year cycle in climate variability. The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

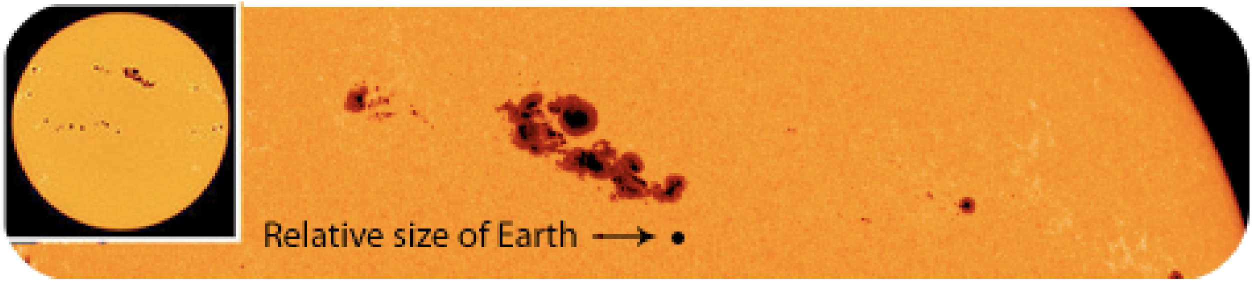


FIGURE 13.90

Sunspots on the face of the Sun.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.

Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather (**Figure** 13.91). Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

FIGURE 13.91

An eruption like Sarychev Volcano (Kuril Islands, northeast of Japan) in 2009 would have very little impact on weather.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**.

The Earth goes through regular variations in its position relative to the Sun:

1. The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

2. The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.

3. The planet's tilt on its axis varies between 22.1^o and 24.5^o. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5^o angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Changes in Atmospheric Greenhouse Gas Levels

Since greenhouse gases trap the heat that radiates off the planet's surfaces, what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises global temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods (**Figure** 13.92).

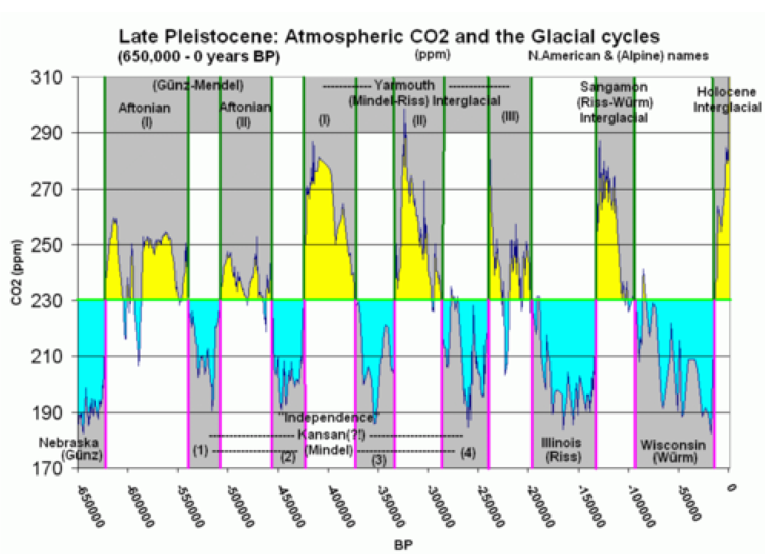


FIGURE 13.92

CO_2 levels during glacial (blue) and interglacial (yellow) periods. Are CO_2 levels relatively high or relatively low during interglacial periods? Current carbon dioxide levels are at 387 ppm, the highest level for the last 650,000 years. BP means years before present.

Natural processes add and remove CO_2 from the atmosphere.

- Processes that add CO_2:
  - volcanic eruptions
  - decay or burning of organic matter.
- Processes that remove CO_2:
  - absorption by plant and animal tissue.

When plants are turned into fossil fuels, the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

What happens to atmospheric CO_2 when the fossil fuels are burned? What happens to global temperatures?

Vocabulary

- **Milankovitch cycles**: Cycles adding up to variations of around 100,000 years regarding Earth's position relative to the Sun that affect global climate.
- **sunspot**: Cool, dark area on the Sun's surface that have lower temperatures than surrounding areas; sunspots usually occur in pairs and come and go on an 11-year cycle.

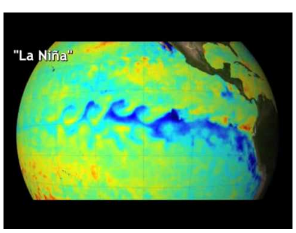
Summary

- The positions of continents, the sizes of oceans and the amount of volcanic activity that takes place are all ways that plate tectonics processes can affect climate.
- Milankovitch cycles affect the way Earth relates to the sun due to the shape of the planet's orbit, its axial tilt, and its wobble.
- Atmospheric greenhouse gas levels correlate with average global temperatures.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=SZBE3yuFzds



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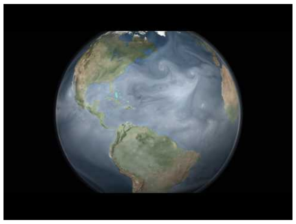
1. What can raise evaporation rates?
2. What are the effects of El Niño?
3. How has solar storm reporting improved?

http://www.youtube.com/watch?v=VlzQ1i2caj4



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4. What are Milankovitch cycles?
5. What is the Holecene?
6. What is happening to climate now?

Review

1. How do Milankovitch cycles affect global temperatures?
2. How do plate tectonics processes affect global climate?
3. How are atmospheric greenhouse gas levels correlated with global temperatures?

13.36 Carbon Cycle and Climate

- Explain the carbon cycle.

What is a diamond?

Carbon takes all sorts of forms as an element and as a compound. A diamond is just carbon, pure carbon. A diamond is good for cutting things, but it's not good for breathing or building proteins out of, yet other forms of carbon are. Carbon is essential for life on Earth and, as carbon dioxide, it is an important atmospheric gas.

The Carbon Cycle

Carbon is a very important element to living things. As the second most common element in the human body, we know that human life without carbon would not be possible. Protein, **carbohydrates**, and fats are all part of the body and all contain carbon. When your body breaks down food to produce energy, you break down protein, carbohydrates, and fat, and you breathe out carbon dioxide.

Carbon occurs in many forms on Earth. The element moves through organisms and then returns to the environment. When all this happens in balance, the ecosystem remains in balance too.

Short Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide (CO_2) in the atmosphere.

Photosynthesis

Through photosynthesis, the inorganic carbon in carbon dioxide plus water and energy from sunlight is transformed into organic carbon (food) (**Figure ??**), with oxygen given off as a waste product. The chemical equation for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6\ CO_2} + \underset{\text{water}}{6\ H_2O} + \text{Energy from sunlight} \rightarrow \underset{\text{glucose (sugar)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\ O_2}$$

Equation for photosynthesis.

Respiration

Plants and animals engage in the reverse of photosynthesis, which is respiration. In respiration, animals use oxygen to convert the organic carbon in sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + useable energy

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2; in respiration, O_2 is converted to CO_2.

Remember that plants do not create energy. They change the energy from sunlight into chemical energy that plants and animals can use as food (**Figure** 13.93).

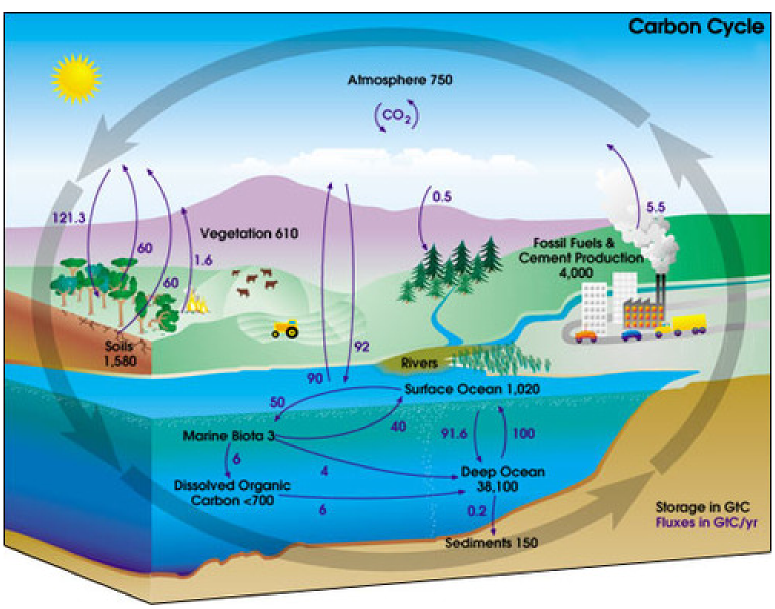

FIGURE 13.93
The carbon cycle shows where a carbon atom might be found. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for gigatons of carbon). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the 70 million GtC of carbonate rock and kerogen.

Long-Term Carbon Cycling

Carbon Sinks and Carbon Sources

Places in the ecosystem that store carbon are reservoirs. Places that supply and remove carbon are **carbon sources** and **carbon sinks**, respectively. If more carbon is provided than stored, the place is a carbon source. If more carbon dioxide is absorbed than is emitted, the reservoir is a carbon sink. What are some examples of carbon sources and sinks?

- Carbon sinks are reservoirs where carbon is stored. Healthy living forests and the oceans act as carbon sinks.
- Carbon sources are reservoirs from which carbon can enter the environment. The mantle is a source of carbon from volcanic gases.

A reservoir can change from a sink to a source and vice versa. A forest is a sink, but when the forest burns it becomes a source.

The amount of time that carbon stays, on average, in a reservoir is the residence time of carbon in that reservoir.

The concept of residence times is explored using the undergraduate population at UGA as an example. In this example the reservoir is the university: http://www.youtube.com/watch?v=cIuaedcVvQg (2:44).

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Atmospheric Carbon Dioxide

Remember that the amount of CO_2 in the atmosphere is very low. This means that a small increase or decrease in the atmospheric CO_2 can have a large effect.

By measuring the composition of air bubbles trapped in glacial ice, scientists can learn the amount of atmospheric CO_2 at times in the past. Of particular interest is the time just before the Industrial Revolution, when society began to use fossil fuels. That value is thought to be the natural content of CO_2 for this time period; that number was 280 parts per million (ppm).

By 1958, when scientists began to directly measure CO_2 content from the atmosphere at Mauna Loa volcano in the Pacific Ocean, the amount was 316 ppm (**Figure** 13.94). In 2011, the atmospheric CO_2 content had risen to 390 ppm.

This is an increase in atmospheric CO_2 of 40% since the before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this (**Figure** 13.95):

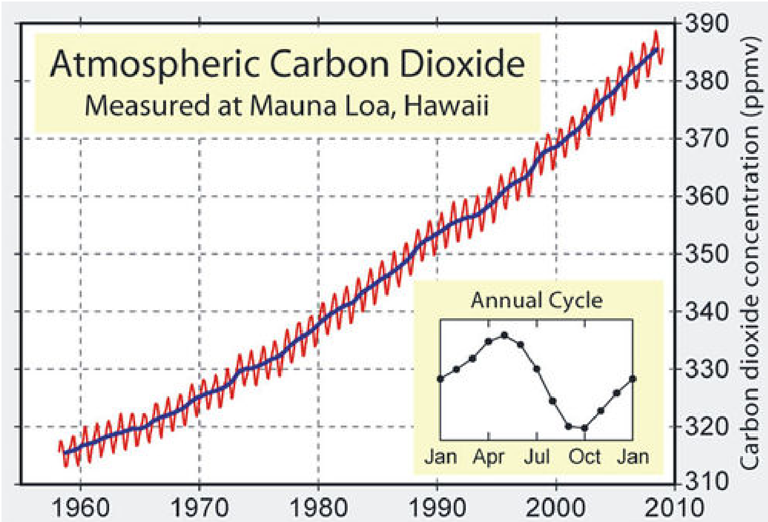


FIGURE 13.94

The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

FIGURE 13.95

Propane combustion formula.

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph above.

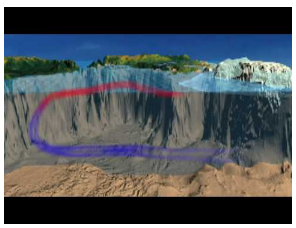
The second largest source of atmospheric CO_2 is **deforestation** (**Figure** 13.96). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

Why the Carbon Cycle is Important

Why is such a small amount of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas. Greenhouse gases trap heat energy that would otherwise radiate out into space, which warms Earth. These gases were discussed in Concept Atmospheric Processes.

This video *Keeping up with Carbon* from NASA, focuses on the oceans. Topics include what will happen as temperature warms and the oceans can hold less carbon, and ocean acidification: http://www.youtube.com/watch?v=HrIr3xDhQ0E (5:39).

FIGURE 13.96
This forest in Mexico has been cut down and burned to clear forested land for agriculture.



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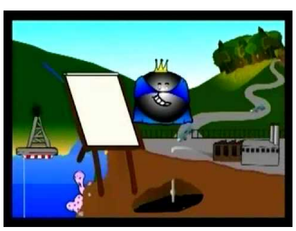
A very thorough but basic summary of the carbon cycle, including the effect of carbon dioxide in the atmosphere, is found in this video: http://www.youtube.com/watch?v=U3SZKJVKRxQ (4:37).



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Vocabulary

- **carbohydrate**: Organic compound that supplies energy to the body; includes sugars, starches and cellulose.
- **carbon sink**: A reservoir for carbon that absorbs more carbon dioxide than it produces.
- **carbon source**: An area of an ecosystem that emits more carbon dioxide than it absorbs.
- **deforestation**: Cutting down and/or burning trees in a forested area.

Summary

- Carbon is essential for life as part of proteins, carbohydrates, and fats.
- The amount of carbon dioxide in the atmosphere is extremely low, but it is extremely important since carbon dioxide is a greenhouse gas, which helps to keep Earth's climate moderate.
- The amount of carbon dioxide in the atmosphere is rising, a fact that has been documented on Mauna Loa volcano since 1958.

Practice

Use this resource to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: **Carbon Cycle**

1. How is carbon moved with photosynthesis?
2. How is carbon moved with respiration?
3. What process releases carbon dioxide to the atmosphere?
4. What gases does combustion produce?
5. What happens to sediment over time?
6. What occurs during weathering?

Review

1. What does it mean to say that photosynthesis and respiration are gas exchange processes?
2. How do scientists learn about carbon levels in the past?
3. How do human activities affect the carbon cycle?

13.37 Global Warming

- Describe the consequences of global warming.

Do polar bears belong in garbage dumps?

Changes due to warmer temperatures are becoming more visible. The Arctic is covered with ice less of the year, so polar bears can't hunt and are raiding garbage dumps for food. Extreme weather events are becoming more common as weather becomes stranger. Sea level is rising, which is a problem during storms.

Global Warming

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**.

Global warming - How Humans are Affecting our Planet from NASA, discusses the basics of global warming science **(4c)**: http://www.youtube.com/watch?feature=player_profilepage#38;v=VXvGPbHXxtc#! (7:58).

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Increasing Temperatures

While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The 12 warmest years on record have all occurred since 2001, and the 20 warmest years have occurred since 1987 (through 2011) (**Figure** 13.97). The 2000s were the warmest decade yet.

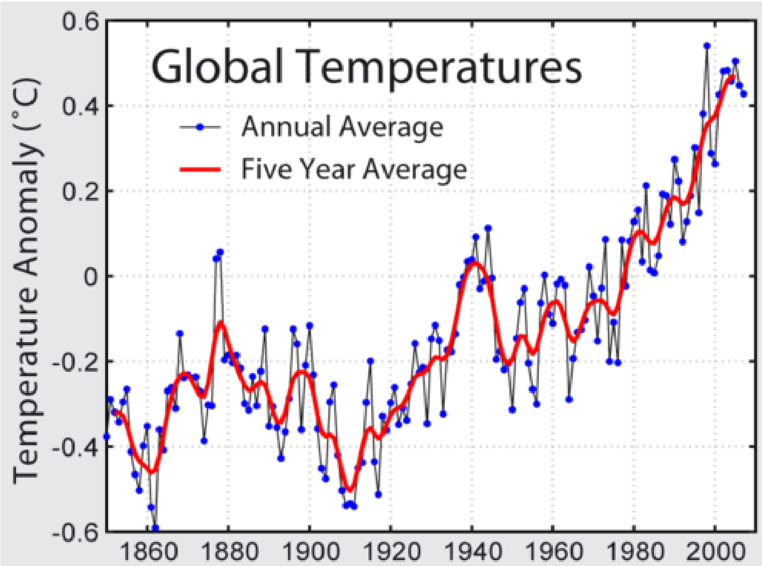

FIGURE 13.97

Recent temperature increases show how much temperature has risen since the Industrial Revolution began.

Annual variations aside, the average global temperature increased about 0.8^{o}C (1.5^{o}F) between 1880 and 2010, according to the Goddard Institute for Space Studies, NOAA. This number doesn't seem very large. Why is it important? http://www.giss.nasa.gov/research/news/20100121/

Greenhouse Gas Emissions

The United States has long been the largest emitter of greenhouse gases, with about 20% of total emissions in 2004. As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gas emissions than the average Chinese person.

An animation of CO_2 released by different fossil fuels is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CO2BTU_3.MPG.

Changes Due to Warming Temperatures

The following images show changes in the Earth and organisms as a result of global warming: **Figure** 13.98, **Figure** 13.99, **Figure** 13.100.

The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer arable because they have become too warm or dry.

Modeled Climate-Induced Glacier Change in Glacier National Park, 1850-2100: http://www.nrmsc.usgs.gov/research/glacier_model.htm.

What are the two major effects being seen in this animation? Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

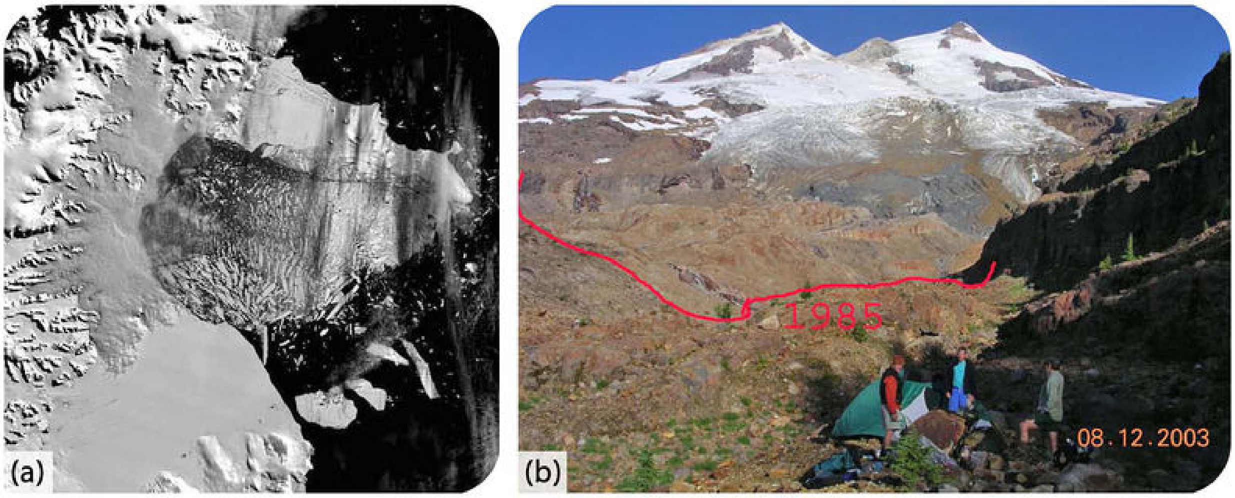

FIGURE 13.98

(a) Breakup of the Larsen Ice Shelf in Antarctica in 2002 was related to climate warming in the region. (b) The Boulder Glacier has melted back tremendously since 1985. Other mountain glaciers around the world are also melting.

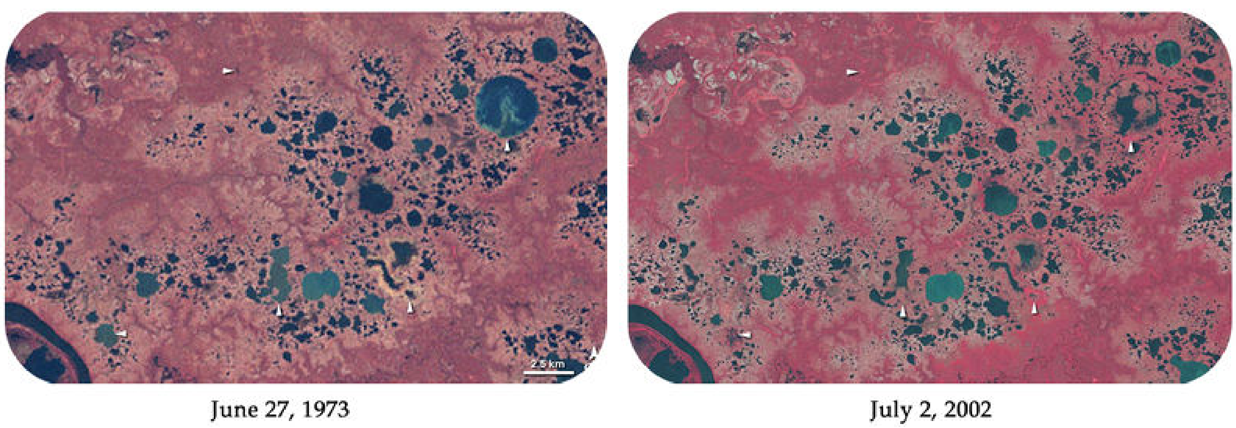

FIGURE 13.99

Permafrost is melting and its extent decreasing. There are now fewer summer lakes in Siberia.

A number of videos on the National Geographic site deal with global warming: http://video.nationalgeographic.com/video/environment/global-warming-environment.

- A no-nonsense look at global warming and what we can do about it is found in "A Way Forward: Facing Climate Change."
- "Antarctic Ice" describes the changes that are already happening to Antarctica and what the consequences of

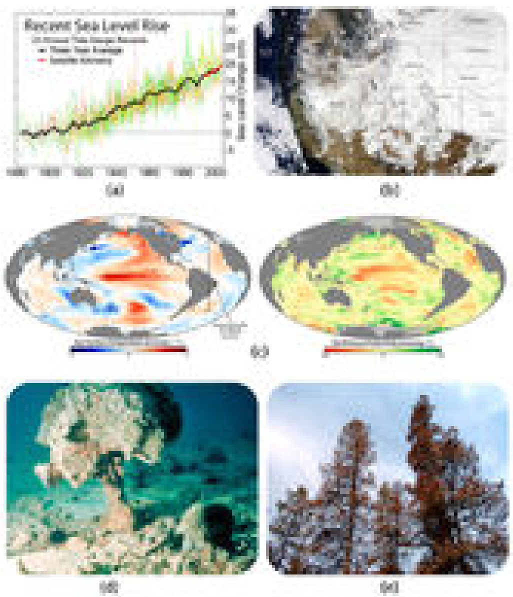

FIGURE 13.100
(a) Melting ice caps add water to the oceans, so sea level is rising Remember that water slightly expands as it warms — this expansion is also causing sea level to rise. (b) Weather is becoming more variable with more severe storms and droughts. Snow blanketed the western United States in December 2009. (c) As surface seas warm, phytoplankton productivity has decreased. (d) Coral reefs are dying worldwide; corals that are stressed by high temperatures turn white. (e) Pine beetle infestations have killed trees in western North America The insects have expanded their ranges into areas that were once too cold.

future melting will be.

- “Glacier Melt” looks at melting in a large alpine glacier and the effects of glacier loss to Europe.
- In “Greenhouse Gases,” researchers look at the effects of additional greenhouse gases on future forests.
- Researchers look for changes in the range of a mountain-top dwelling mammal, the pika, in “Hamster-like Pika in Peril.”
- “State of Polar Bears” show how polar bears, in their specialized habitat in the Arctic, are among the species already affected by warming temperatures.

Warming temperatures are bringing changes to much of the planet, including California. Sea level is rising, snow pack is changing, and the ecology of the state is responding to these changes.

Find out more at http://www.kqed.org/quest/television/climate-watch-california-at-the-tipping-point-part-one.

Adobe Flash

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Vocabulary

- **global warming**: Warming of Earth’s atmosphere because of the addition of greenhouse gases. The increase in average global temperature is caused by human activities.

Summary

- Greenhouse gases trap heat in the atmosphere; burning fossil fuels and other human activities release greenhouse gases into the atmosphere; greenhouse gas levels in the atmosphere are increasing; and global tempera-

tures are increasing.
- Average global temperature has been rising since the end of the ice ages but the rate of its rise has increased in recent decades.
- Changes due to increasing temperatures are seen around the globe but are most dramatic in the polar regions.

Practice

Use this resource to answer the questions that follow.

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

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1. How much has the global temperature risen in the last few decades?
2. What contributes to global warming?
3. What is the greenhouse effect?
4. What is the evidence for global warming?
5. What was the warmest recorded year?
6. What gases have been recorded at their highest levels in history?
7. What do researchers predict will happen?

Review

1. The first point in the summary above is a set of facts. Does it logically follow that human activities are causing global temperatures to rise? Is there a different explanation that fits with the facts?
2. Why is average global temperature the most important value when talking about climate change?
3. What are some of the effects of climate change that are already being seen?

13.38 Impact of Continued Global Warming

- Describe likely impacts of continued global warming.

"The Inuit see this and the world should know this..."

"It's happening right before our eyes. If we're going to be ignored, it's like putting a shotgun in our mouth and pulling the trigger." — 23-year-old Jordan Konek, one of the native people of the Canadian Arctic, to the 2011 Climate Change Conference in Durban, South Africa.

Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made.

If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63% greater than they were in 2002.

Temperature Scenarios

Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions. If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5^{o}C and 2.0^{o}C (0.9^{o}F and 3.6^{o}F) by 2050 and between 2^o and 4.5^{o}C (3.5^o and 8^{o}F) by 2100, with CO_2 levels over 800 parts per million (ppm) (**Figure** 13.102). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1^{o}C (2^{o}F) by 2100.

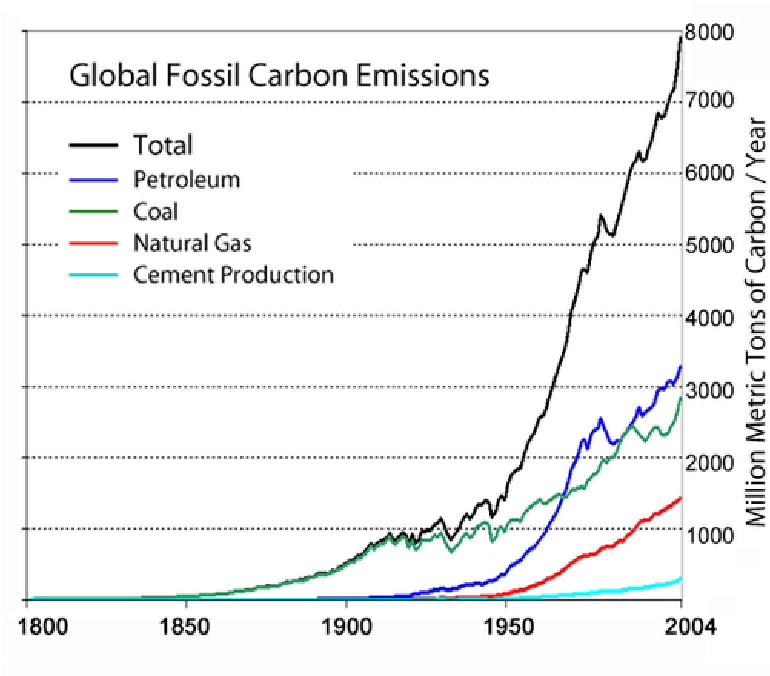
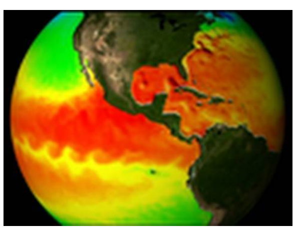


FIGURE 13.101
Global CO_2 emissions are rising rapidly. The industrial revolution began about 1850 and industrialization has been accelerating.

This video explores the tools NASA scientists use to determine how the climate is changing: http://www.youtube.com/watch?v=JRayIgKublg#38;feature=channel (4:00).



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Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8^{o}C (5^{o}F) would result in 0.6^o to 1.2^{o}C (1^o to 2^{o}F) at the equator, but up to 6.7^{o}C (12^{o}F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica (**Figure** 13.103).

Animations of temperature anomalies for 5- and 10-year periods: http://data.giss.nasa.gov/gistemp/animations/.

Global Changes

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10% to 20% of shellfish (mussels) being replaced by acid-tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0^{o}C (8^{o}F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snow packs, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water

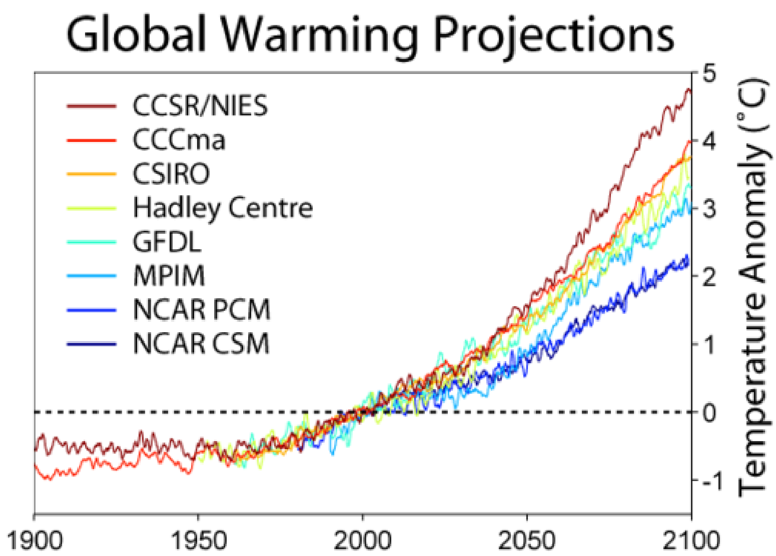

FIGURE 13.102
Various climate prediction models show how temperature is likely to rise by 2100.

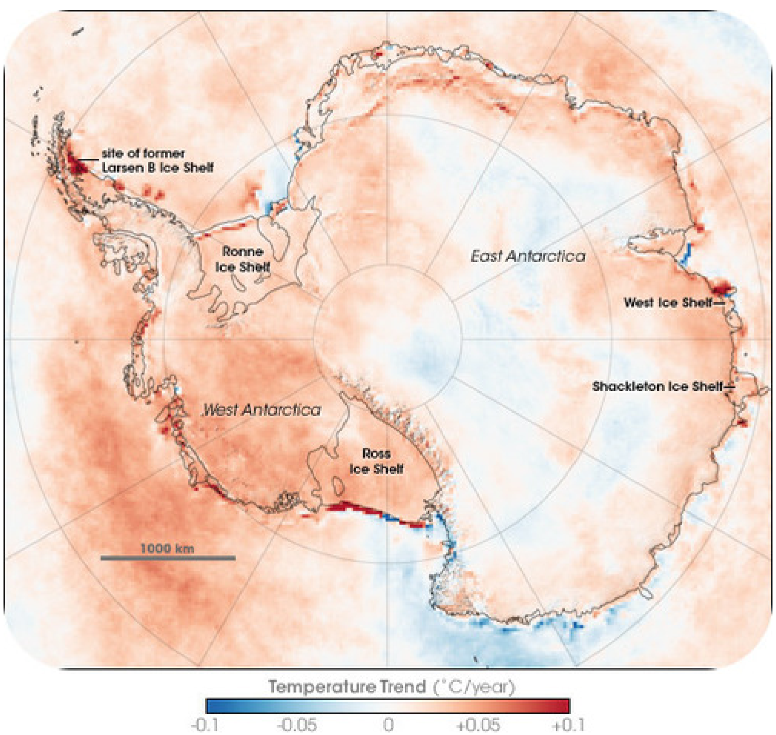

FIGURE 13.103
Temperature changes over Antarctica.

available in some regions of the world, including the western United States and much of Asia. Ice will continue to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100 (**Figure** 13.104). An increase this large will gradually flood coastal regions, where about one-third of the world's population lives, forcing billions of people to move inland.

Weather will become more extreme, with more frequent and more intense heat waves and droughts. Some modelers predict that the midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10% to 50% of current cropland worldwide may become unusable if CO_2 doubles.

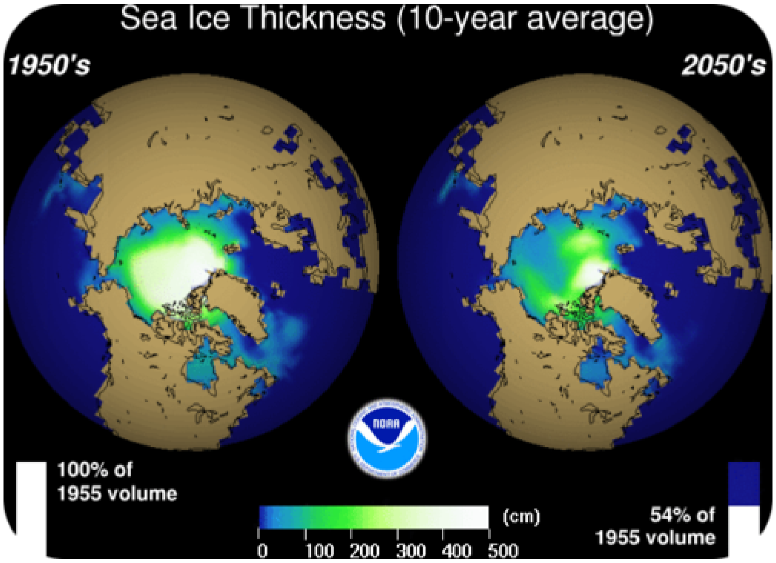

FIGURE 13.104
Sea ice thickness around the North Pole has been decreasing in recent decades and will continue to decrease in the coming decades.

Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent. Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm — quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The answer is no. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, and other atmospheric gases cannot account for the increase in temperature that has already happened in the past decades.

This video discusses how, by using the CERES satellite, scientists monitor energy in the atmosphere, including incoming solar energy and reflected and absorbed energy. Greenhouse warming that results from atmospheric greenhouse gasses is also monitored: http://www.youtube.com/watch?v=JFfD6jn_OvA (4:31).

MEDIA
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Along with the rest of the world's oceans, San Francisco Bay is rising. Changes are happening slowly in the coastal arena of the San Francisco Bay Area and even the most optimistic estimates about how high and how quickly this rise will occur indicate potentially huge problems for the region.

Find out more at http://science.kqed.org/quest/video/going-up-sea-level-rise-in-san-francisco-bay/.

MEDIA
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How Bad Could a Few Degrees Be?

How bad could a few degrees be? National Geographic has a set of videos about what to expect if temperature rises by each of these amounts by degree Celsius.

- 1^{o}: http://www.youtube.com/watch?v=2_ZQRIsn2pA#38;feature=channel
- 2^{o}: http://www.youtube.com/watch?v=P-0_gDXqYeQ#38;feature=channel
- 3^{o}: http://www.youtube.com/watch?v=6rdLu7wiZOE#38;feature=channel
- 4^{o}: http://www.youtube.com/watch?v=skFrR3g4BRQ#38;feature=channel
- 5^{o}: http://www.youtube.com/watch?v=7nRf2RTqANg#38;feature=channel
- 6^{o}: http://www.youtube.com/watch?v=O8qmaAMK4cM#38;feature=channel

Summary

- An increase in greenhouse gases will increase the changes that are already being seen including in ocean acidity.
- A decrease in snow pack will cause a shortage of water in a lot of regions that depend on a summer melt to supply water in the dry months.
- Temperature changes are not uniform around the globe. The largest changes are being seen in the polar regions.

Practice

NASA Global Climate Change - Effects

http://climate.nasa.gov/effects/

1. What is the evidence that climate change is occurring?

2. What do scientists expect to see in the coming decades?

3. What is the expected temperature change for the next century?

4. What changes are expected to be seen in North America?

5. What phenomenon is virtually certain to occur in the future?

Review

1. What does a computer model that predicts environmental changes due to increases in atmospheric greenhouse gases need to take into account?

2. Why does a small change in average global temperature have a large effect on the planet?

3. Why do you think that scientists do not have a firm understanding of how Earth will respond to increases in global temperature in the future?

13.39 Reducing Greenhouse Gas Pollution

- Describe how greenhouse gas pollution can be reduced.

"The chance of averting catastrophic climate change is slipping through our hands with every passing year that nations fail to agree on a rescue plan for the planet." — Greenpeace International director Kumi Naidoo, at the Durban, South Africa Climate Change Conference in 2011.

Reducing Greenhouse Gases

Climate scientists agree that climate change is a global problem that must be attacked by a unified world with a single goal. All nations must come together to reduce greenhouse gas emissions. However, getting nations to agree on anything has proven to be difficult. A few ideas have been proposed and in some nations are being enacted.

International Agreements

The first attempt to cap greenhouse gas emissions was the Kyoto Protocol, which climate scientists agree did not do enough in terms of cutting emissions or in getting nations to participate. The Kyoto Protocol set up a **cap-and-trade**

system. Cap-and-trade provides a monetary incentive for nations to develop technologies that will reduce emissions and to conserve energy. Some states and cities within the United States have begun their own cap-and-trade systems.

The United Nations Climate Change Conference meets in a different location annually. Although recommendations are made each year, the group has not gotten the nations to sign on to a binding agreement. By doing nothing we are doing something - continuing to raise greenhouse gas levels and failing to prepare for the coming environmental changes.

Carbon Tax

The easiest and quickest way is to reduce greenhouse gas emissions is to increase energy efficiency. One effective way to encourage efficiency is financial. A **carbon tax** can be placed on CO_2 emissions to encourage conservation. The tax would be placed on gasoline, carbon dioxide emitted by factories, and home energy bills so people or businesses that emit more carbon would pay more money. This would encourage conservation since when people purchase a new car, for example, they would be more likely to purchase an energy-efficient model. The money from the carbon tax would be used for research into alternative energy sources. All plans for a carbon tax allow a tax credit for people who cannot afford to pay more for energy so that they do not suffer unfairly.

New technologies can be developed, such as renewable sources that were discussed in Concept Natural Resources. **Biofuels** can replace gasoline in vehicles, but they must be developed sensibly (**Figure** 13.105). So far much of the biofuel is produced from crops such as corn. But when food crops are used for fuel, the price of food goes up. Modern agriculture is also extremely reliant on fossil fuels for pesticides, fertilizers, and the work of farming. This means that not much energy is gained from using a biofuel over using the fossil fuels directly. More promising crops for biofuels are now being researched. Surprisingly, algae is being investigated as a source of fuel! The algae can be grown in areas that are not useful for agriculture, and it also contains much more usable oil than crops such as corn.

FIGURE 13.105
A bus that runs on soybean oil shows the potential of biofuels.

Carbon Capture and Sequestration

If climate change becomes bad enough, people can attempt to remove greenhouse gases from the atmosphere after they are emitted. **Carbon sequestration** occurs naturally when carbon dioxide is removed from the atmosphere by trees in a forest. One way to remove carbon would be to plant more trees, but unfortunately, more forest land is currently being lost than gained.

Carbon can also be artificially sequestered. For example, carbon can be captured from the emissions from gasification plants and then stored underground in salt layers or coal seams. While some small sequestration projects are in development, large-scale sequestration has not yet been attempted.

This type of carbon capture and sequestration comes under the heading of geoengineering. There are many other fascinating ideas in geoengineering that people have proposed that are worth looking at. One wild example is to shadow the planet with large orbiting objects. A large mirror in orbit could reflect about 2% of incoming solar radiation back into space. These sorts of solutions would be expensive in cost and energy.

Just as individuals can diminish other types of air pollution, people can fight global warming by conserving energy. Also, people can become involved in local, regional, and national efforts to make sound choices on energy policy.

Vocabulary

- **biofuel**: A fuel made from living materials, usually crop plants.
- **cap-and-trade system**: A monetary system that encourages conservation and development of alternative energy sources. A cap is put on a nation's allowed carbon emissions and nations can trade for rights to emit carbon pollution.
- **carbon sequestration**: Removal of carbon dioxide from the atmosphere, so that it does not act as a greenhouse gas in the atmosphere.
- **carbon tax**: A tax placed on energy sources that emit carbon to discourage their use and to raise funds to research alternative energy sources.

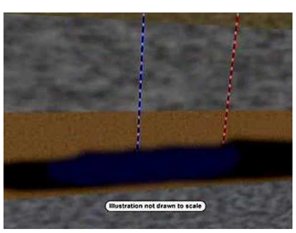
Summary

- A cap-and-trade system gives nations a cap on the greenhouse gas emissions they're allowed and allows them to trade allowances with other nations so that they can meet their cap.
- A carbon tax taxes carbon emissions to encourage conservation.
- Carbon capture and sequestration is a geoengineering solution for removing excess carbon dioxide from the atmosphere.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=OtfuYlhDjw4



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1. What is the purpose of carbon sequestration?
2. What are the three pillars of the Global Climate Change Initiative?
3. What is CCS?
4. What is CCS being used for today?
5. What type of stone is carbon dioxide pumped into? Why?
6. What are cap rocks? Why are they important?

Review

1. Why would a carbon tax be effective at reducing greenhouse gas emissions?

2. How does a carbon tax not penalize people who can't afford to pay more for fuel and other items?

3. What are the advantages and disadvantages of using geoengineering solutions to reduce climate change rather than things like cap-and-trade or a carbon tax?

Summary

Human population grew by 1 billion in the past 12 years to reach 7 billion. In 1960, the human population was only 3 billion. The population growth of every species on Earth is limited by some limiting factor so that within each ecosystem the carrying capacity for each species is set. Human ingenuity due to our brains and our hands, has allowed us to blow past any previously held idea of what Earth's carrying capacity for humans is. The development of and advances in agriculture over for the past 10,000 years have been the largest factors. How long can human population continue to grow? No one knows, and no one knows what the planet's ultimate carrying capacity for humans will be. The enormous number of people, and the tremendous consumption of the percentage of the world's population that does more than just meet its basic needs, has put a strain on Earth's resources and generated a tremendous amount of waste. Land is used for farming and other activities and also for the disposal of hazardous wastes. Water is used for drinking, bathing, agricultural and industrial uses, which may deplete supplies and pollute water sources. Much of what has fueled development in agriculture and industry has been the availability of cheap fossil fuels, which pollute the air and emit carbon dioxide into the atmosphere. Carbon dioxide is one of the greenhouse gases that trap heat and moderate Earth's temperature. As the levels of carbon dioxide and other greenhouse gases in the atmosphere rise, they can trap more heat, which causes global temperatures to warm. The effects of global warming are already being seen as ice melts and sea level rises, species are forced to move uphill or higher in latitude seeking a suitable habitat, the oceans become ore acidic, and many other consequences.

13.40 References

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CHAPTER 14 The Solar System

Chapter Outline

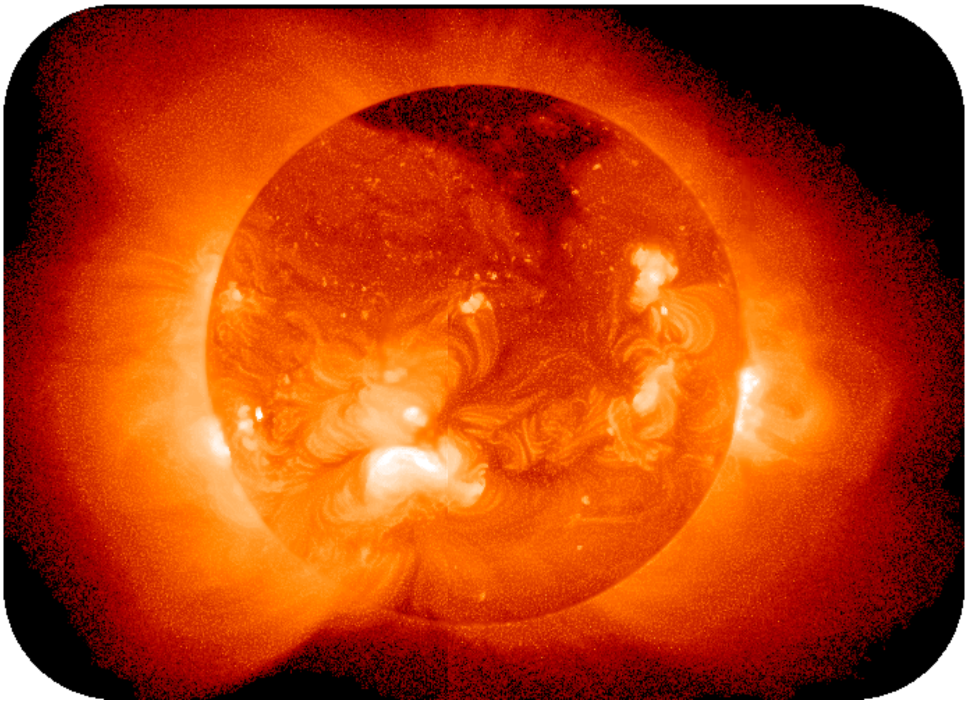
Introduction

There's no place like home.

Our solar system is enormous, with dwarf planets in orbit around the Sun tens of thousands of times further away than Earth. It took astronauts three days to get to our nearest neighbor, the Moon, and would take about six months each way for people to get to Mars and back. This image was the first ever taken that had Moon and Earth in the same frame, and it wasn't until 1977, when Voyager I was 7,250,000 miles away. But compared to the Milky Way Galaxy, the solar system is just a cozy little spot in a big world. There are lots of planets and lots of stars and lots of galaxies, but our planet is different. It is one (maybe one of many) that has intelligent life.

14.1 Interior of the Sun

- Define plasma and nuclear fusion.
- Describe the internal and atmospheric layers of the Sun.



Can you visit the Sun?

Of course not. In Greek mythology, Icarus, got too close and his wax wings melted. Today, we have other ways to see the Sun. Spacecraft take photos and some have instruments that allow us to study the interior. Unlike Icarus, we don't need to worry about our wax wings melting.

Layers of the Sun

The Sun is a sphere, composed almost entirely of the elements hydrogen and helium. The Sun is not solid, nor is it a typical gas. Most atoms in the Sun exist as **plasma**, a fourth state of matter made up of superheated gas with a positive electrical charge.

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers (**Figure** 14.1). From inward to outward they are:

- The Sun's central core is plasma with a temperature is around 27 million^{o}C. At such high temperatures hydrogen combines to form helium by **nuclear fusion**, a process that releases vast amounts of energy. This energy moves outward, towards the outer layers of the Sun.

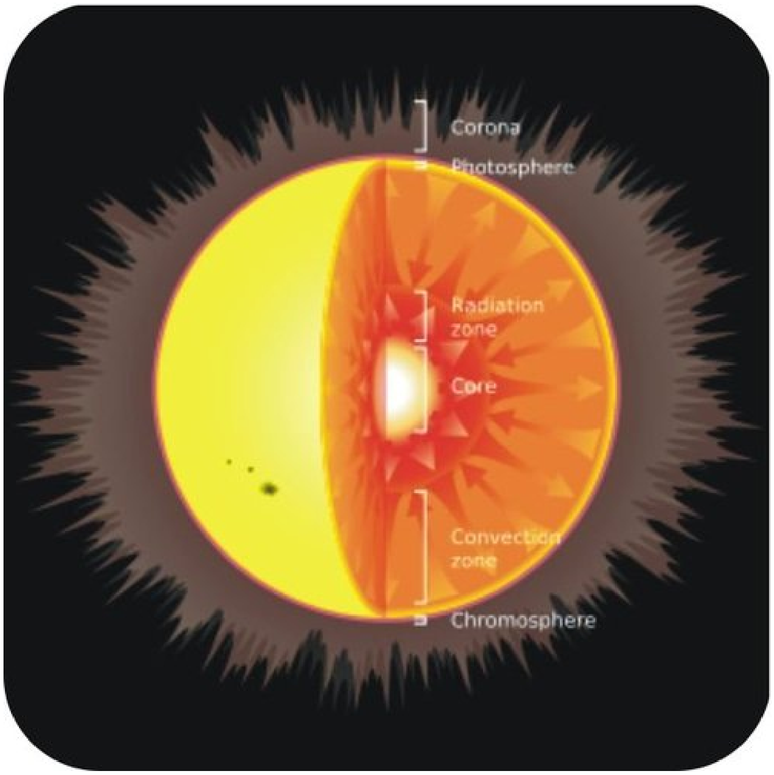
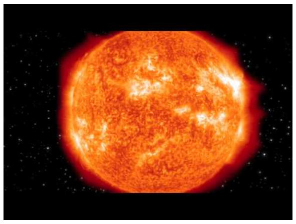


FIGURE 14.1
The layers of the Sun.

- The **radiative zone**, just outside the core, has a temperature of about 7 million^{o}C. The energy released in the core travels extremely slowly through the radiative zone. A particle of light, called a **photon**, travels only a few millimeters before it hits another particle. The photon is absorbed and then released again. A photon may take as long as 50 million years to travel all the way through the radiative zone.
- In the **convection zone**, hot material from near the radiative zone rises, cools at the Sun's surface, and then plunges back downward to the radiative zone. Convective movement helps to create solar flares and sunspots.

The first video describes the basics of our Sun, including how it is powered by nuclear reactions: http://www.youtube.com/watch?feature=player_profilepage#38;v=JHf3dG0Bx7I (8:34).



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The second video discusses what powers the sun and what is its influence on Earth and the rest of the solar system: http://www.youtube.com/watch?v=S6VRKKh6gyA#38;feature=related (8:25).

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The Outer Layers

The next three layers make up the Sun's atmosphere. Since there are no solid layers to any part of the Sun, these boundaries are fuzzy and indistinct.

- The **photosphere** is the visible surface of the Sun, the region that emits sunlight. The photosphere is relatively cool — only about 6,700^{o}C. The photosphere has several different colors, including oranges, yellow and reds. This characteristic gives it a grainy appearance.
- The **chromosphere** is a thin zone, about 2,000 km thick, that glows red as it is heated by energy from the photosphere (**Figure** 14.2). Temperatures in the chromosphere range from about 4,000^{o}C to about 10,000^{o}C. Jets of gas fire up through the chromosphere at speeds up to 72,000 km per hour, reaching heights as high as 10,000 km.

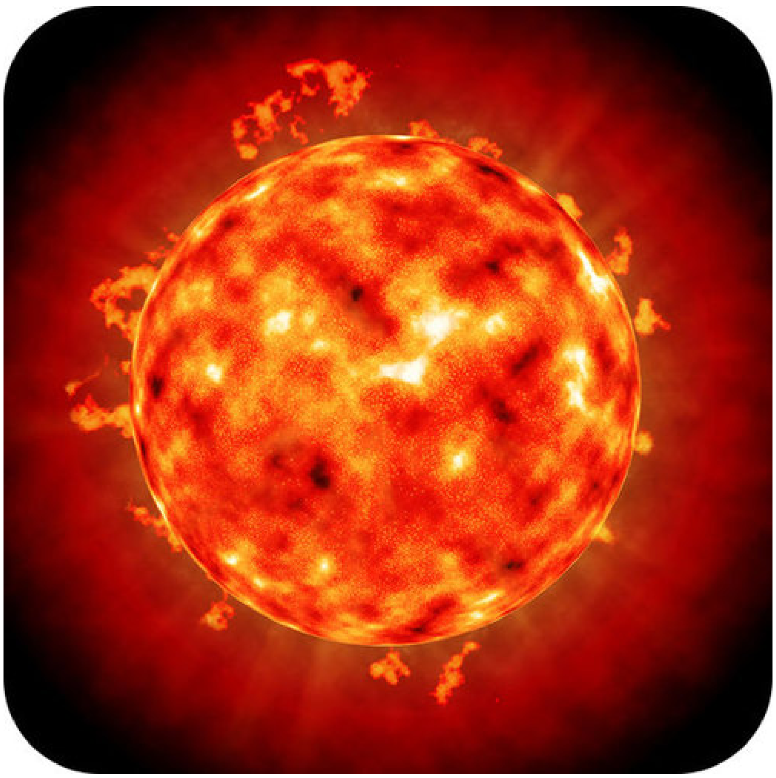


FIGURE 14.2
The chromosphere.

- The **corona** is the outermost plasma layer. It is the Sun's halo or "crown." The corona's temperature of 2 to 5 million^{o}C is much hotter than the photosphere (**Figure** 14.3).

The movie "Seeing a Star in a New Light" can be seen here: http://sdo.gsfc.nasa.gov/gallery/youtube.php.

Vocabulary

- **chromosphere**: Thin layer of the Sun's atmosphere that lies directly above the photosphere; glows red.
- **convection zone**: Layer of the Sun that surrounds the radiative zone where energy moves as flowing cells of gas.
- **corona**: Outermost layer of the Sun; a plasma that extends millions of kilometers into space.

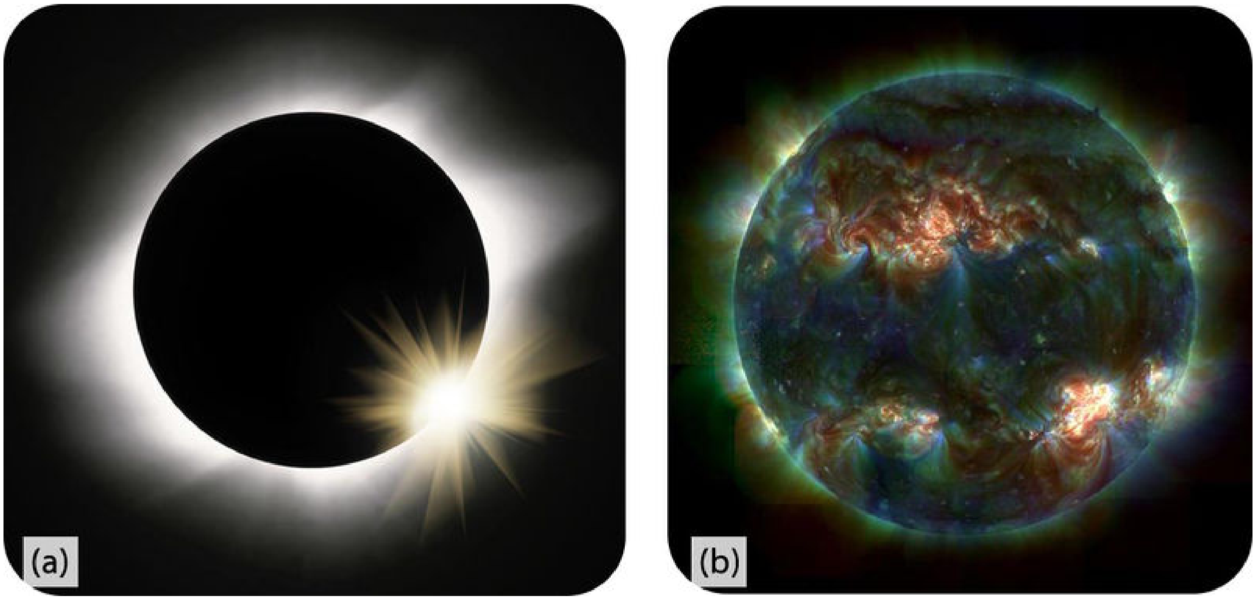


FIGURE 14.3
(a) During a solar eclipse, the Sun's corona is visible extending millions of kilometers into space. (b) The corona and coronal loops in the lower solar atmosphere taken by the TRACE space telescope.

- **nuclear fusion**: The merging together of the nuclei of atoms to form new, heavier chemical elements; huge amounts of nuclear energy are released in the process.
- **photosphere**: The visible surface of the Sun.
- **photon**: A particle of light.
- **plasma**: A high energy, high temperature form of matter. Electrons are removed from atoms, leaving each atom with a positive electrical charge.
- **radiative zone**: Layer of the Sun immediately surrounding the core where energy moves atom to atom as electromagnetic waves.

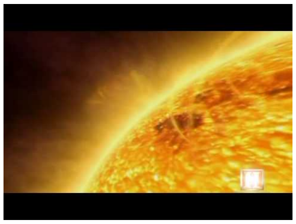
Summary

- The Sun is made mostly of plasma, a fourth state of matter made up of superheated gas with a positive electrical charge.
- At the Sun's center is plasma, where nuclear fusion takes place. The radiative zone is outside the core. The convection zone, where convection takes place, is located outward from that.
- The photosphere is the visible surface of the Sun, where sunlight is emitted from. The reddish chromosphere is heated by the photosphere and the outer corona is the Sun's crown.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=S98L93J8AGQ



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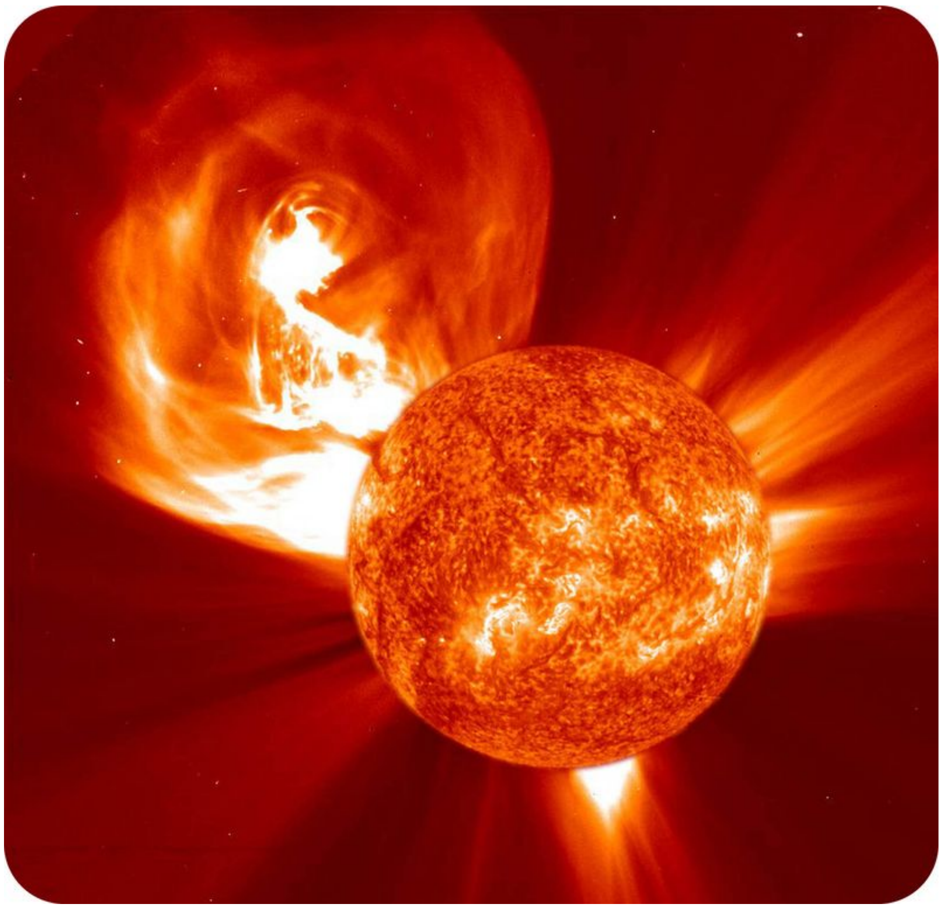
1. What two elements make up the Sun?
2. What is our Sun?
3. What is the Sun's surface temperature?
4. What process powers the Sun?
5. What state occurs in the core of the Sun?
6. How much energy is produced by the Sun?

Review

1. The Sun is very dense, so is there solid matter at the center? Why or why not?
2. What are the layers of the Sun and what are their characteristics?
3. What powers the Sun?

14.2 Surface Features of the Sun

- Describe the major features of the Sun's surface, such as flares and sunspots.



Can solar activity get you lost?

Large explosions on the Sun's surface can disrupt the high-precision GPS systems that are used by airlines. Radars and long-range radio communications may also be temporarily lost.

Surface Features

The Sun's surface features are quite visible, but only with special equipment. For example, sunspots are only visible with special light-filtering lenses.

Sunspots

The most noticeable surface features of the Sun are cooler, darker areas known as **sunspots** (**Figure** 14.4). Sunspots are located where loops of the Sun's magnetic field break through the surface and disrupt the smooth transfer of heat from lower layers of the Sun, making them cooler, darker, and marked by intense magnetic activity. Sunspots usually occur in pairs. When a loop of the Sun's magnetic field breaks through the surface, a sunspot is created where the loop comes out and where it goes back in again. Sunspots usually occur in 11-year cycles, increasing from a minimum number to a maximum number and then gradually decreasing to a minimum number again.

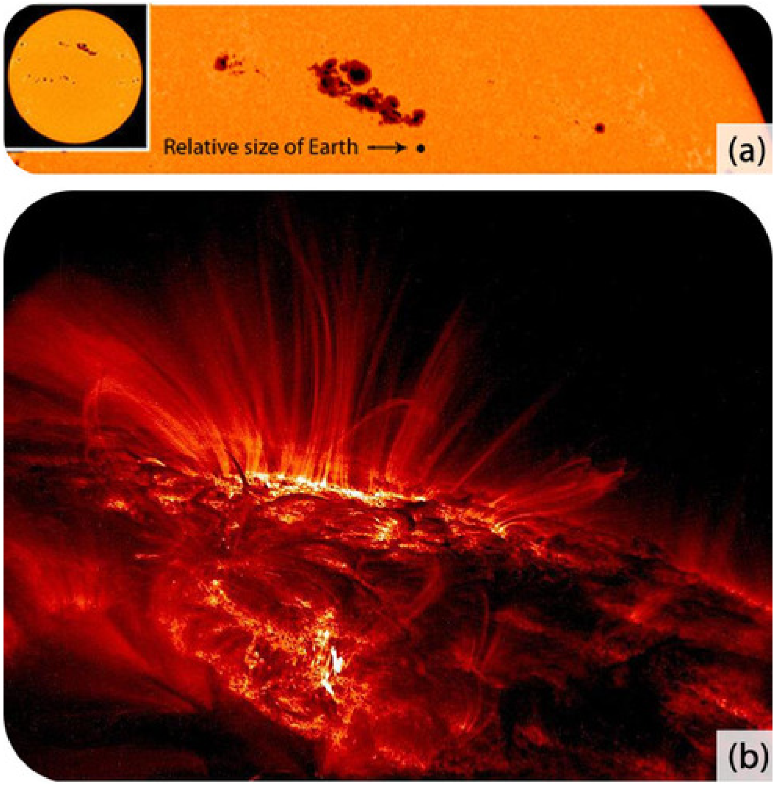


FIGURE 14.4
(a) Sunspots; (b) A close-up of a sunspot taken in ultraviolet light.

Solar Flares

There are other types of interruptions of the Sun's magnetic energy. If a loop of the sun's magnetic field snaps and breaks, it creates **solar flares**, which are violent explosions that release huge amounts of energy (**Figure** 14.5).

A movie of the flare is seen here: http://www.youtube.com/watch?v=MDacxUQWeRw.

A strong solar flare can turn into a coronal mass ejection. A solar flare or coronal mass ejection releases streams of highly energetic particles that make up the solar wind. The solar wind can be dangerous to spacecraft and astronauts because it sends out large amounts of radiation that can harm the human body. Solar flares have knocked out entire power grids and disturbed radio, satellite, and cell phone communications.

Solar Prominences

Another highly visible feature on the Sun are **solar prominences**. If plasma flows along a loop of the Sun's magnetic field from sunspot to sunspot, it forms a glowing arch that reaches thousands of kilometers into the Sun's atmosphere. Prominences can last lengths of time ranging from a day to several months. Prominences are also visible during a total solar eclipse.

Solar prominences are displayed in this video from NASA's Solar Dynamics Observatory (SDO): http://www.youtube.com/watch?v=QrmUUcr4HXg.

Most of the imagery comes from SDO's AIA instrument; different colors represent different temperatures, a common

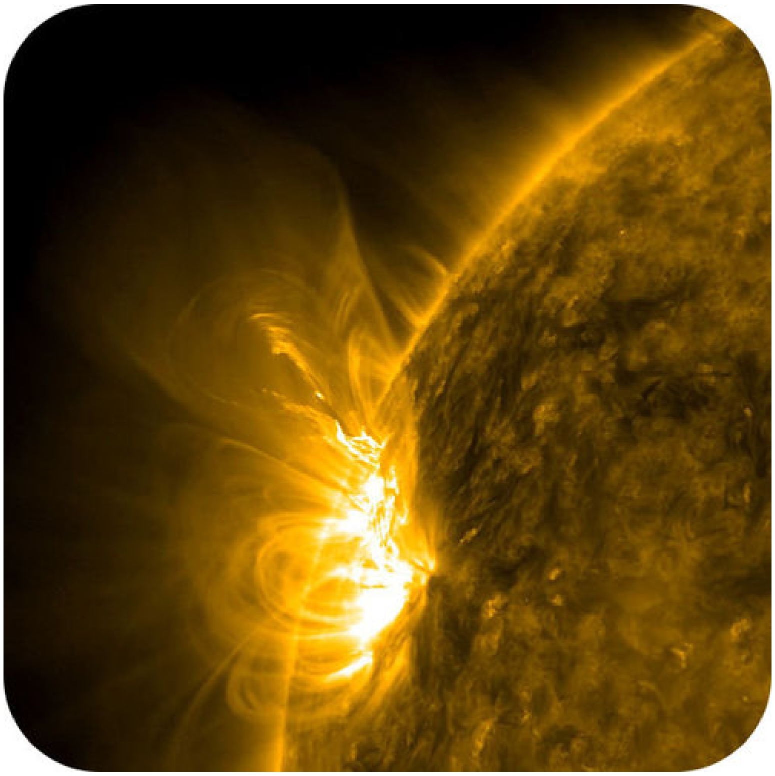


FIGURE 14.5
Magnetic activity leads up to a small solar flare.

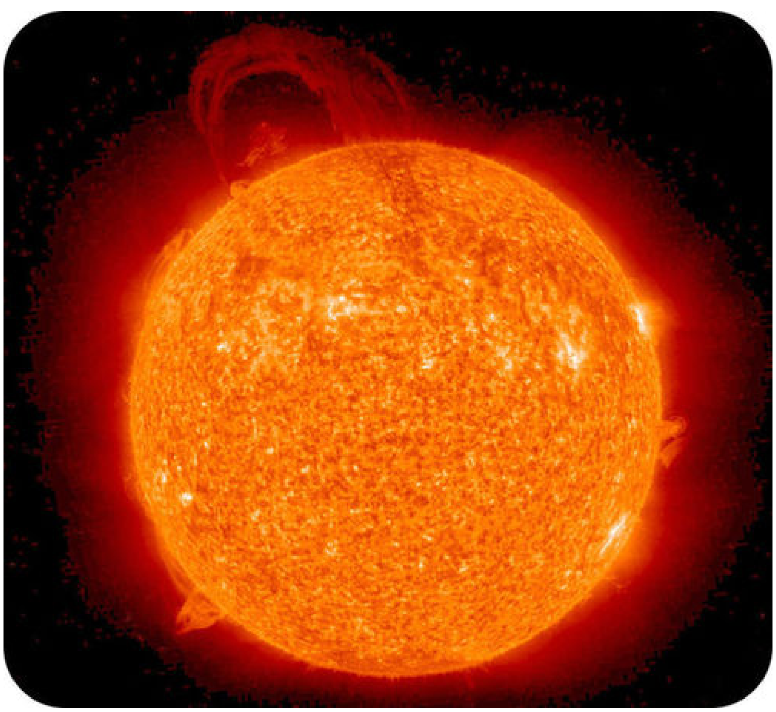


FIGURE 14.6
A solar prominence.

technique for observing solar features. SDO sees the entire disk of the Sun in extremely high spatial and temporal resolution, allowing scientists to zoom in on notable events such as flares, waves, and sunspots.

Solar Dynamics Observatory

The video above was taken from the SDO, the most advanced spacecraft ever designed to study the Sun. During its five-year mission, SDO will examine the Sun's magnetic field and also provide a better understanding of the role the Sun plays in Earth's atmospheric chemistry and climate. Since just after its launch on February 11, 2010, SDO is providing images with clarity 10 times better than high-definition television and will return more comprehensive science data faster than any other solar-observing spacecraft.

The Solar Dynamics Observatory is a NASA spacecraft launched in early 2010 is obtaining IMAX-like images of the sun every second of the day, generating more data than any NASA mission in history. The data will allow researchers to learn about solar storms and other phenomena that can cause blackouts and harm astronauts.

Find out more at http://www.kqed.org/quest/television/journey-into-the-sun.

Adobe Flash

MEDIA

Click image to the left for more content.

Vocabulary

- **solar flare**: A violent explosion on the Sun's surface.
- **solar prominence**: Plasma loop flowing between sunspots.
- **sunspot**: Cool, dark area on the Sun's surface that have lower temperatures than surrounding areas; sunspots usually occur in pairs and come and go on an 11-year cycle.

Summary

- Sunspots occur in pairs because each is one side of a loop of the Sun's magnetic field that reaches the Sun's surface. These spots are cooler and darker than the rest of the Sun's surface and they are marked by intense magnetic activity.
- Solar prominences are the plasma loops that connect two sunspots.
- Solar flares and coronal mass ejections are eruptions of highly energetic particles that can erupt from the Sun's surface and cause problems with power grids and communications on Earth.

Practice

Use these resources to answer the questions that follow.

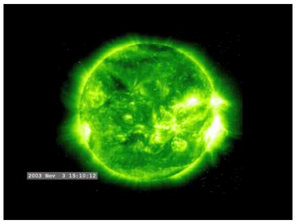
http://www.youtube.com/watch?v=uHdJ1lAHejw

MEDIA

Click image to the left for more content.

1. What are sunspots?
2. What about the Sun interests scientists?
3. How hot is a sunspot?
4. How does the temperature of a sunspot compare to the rest of the sun?

http://www.youtube.com/watch?v=mIsJO9UWSBg



MEDIA

Click image to the left for more content.

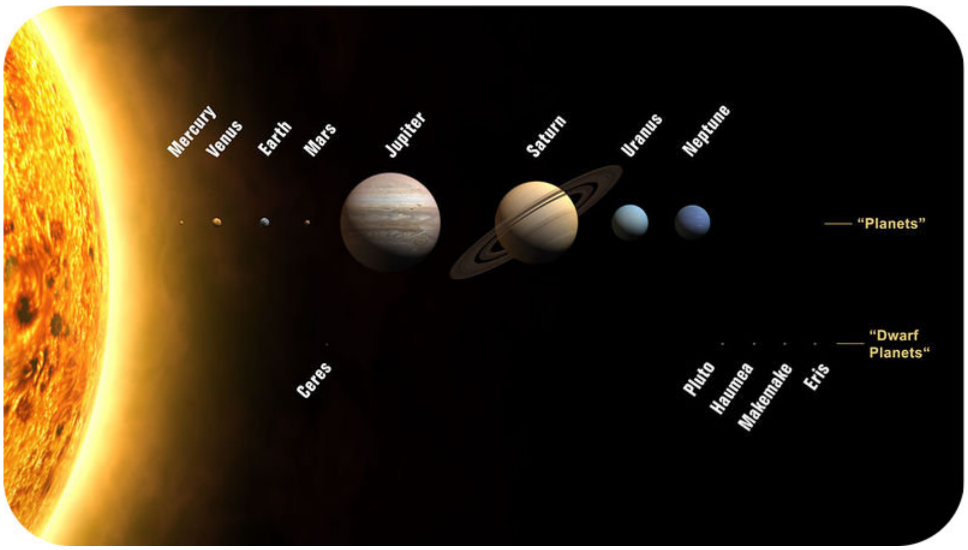
5. How can solar flares affect the Earth?
6. What is the solar cycle?
7. What is a solar flare?
8. What causes solar flares?
9. When was the largest solar flare recorded? What was its rating?
10. Who monitors the sun? Why is this important?

Review

1. What are sunspots and what is a sunspot cycle?
2. How are solar prominences related to sunspots?
3. What is being learned from the Solar Dynamics Observatory?

14.3 Planets of the Solar System

- Define astronomical unit.
- Identify the solar system's eight planets and their characteristics, including size and length of orbit relative to Earth.



Who is in the Sun's family?

The family includes the Sun, its eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), and the five known dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris). In the image above, relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are correct, but the relative distances are not.

Eight Planets

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

Although the Sun is just an average star compared to other stars, it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Table 14.1 gives data on the sizes of the Sun and planets relative to Earth.

TABLE 14.1: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter

TABLE 14.1: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

Orbits and Rotations

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. **Table** 14.2 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

TABLE 14.2: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Here is a website that illustrates both the sizes of the planets, and the distance between them: http://www.scalesolarsystem.66ghz.com/#sun.

Vocabulary

- **astronomical unit (AU)**: A unit of measure; 1 AU is the distance from the Sun to Earth.

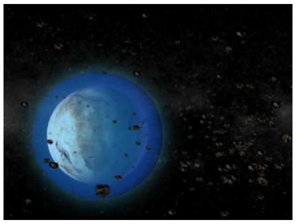
Summary

- The planets of the solar system, with increasing distance from the Sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The five known dwarf planets are Ceres, Pluto, Makemake, Haumea, and Eris.
- Solar system distances are measured as multiples of the distance between Earth and Sun, which is defined as one astronomical unit (AU).
- All planets and dwarf planets orbit the Sun and rotate on their axes.

Practice

Use this resource to answer the questions that follow.

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



MEDIA

Click image to the left for more content.

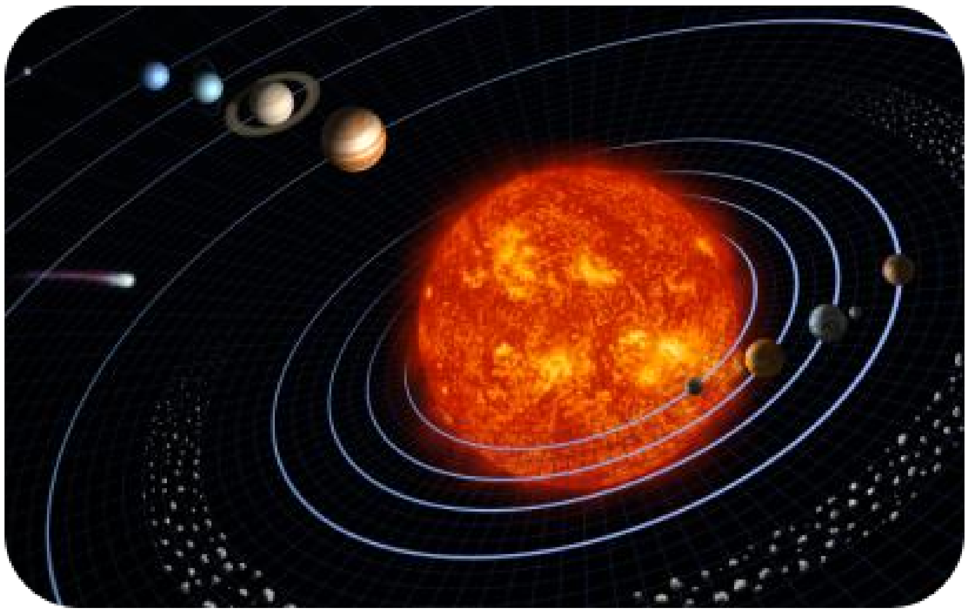
1. How old is our solar system?
2. How did the planets form?
3. What are the two main regions of the solar system?
4. List the inner planets.
5. List the outer planets.
6. What are the requirements to be a planet?
7. Why was Pluto demoted?
8. What is the Kuiper Belt?
9. What are found in the Kuiper Belt?
10. What is the scattered disk?
11. What is the heliosphere?

Review

1. Why does the number of dwarf planets recognized by astronomers in the solar system periodically increase?
2. What is the order of planets and dwarf planets by distance from the Sun?
3. What is an astronomical unit? Why is this unit used to measure distances in the solar system?

14.4 Planet Orbits in the Solar System

- Describe the size and shape of planetary orbits.



"Accordingly, since nothing prevents the earth from moving...

...I suggest that we should now consider also whether several motions suit it, so that it can be regarded as one of the planets. For, it is not the center of all the revolutions." - Nicolaus Copernicus

The Size and Shape of Orbits

Figure 14.7 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical, with the Sun located at one of the foci (See opening image).

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to make one complete orbit around the Sun, its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

Scaling the solar system creates a scale to measure all objects in solar system **(1i - I&E Stand.)**: http://www.youtube.com/watch?feature=player_profilepage#38;v=-6szEDHMxP4 (4:44).

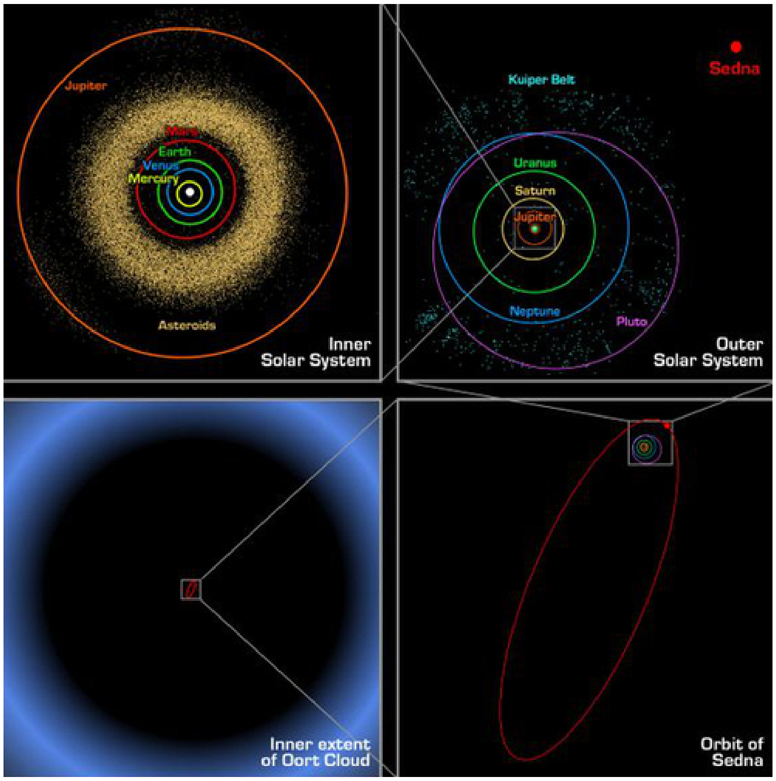


FIGURE 14.7

The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

MEDIA

Click image to the left for more content.

Summary

- The eight planets orbit the Sun along slightly elliptical paths, with Sun located at one of the foci.
- Kepler discovered that by using a planet's orbital period, it is possible to determine its distance from the Sun.
- The farther the planets are from the Sun, the greater their distance from each other.

Practice

Use this resource to answer the questions that follow.

http://www.classzone.com/books/earth_science/terc/content/visualizations/es2701/es2701page01.cfm?chapter_no=visualization

1. What does this animation show?

2. Describe what you see in this animation.

3. How long would it take to travel the solar system on today's fastest spacecraft?

4. How long would the trip take at the speed of light?

5. How fast is this animation?

Review

1. When you look at the diagram of planet orbits, which planet doesn't fit the criteria of a planet?
2. How can a planet's orbital period be used to determine a its distance from the Sun?
3. Why would your age be different on a different planet?

14.5 Gravity in the Solar System

- Define Newton's Universal Law of Gravitation.
- Explain the influence of gravity on the relative positions of Earth to the Sun and the Moon.

"I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses." - Isaac Newton, in *Philosophiae Naturalis Principia Mathematica*, 1687.

The Role of Gravity

Isaac Newton first described gravity as the force that causes objects to fall to the ground and also the force that keeps the Moon circling Earth instead of flying off into space in a straight line. Newton defined the Universal Law of Gravitation, which states that a force of attraction, called **gravity**, exists between all objects in the universe (**Figure** 14.8). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between objects, the smaller the force of attraction.

The distance between the Sun and each of its planets is very large, but the Sun and each of the planets are also very large. Gravity keeps each planet orbiting the Sun because the star and its planets are very large objects. The force of gravity also holds moons in orbit around planets.

BigThink video: Who was the greatest physicist in history? According to Neal deGrasse Tyson, it was Sir Isaac Newton: http://bigthink.com/ideas/13154.

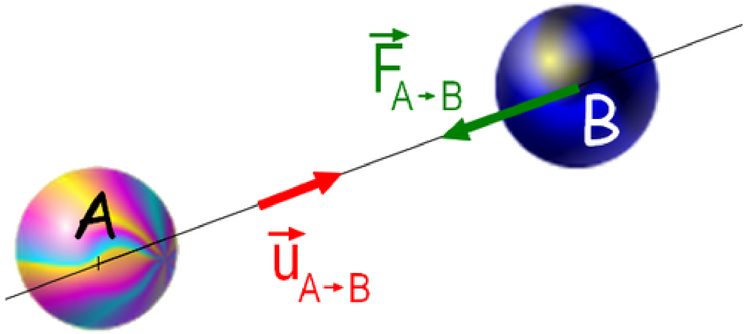


FIGURE 14.8

The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them.

Vocabulary

- **gravity**: The attraction of bodies to each other with a force proportional to their masses.

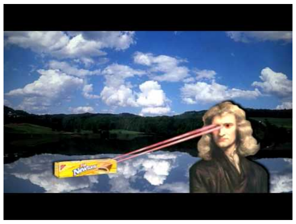
Summary

- Newton developed the Universal Law of Gravitation, which recognizes the gravitational attraction between objects.
- All objects have a force of attraction between them that is proportional to their mass and distance from each other.
- Gravity keeps the planets orbiting the Sun because they are very large, just as gravity keeps satellites orbiting the planets.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Jk5E-CrE1zg



MEDIA

Click image to the left for more content.

1. How long have the Earth and moon existed?
2. What evidence shows that the moon's gravity affects the Earth?
3. What does Newton's law of gravitation state?
4. What happens as mass increases?
5. What happens as distance increases?

Review

1. Why is the gravitational attraction of the Moon to Earth greater than the attraction of Earth to Sun?

2. Why doesn't the Moon fly off into space? Why does an apple fall to the ground rather than orbiting Earth at a distance?

3. What is the Universal Law of Gravitation?

14.6 Inner versus Outer Planets

- Compare and contrast the inner and outer planets.

"The sun, with all those planets revolving around it and dependent on it...

"...can still ripen a bunch of grapes as if it had nothing else in the universe to do." — Galileo Galilei

The Inner Planets

The **inner planets**, or **terrestrial planets**, are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. **Figure** 14.9 shows the relative sizes of these four inner planets.

Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings.

The Outer Planets

The four planets farthest from the Sun are the **outer planets**. **Figure** 14.10 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called **gas giants**.

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers think that hydrogen and helium gases comprised much of the solar system when it first formed. Since the inner planets didn't have enough mass to hold on to these light gases, their hydrogen and helium floated away into space. The Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

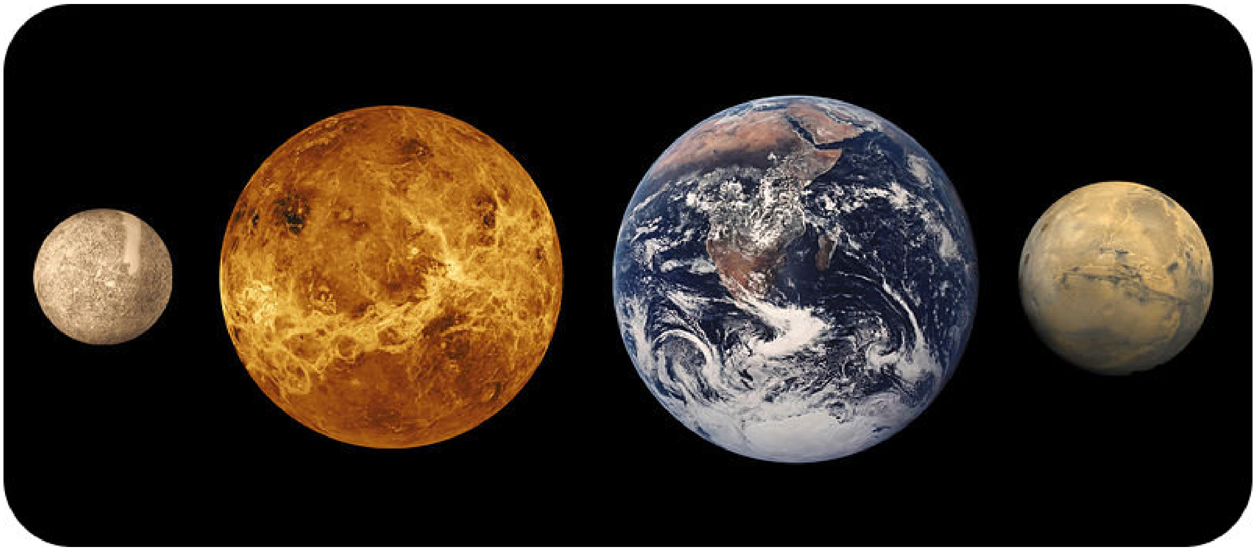


FIGURE 14.9
This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

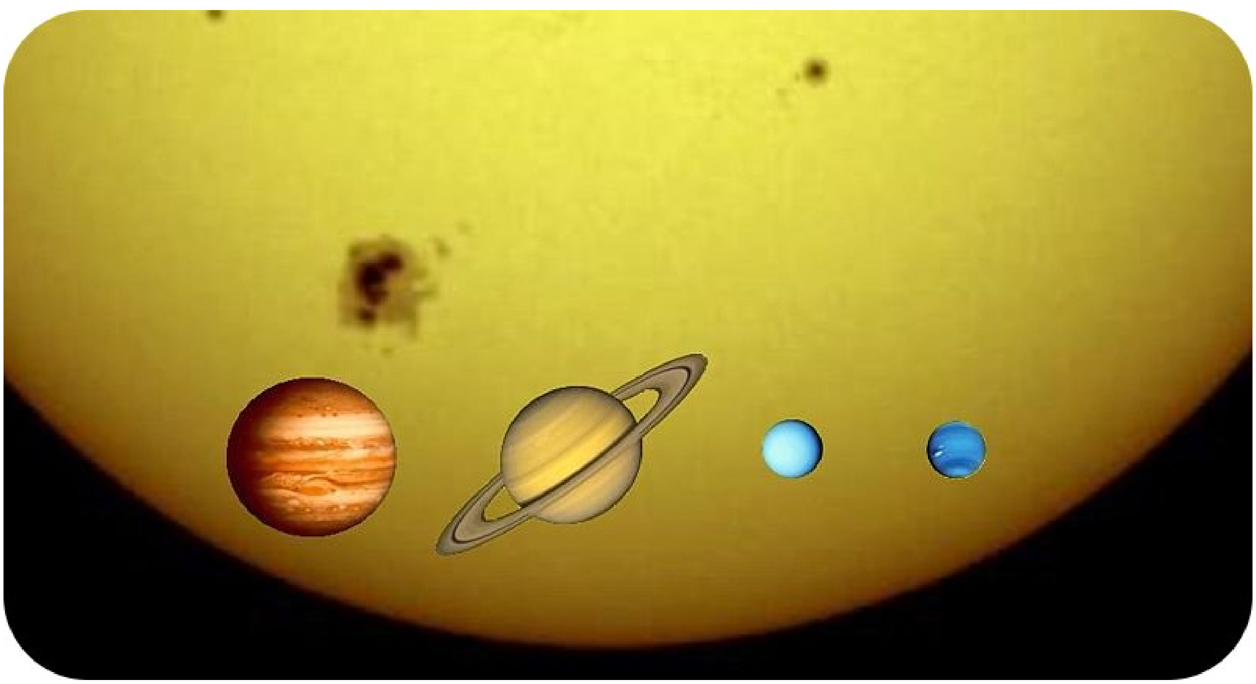


FIGURE 14.10
This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

All of the outer planets have numerous moons. They all also have **planetary rings**, composed of dust and other small particles that encircle the planet in a thin plane.

Vocabulary

- **inner planets** or **terrestrial planets**: The four solid, dense, rocky planets that are inside the asteroid belt: Mercury, Venus, Earth, and Mars.
- **outer planets** or **gas giants**: The four large outer planets composed of the gases hydrogen and helium that are beyond the asteroid belt in our solar system: Jupiter, Saturn, Uranus, and Neptune.
- **planetary rings**: Rings of dust and rock encircling a planet in a thin plane.

Summary

- The four inner planets have slower orbits, slower spin, no rings, and they are made of rock and metal.
- The four outer planets have faster orbits and spins, a composition of gases and liquids, numerous moons, and rings.
- The outer planets are made of hydrogen and helium, so they are called gas giants.

Practice

Use this resource to answer the questions that follow.

http://www.kidsastronomy.com/solar_system.htm

1. Which inner planets have no moons?

2. Which inner planet is the hottest?

3. What do all the inner planets have in common?

4. What divides the inner planets from the outer planets?

5. What characteristics do the outer planets share?

6. Which planet has the largest ring system?

7. Which planet has the most moons?

Review

1. What are the four inner planets? What are the four outer planets?

2. What is the difference in composition between the inner and outer planets? What accounts for the difference?

3. How does the arrangement of planets support the model for the formation of the solar system discussed in "Concept Earth History"?

14.7 Mercury

- Describe the characteristics of Mercury.

How did tiny Mercury get its name?

Mercury was named for the Roman messenger god who traveled rapidly on his winged sandals. From the vantage point of Earth, the planet Mercury travels swiftly across the face of the Sun.

Mercury

The smallest planet, Mercury, is the planet closest to the Sun. Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. However, the Mariner 10 spacecraft, shown in **Figure** 14.11, visited Mercury from 1974 to 1975.

The MESSENGER spacecraft has been studying Mercury in detail since 2005. The craft is currently in orbit around the planet, where it is creating detailed maps. MESSENGER stands for Mercury Surface, Space Environment, Geochemistry and Ranging.

FIGURE 14.11

(a) Mariner 10 made three flybys of Mercury in 1974 and 1975. (b) A 2008 image of compiled from a flyby by MESSENGER.

As **Figure** 14.12 shows, the surface of Mercury is covered with craters, like Earth's moon. Ancient impact craters means that for billions of years Mercury hasn't changed much geologically. Also, with very little atmosphere, the processes of weathering and erosion do not wear down structures on the planet.

There are many images, movies, and activities on the MESSENGER site: http://messenger.jhuapl.edu/index.php

Short Year, Long Days

Mercury is named for the Roman messenger god, who could run extremely quickly, just as the planet moves very quickly in its orbit around the Sun. A year on Mercury — the length of time it takes to orbit the Sun — is just 88 Earth days.

Despite its very short years, Mercury has very long days. A day is defined as the time it takes a planet to turn on its axis. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 57 Earth days long. In other words, on Mercury, a year is only a Mercury day and a half

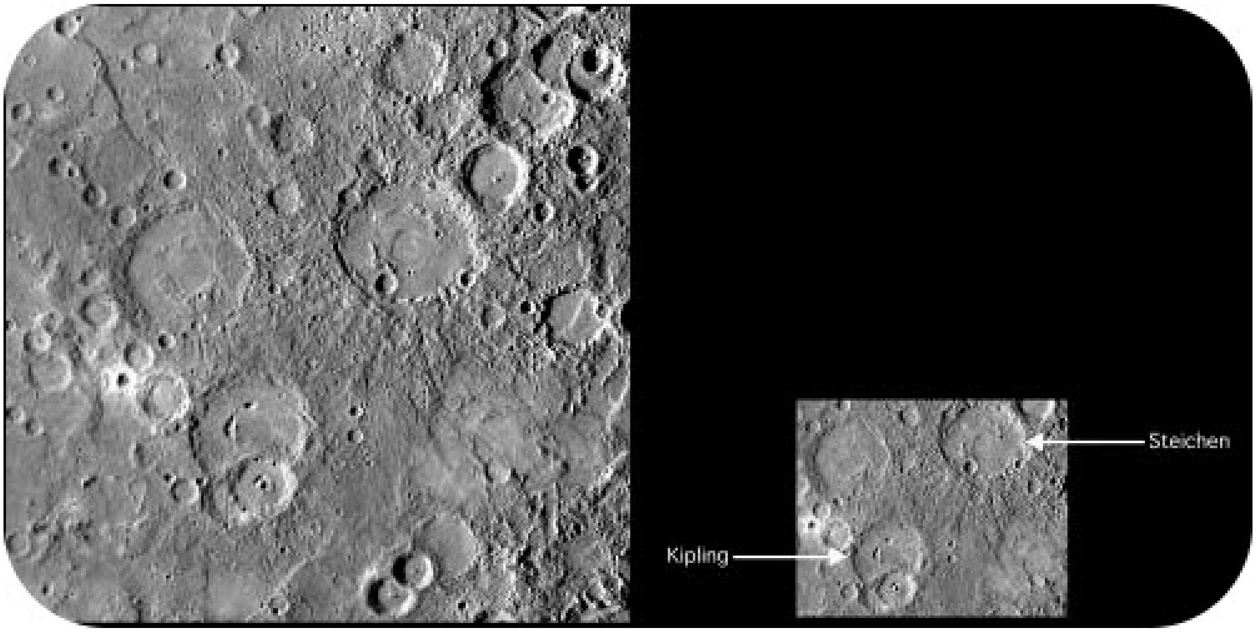


FIGURE 14.12
Mercury is covered with craters, like Earth's moon. MESSENGER has taken extremely detailed pictures of the planet's surface.

long!

Extreme Temperatures

Mercury is close to the Sun, so it can get very hot. However, Mercury has virtually no atmosphere, no water to insulate the surface, and it rotates very slowly. For these reasons, temperatures on the surface of Mercury vary widely. In direct sunlight, the surface can be as hot as 427^{o}C (801^{o}F). On the dark side, or in the shadows inside craters, the surface can be as cold as -183^{o}C (-297^{o}F)! Although most of Mercury is extremely dry, scientists think there may be a small amount of water in the form of ice at the poles of Mercury, in areas that never receive direct sunlight.

A Liquid Metal Core

Figure 14.13 shows a diagram of Mercury's interior. Mercury is one of the densest planets. It's relatively large, liquid core, made mostly of melted iron, takes up about 42% of the planet's volume.

Summary

- Mercury appears to be moving rapidly because it's so close to the Sun.
- Mercury has short years, just 88 Earth days, but long days, about 57 Earth days.
- Mercury is extremely hot and has a liquid metal core.

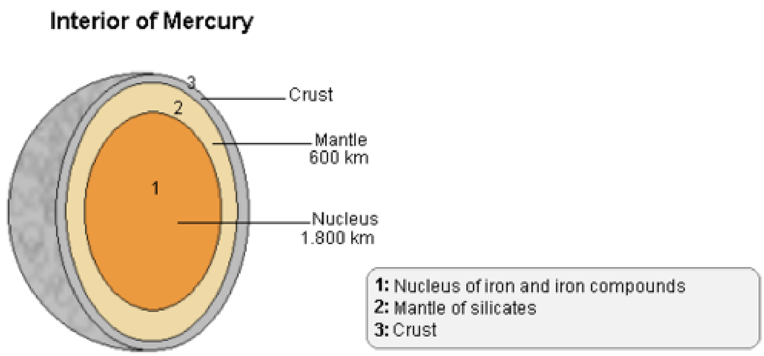


FIGURE 14.13
Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=H-doT9gNsI8

MEDIA
Click image to the left for more content.

1. What probe was sent to Mercury?
2. How does Mercury compare in size to the other planets?
3. Why does Mercury have a large core?
4. Describe the temperature variations on Mercury.
5. How long does a day last on Mercury?
6. What is the evidence of volcanic activity on Mercury?
7. Why do scientists think there may be ice on Mercury?
8. Why can't the Hubble Space Telescope be used to view Mercury?

Want to know more about Mercury? See https://www.windows2universe.org/mercury/mercury.html#38;edu=high.

Review

1. Why is a year on Mercury only 88 days long?
2. Why is Mercury mostly really hot, but very cold in spots?
3. Think about the formation of the solar system. Why is Mercury the densest planet?

14.8 Venus

- Describe the characteristics of Venus.

"Venus favors the bold". — Ovid, a Roman poet.

Our nearest planetary neighbor, Venus, was named after the Roman goddess of love because it appeared as the brightest and most beautiful star in the skies. Most of the planet's features are named for real or mythological women.

Venus

Venus' thick clouds reflect sunlight well, so Venus is very bright. When it is visible, Venus is the brightest object in the sky besides the Sun and the Moon. Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. When Venus rises just before the Sun rises, the bright object is called the morning star. When it sets just after the Sun sets, it is the evening star.

Of the planets, Venus is most similar to Earth in size and density. Venus is also our nearest neighbor. The planet's interior structure is similar to Earth's, with a large iron core and a silicate mantle (**Figure** 14.14). But the resemblance between the two inner planets ends there.

Find out more about Venus at the following link: http://www.nasa.gov/worldbook/venus_worldbook.html.

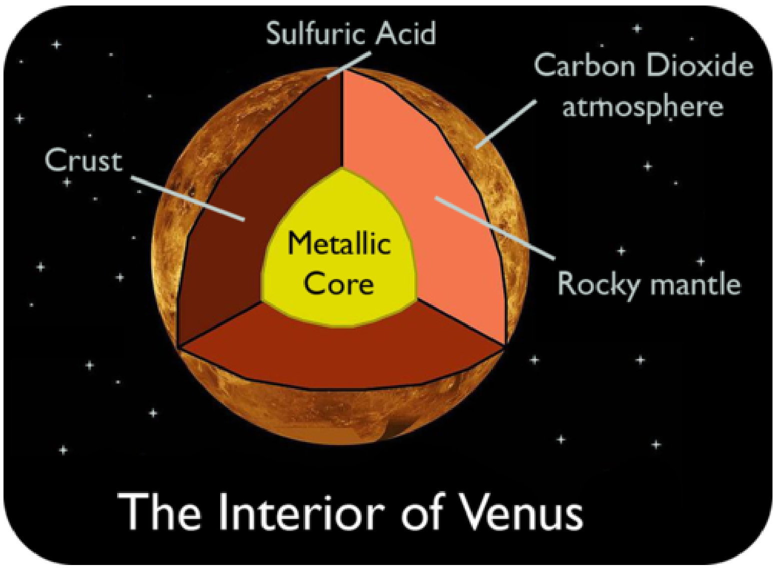


FIGURE 14.14
Venus's interior is similar to Earth's.

Motion

Venus rotates in a direction opposite the other planets and opposite to the direction it orbits the Sun. This rotation is extremely slow, only one turn every 243 Earth days. This is longer than a year on Venus — it takes Venus only 224 days to orbit the Sun.

Extreme Atmosphere

Venus is covered by a thick layer of clouds, as shown in pictures of Venus taken at ultraviolet wavelengths (**Figure** 14.15).

Venus' clouds are not made of water vapor like Earth's clouds. Clouds on Venus are made mostly of carbon dioxide with a bit of sulfur dioxide. They also contain corrosive sulfuric acid. Because carbon dioxide is a greenhouse gas, the atmosphere traps heat from the Sun and creates a powerful greenhouse effect. Even though Venus is further from the Sun than Mercury, the greenhouse effect makes Venus the hottest planet. Temperatures at the surface reach 465^{o}C (860^{o}F). That's hot enough to melt lead.

The atmosphere of Venus is full of acid, its pressure is crushing, and the enormous amount of carbon dioxide causes runaway greenhouse effect **(4d)**: http://www.youtube.com/watch?v=HqFVxWfVtoo (2:05).

FIGURE 14.15
This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus.

MEDIA
Click image to the left for more content.

The atmosphere of Venus is so thick that the atmospheric pressure on the planet's surface is 90 times greater than the atmospheric pressure on Earth's surface. The dense atmosphere totally obscures the surface of Venus, even from spacecraft orbiting the planet.

Venus's Surface

Since spacecraft cannot see through the thick atmosphere, radar is used to map Venus' surface. Many features found on the surface are similar to Earth and yet are very different. **Figure** 14.16 shows a topographical map of Venus produced by the Magellan probe using radar.

Orbiting spacecraft have used radar to reveal mountains, valleys, and canyons. Most of the surface has large areas of volcanoes surrounded by plains of lava. In fact, Venus has many more volcanoes than any other planet in the solar system, and some of those volcanoes are very large.

Most of the volcanoes are no longer active, but scientists have found evidence that there is some active volcanism (**Figure** 14.17). Think about what you know about the geology of Earth and what produces volcanoes. What does the presence of volcanoes suggest about the geology of Venus? What evidence would you look for to find the causes of volcanism on Venus?

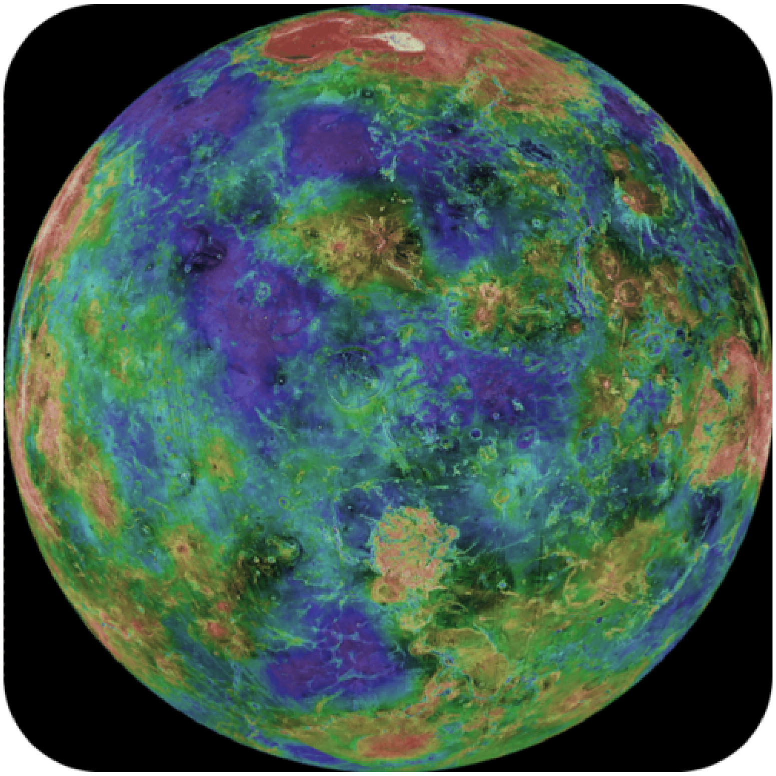


FIGURE 14.16
This false color image of Venus was made from radar data collected by the Magellan probe between 1990 and 1994. What features can you identify?

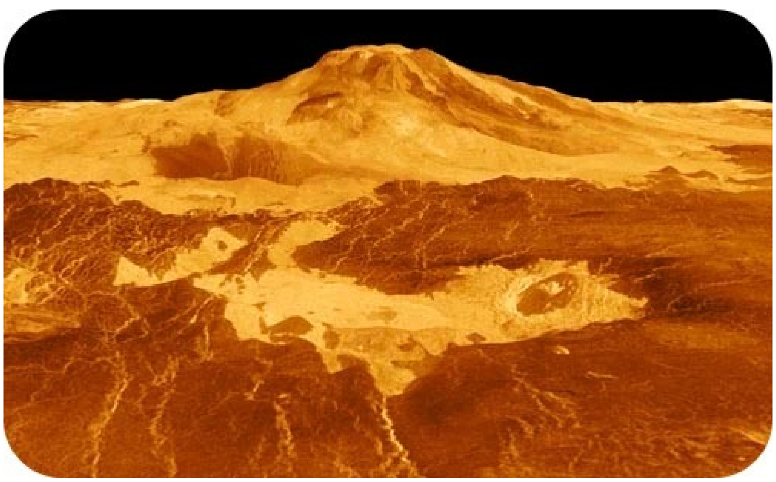


FIGURE 14.17
This image of the Maat Mons volcano with lava beds in the foreground was generated by a computer from radar data. The reddish-orange color is close to what scientists think the color of sunlight would look like on the surface of Venus.

Venus also has very few impact craters compared with Mercury and the Moon. What is the significance of this? Earth has fewer impact craters than Mercury and the Moon, too. Is this for the same reason that Venus has fewer impact craters?

It's difficult for scientists to figure out the geological history of Venus. The environment is too harsh for a rover to go there. It is even more difficult for students to figure out the geological history of a distant planet based on the information given here. Still, we can piece together a few things.

On Earth, volcanism is generated because the planet's interior is hot. Much of the volcanic activity is caused by plate tectonic activity. But on Venus, there is no evidence of plate boundaries and volcanic features do not line up the way they do at plate boundaries.

Because the density of impact craters can be used to determine how old a planet's surface is, the small number of impact craters means that Venus' surface is young. Scientists think that there is frequent, planet-wide resurfacing of Venus with volcanism taking place in many locations. The cause is heat that builds up below the surface, which has no escape until finally it destroys the crust and results in volcanoes.

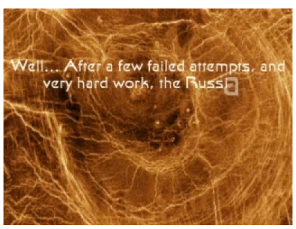
Summary

- Venus has a very thick, carbon dioxide-rich atmosphere, so the planet has a very strong greenhouse effect.
- The surface of Venus has very few impact craters, so it must be very young. This suggests that the planet experiences volcanism and has a hot interior.
- Venus has a lot of volcanoes, including some very large ones.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=NjXt4CtH_9o



MEDIA

Click image to the left for more content.

1. How long is a day on Venus?

2. How is Venus similar to Earth?

3. Describe Venus' atmospheric composition.

4. What is the average temperature of Venus?

5. What is the rain on Venus?

6. How bright does Venus look to us?

7. Describe the conditions on Venus' surface.

8. What is Sif Mons?

9. How would a probe last on Venus?

10. What country successfully landed probes on Venus?

Want to know more about Venus? See https://www.windows2universe.org/venus/venus.html.

Review

1. Under what conditions is a planet subject to such a large greenhouse effect?

2. Why does the number of impact craters on the surface of a planet indicate the conditions found in the interior?

3. Why does Venus always appear to be near the Sun when viewed from Earth?

14.9 Moon

- Describe the characteristics of Earth's Moon.

That's one small step for [a] man, one giant leap for mankind. — Neil Armstrong

On July 20, 1969, hundreds of millions of people all over the world witnessed something incredible. Never before had a human being walked on a planetary body other than Earth. But on that day, Neil Armstrong and Buzz Aldrin walked on the Moon. The footprints the men left behind are the first signs of life ever on the Moon. Scientists have learned a great deal about the Moon from the Apollo missions and from rovers and satellites sent to the Moon for study.

Lunar Characteristics

The Moon is Earth's only natural satellite, a body that moves around a larger body in space. The Moon orbits Earth for the same reason Earth orbits the Sun — gravity. The Moon is 3,476 km in diameter, about one-fourth the size of Earth. The satellite is also not as dense as the Earth; gravity on the Moon is only one-sixth as strong as it is on Earth. An astronaut can jump six times as high on the Moon as on Earth!

The Moon makes one complete orbit around the Earth every 27.3 days. The Moon also rotates on its axis once every 27.3 days. Do you know what this means? The same side of the Moon always faces Earth, so that side of the Moon is what we always see in the night sky (**Figure** 14.18). The Moon makes no light of its own, but instead only reflects light from the Sun.

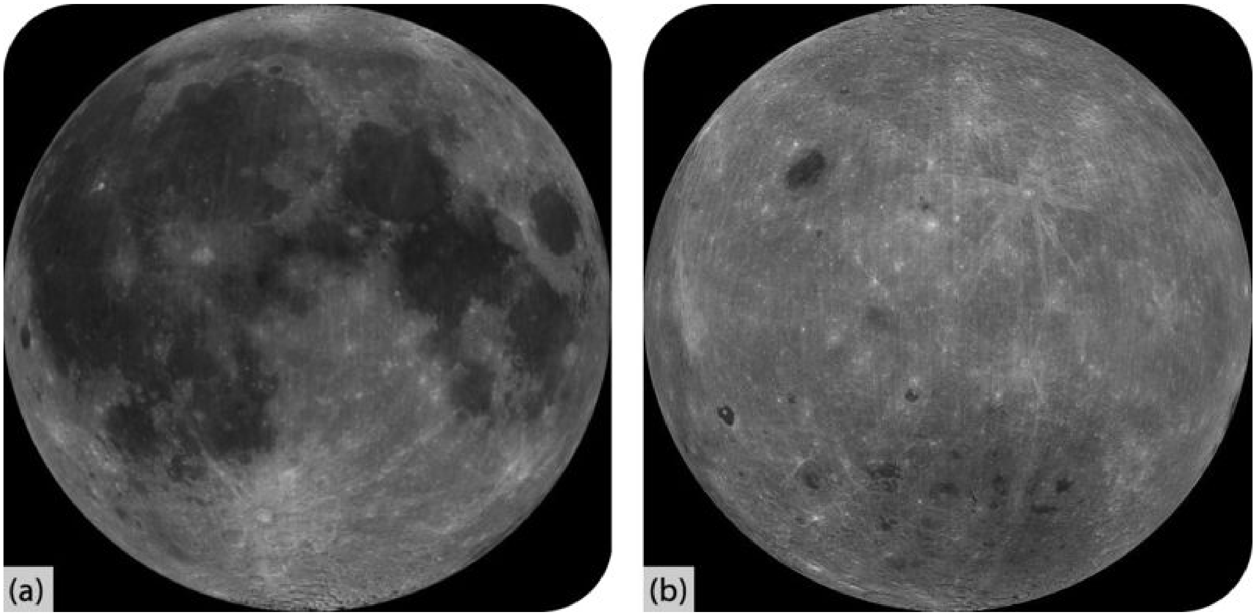


FIGURE 14.18

(a) The near side of the Moon faces Earth continually. It has a thinner crust with many more maria (flat areas of basaltic rock). (b) The far side of the Moon has only been seen by spacecraft. It has a thicker crust and far fewer maria (flat areas of basaltic rock).

The Lunar Surface

The Moon has no atmosphere. Since an atmosphere moderates temperature, the Moon's average surface temperature during the day is approximately 225^{o}F, but drops to -243^{o}F at night. The coldest temperatures, around -397^{o}F, occur in craters in the permanently shaded south polar basin. These are among the coldest temperatures recorded in the entire solar system.

Earth's landscape is extremely varied, with mountains, valleys, plains and hills. This landscape is always changing as plate tectonics builds new features and weathering and erosion destroys them. The landscape of the Moon is very different. With no plate tectonics, features are not built. With no atmosphere, features are not destroyed. Still, the Moon has a unique surface. **Lunar** surface features include the bowl-shaped **craters** that are caused by meteorite impacts (**Figure** 14.19). If Earth did not have plate tectonics or erosion, its surface would also be covered with meteorite craters.

Even from Earth, the Moon has visible dark areas and light areas. The dark areas are called **maria**, which means "seas" because that's what the ancients thought they were. In fact, the maria are not water but solid, flat areas of basaltic lava. From about 3.0 to 3.5 billion years ago the Moon was continually bombarded by meteorites. Some of these meteorites were so large that they broke through the Moon's newly formed surface. Then, magma flowed out and filled the craters. Scientists estimate volcanic activity on the Moon ceased about 1.2 billion years ago, but most occurred long before that.

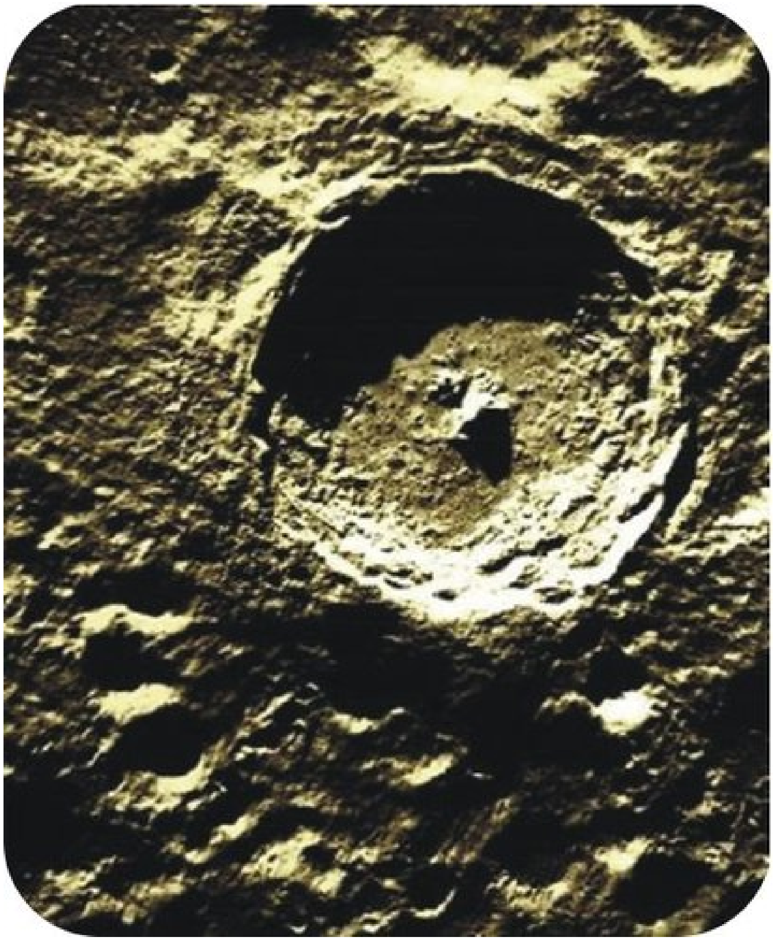


FIGURE 14.19
A crater on the surface of the Moon.

The lighter parts of the Moon are called **terrae** or highlands (**Figure** 14.20). The terrae are higher than the maria and include several high mountain ranges. The terrae are the light silicate minerals that precipitated out of the ancient magma ocean and formed the early lunar crust.

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface, but water in the form of ice has been found in the extremely cold craters and bound up in the lunar soil. Despite the possible presence of water, the lack of an atmosphere and the extreme temperatures make it no surprise to scientists that the Moon has absolutely no evidence of life.

Life from Earth has visited the Moon and there are footprints of astronauts on the lunar surface. With no wind, rain, or living thing to disturb them, these footprints will remain as long as the Moon exists. Only an impact with a meteorite could destroy them.

Interior of the Moon

Like Earth, the Moon has a distinct crust, mantle, and core. What is known about the Moon's interior was determined from the analysis of rock samples gathered by astronauts and from unmanned spacecraft sent to the Moon (**Figure** 14.21).

- The Moon's small core, 600 to 800 kilometers in diameter, is mostly iron with some sulfur and nickel.

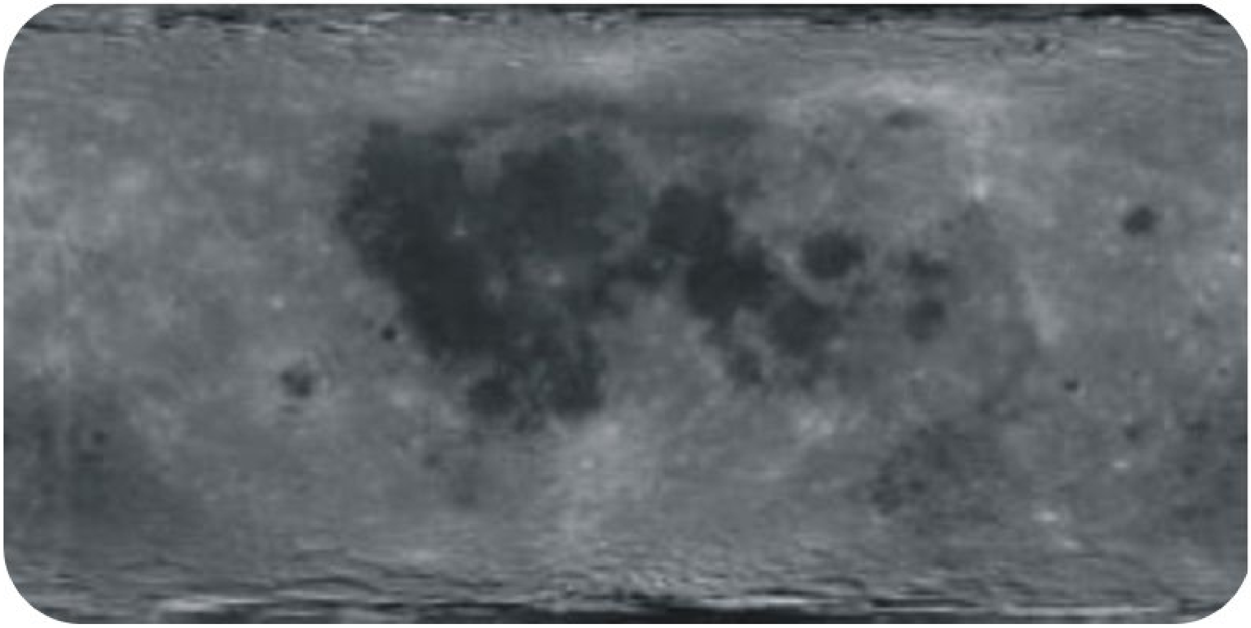


FIGURE 14.20

A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon's surface, mostly on the side of the Moon we see.

FIGURE 14.21

The Moon's internal structure shows a small metallic core (yellow), a primitive mantle (orange), a depleted mantle (blue), and a crust (gray).

- The mantle is composed of the minerals olivine and orthopyroxene. Analysis of Moon rocks indicates that there may also be high levels of iron and titanium in the lunar mantle.
- The crust is composed of igneous rock rich in the elements oxygen, silicon, magnesium, and aluminum. The crust is about 60 km thick on the near side of the Moon and about 100 km thick on the far side.

LCROSS crashed into the Moon in May 2009. This QUEST video describes the mission. After watching, look up the mission to see what they found!

Watch it at http://science.kqed.org/quest/video/nasa-ames-rocket-to-the-moon/.

MEDIA
Click image to the left for more content.

Vocabulary

- **crater**: Bowl-shaped depressions on the surface of the Moon caused by impact from meteorites.
- **lunar**: Related to the Moon.
- **maria**: The dark parts of the Moon's surface, made up of ancient basaltic eruptions.
- **terrae**: The light parts of the Moon's surface, composed of high crater rims.

Summary

- The Moon revolves around Earth as they orbit the Sun; the same side of Moon always faces Earth.
- The lunar surface has dark basalt maria and light highlands called terrae.
- The Moon has a crust, mantle, and core, but no water or atmosphere.

Practice

Use this resource to answer the questions that follow.

MEDIA
Click image to the left for more content.

1. What is the moon?
2. How far is the moon from the Earth?
3. What did Galileo prove about the moon?
4. Where did the moon come from?
5. What is happening to the moon?
6. Why do we always see the same side of the moon?
7. Describe the moon's structure.

8. What are maria?

9. What are terra?

10. What created the craters on the moon?

11. What is the gravity on the moon?

12. What is in an eclipse?

13. What is a lunar eclipse?

14. What is a solar eclipse?

15. Why is the moon unique?

16. Who was the first person the moon?

For additional information go to: https://www.windows2universe.org/earth/moons_and_rings.html.

Review

1. Explain why one side of the Moon always faces toward Earth and the other side always faces away from Earth.

2. How did the Moon's terrae form?

3. What is significant about the Moon's core?

14.10 Mars

- Describe the characteristics of Mars.

"Ladies and gentlemen, I have a grave announcement to make...

...Incredible as it may seem, strange beings who landed in New Jersey tonight are the vanguard of an invading army from Mars." — Orson Welles, "The War of the Worlds" radio broadcast, October 30, 1938.

Orson Welles caused a panic when some people took his news bulletins, meant to be a radio drama anthology, as the truth. No evidence of life has been found on Mars. Would people believe it if he broadcasted this today? Would you?

Characteristics

Mars is the fourth planet from the Sun, and the first planet beyond Earth's orbit (**Figure** 14.22). Mars is a quite different from Earth and yet more similar than any other planet. Mars is smaller, colder, drier, and appears to have no life, but volcanoes are common to both planets and Mars has many.

Mars is easy to observe, so Mars has been studied more thoroughly than any other extraterrestrial planet. Space probes, rovers, and orbiting satellites have all yielded information to planetary geologists. Although no humans have ever set foot on Mars, both NASA and the European Space Agency have set goals of sending people to Mars sometime between 2030 and 2040.

Find out all you want to know about Mars at http://mars.jpl.nasa.gov/extreme/.

FIGURE 14.22
This image of Mars, taken by the Hubble Space Telescope in October, 2005, shows the planet's red color, a small ice cap on the south pole, and a dust storm.

A Red Planet

Viewed from Earth, Mars is reddish in color. The ancient Greeks and Romans named the planet after the god of war. The surface is not red from blood but from large amounts of iron oxide in the soil.

The Martian atmosphere is very thin relative to Earth's and has much lower atmospheric pressure. Although the atmosphere is made up mostly of carbon dioxide, the planet has only a weak greenhouse effect, so temperatures are only slightly higher than if the planet had no atmosphere.

Surface Features

Mars has mountains, canyons, and other features similar to Earth. Some of these surface features are amazing for their size! Olympus Mons is a shield volcano, similar to the volcanoes that make up the Hawaiian Islands. But Olympus Mons is also the largest mountain in the solar system (**Figure** 14.23).

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 14.24).

Mars has more impact craters than Earth, though fewer than the Moon. A video comparing geologic features on Mars and Earth is seen here: http://news.discovery.com/videos/space-3-questions-mars-tectonics.html.

Is There Water on Mars?

Water cannot stay in liquid form on Mars because the atmospheric pressure is too low. However, there is a lot of water in the form of ice and even prominent ice caps (**Figure** 14.25). Scientists also think that there is a lot of ice present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

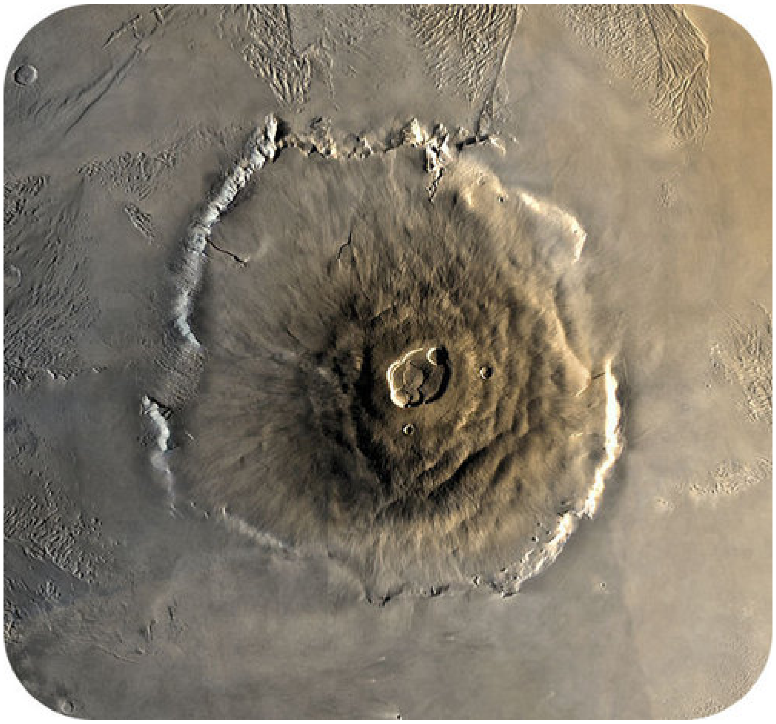


FIGURE 14.23

Olympus Mons is about 27 km (16.7 miles/88,580 ft) above the Martian surface, more than three times taller than Mount Everest. The volcano's base is about the size of the state of Arizona.

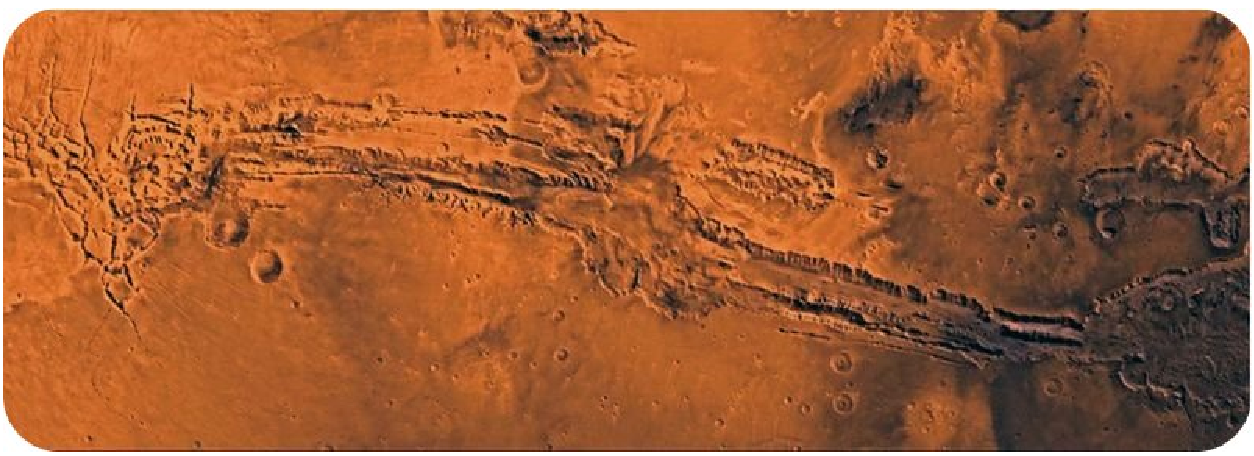


FIGURE 14.24

Valles Marineris is 4,000 km (2,500 mi) long, as long as Europe is wide, and one-fifth the circumference of Mars. The canyon is 7 km (4.3 mi) deep. By comparison, the Grand Canyon on Earth is only 446 km (277 mi) long and about 2 km (1.2 mi) deep.

Scientists think that water once flowed over the Martian surface because there are surface features that look like water-eroded canyons. The presence of water on Mars, even though it is now frozen as ice, suggests that it might have been possible for life to exist on Mars in the past.

A video of the top five Phoenix Lander sites on Mars is seen here: http://news.discovery.com/videos/space-top-5

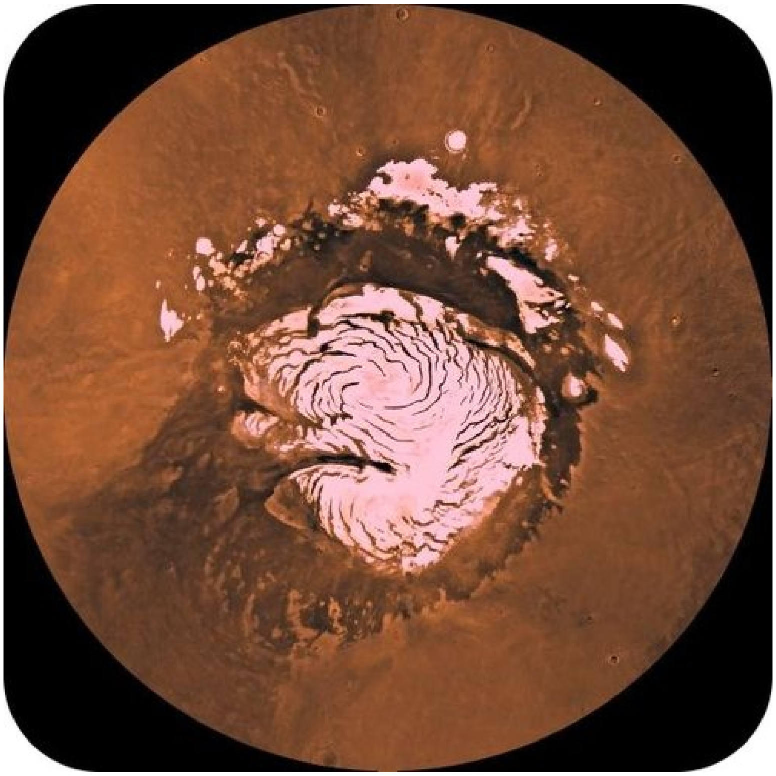


FIGURE 14.25
The north polar ice cap on Mars.

-mars-phoenix-lander-images.html.

Two Martian Moons

Mars has two very small moons that are irregular rocky bodies (**Figure** 14.26). Phobos and Deimos are named after characters in Greek mythology — the two sons of Ares, who followed their father into war. Ares is equivalent to the Roman god Mars.

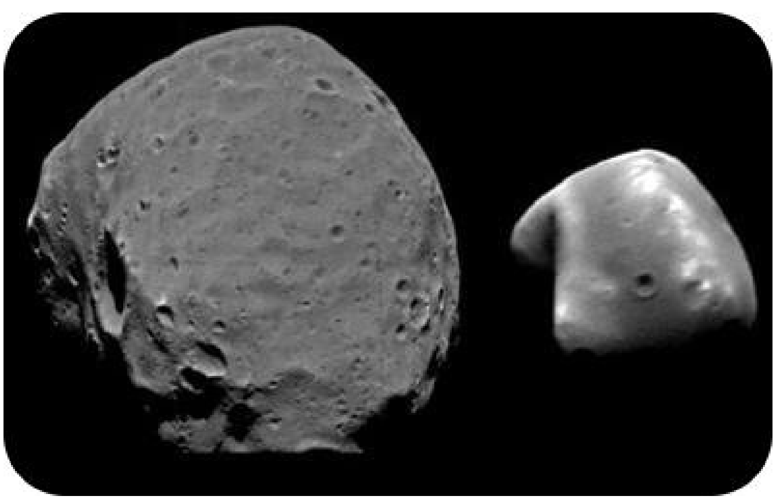


FIGURE 14.26
Mars has two small moons, Phobos (left) and Deimos (right). Both were discovered in 1877 and are thought to be captured asteroids.

An animation of the moons orbiting Mars is seen here: http://en.wikipedia.org/wiki/File:Orbits_of_Phobos_and_Deimos.gif.

The Mars Science Laboratory was launched on November 26, 2011 and will search for any evidence that the Red Planet was once capable of supporting life. Curiosity is a car-sized rover that will scour the red planet for clues after it lands in August 2012.

See more at http://science.kqed.org/quest/video/searching-for-life-on-mars/.

Adobe Flash

MEDIA

Click image to the left for more content.

Summary

- Mars is the easiest planet to study because it doesn't have thick clouds obscuring its surface.
- The surface of Mars has volcanoes and channels that were once filled with water.
- Mars has two moons that are thought to be captured asteroids.

Practice

Use this resource to answer the questions that follow.

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

MEDIA

Click image to the left for more content.

1. What is the diameter of Mars?
2. What is primary component of Mars' atmosphere?
3. Why is Mars red?
4. What does the absence of plate tectonics on Mars mean?
5. What type of volcano is Olympus Mons?
6. What is Valles Marineris?
7. Which NASA spacecraft found water on Mars?
8. Which NASA spacecraft discovered snow?
9. Why isn't snow seen on the surface of Mars?
10. Why aren't the Dust Devils dangerous on Mars?

Want to know more about Mars? See https://www.windows2universe.org/mars/mars.html.

Review

1. Why is Mars red?
2. Why doesn't Mars have liquid water now? What evidence is there that Mars once had liquid water?
3. Is the surface of Mars young, like the surface of Venus? How would you know?

14.11 Jupiter

- Describe the characteristics of Jupiter.

"What Jupiter? Do not trifle. There is no Jupiter." — Socrates

The Romans named the largest planet for their most important god. They followed the tradition of the Greeks, who had similarly named the planet Zeus. They built a temple to Jupiter on the hill. Was Socrates denying the existence of the most important Roman god?

Characteristics

Jupiter is enormous, the largest object in the solar system besides the Sun. Although Jupiter is over 1,300 times Earth's volume, it has only 318 times the mass of Earth. Like the other gas giants, it is much less dense than Earth.

Because Jupiter is so large, it reflects a lot of sunlight. Jupiter is extremely bright in the night sky; only the Moon and Venus are brighter (**Figure** 14.27). This brightness is all the more impressive because Jupiter is quite far from the Earth — 5.20 AUs away. It takes Jupiter about 12 Earth years to orbit once around the Sun.

Check out NASA's world book to learn more about Jupiter: http://www.nasa.gov/worldbook/jupiter_worldbook.html .

A Ball of Gas and Liquid

Astronauts trying to land a spaceship on the surface of Jupiter would find that there is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements (**Figure** 14.28). Jupiter's atmosphere is composed of hydrogen and helium. Deeper within the planet, pressure compresses the gases into a liquid. Some evidence suggests that Jupiter may have a small rocky core of heavier elements at its center.

FIGURE 14.27
This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details.

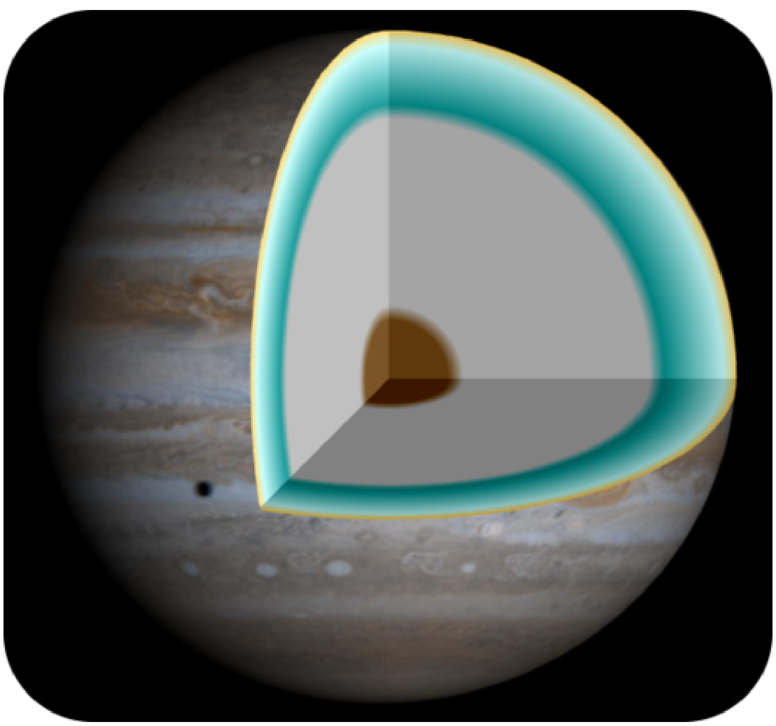


FIGURE 14.28
Jupiter's structure.

A Stormy Atmosphere

The upper layer of Jupiter's atmosphere contains clouds of ammonia (NH_3) in bands of different colors. These bands rotate around the planet, but also swirl around in turbulent storms. The **Great Red Spot** (**Figure** 14.29) is an enormous, oval-shaped storm found south of Jupiter's equator. This storm is more than three times as wide as the entire Earth. Clouds in the storm rotate in a counterclockwise direction, making one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years, since astronomers could first see the storm through telescopes. Do you think the Great Red Spot is a permanent feature on Jupiter? How could you know?

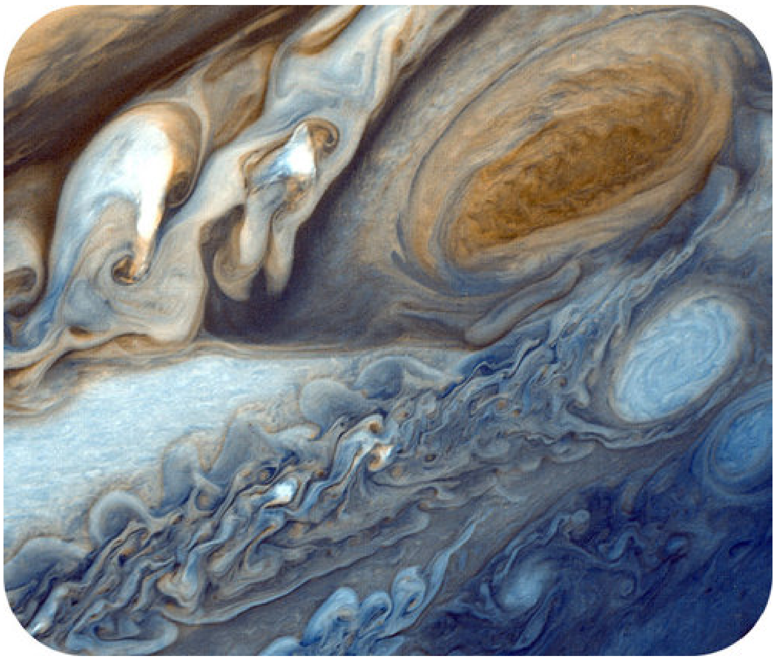


FIGURE 14.29
This image of Jupiter's Great Red Spot (upper right of image) was taken by the Voyager 1 spacecraft. The white storm just below the Great Red Spot is about the same diameter as Earth.

Jupiter's Moons and Rings

Jupiter has a very large number of moons — 63 have been discovered so far. Four are big enough and bright enough to be seen from Earth, using no more than a pair of binoculars. These moons — Io, Europa, Ganymede, and Callisto — were first discovered by Galileo in 1610, so they are sometimes referred to as the **Galilean moons** (**Figure** 14.30). The Galilean moons are larger than the dwarf planets Pluto, Ceres, and Eris. Ganymede is not only the biggest moon in the solar system; it is even larger than the planet Mercury!

Scientists are particularly interested in Europa because it may be a place to find extraterrestrial life. What features might make a satellite so far from the Sun a candidate for life? Although the surface of Europa is a smooth layer of ice, there is evidence that there is an ocean of liquid water underneath (**Figure** 14.31). Europa also has a continual source of energy — it is heated as it is stretched and squashed by tidal forces from Jupiter. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

In 1979, two spacecraft — Voyager 1 and Voyager 2 — visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is difficult to observe from Earth.

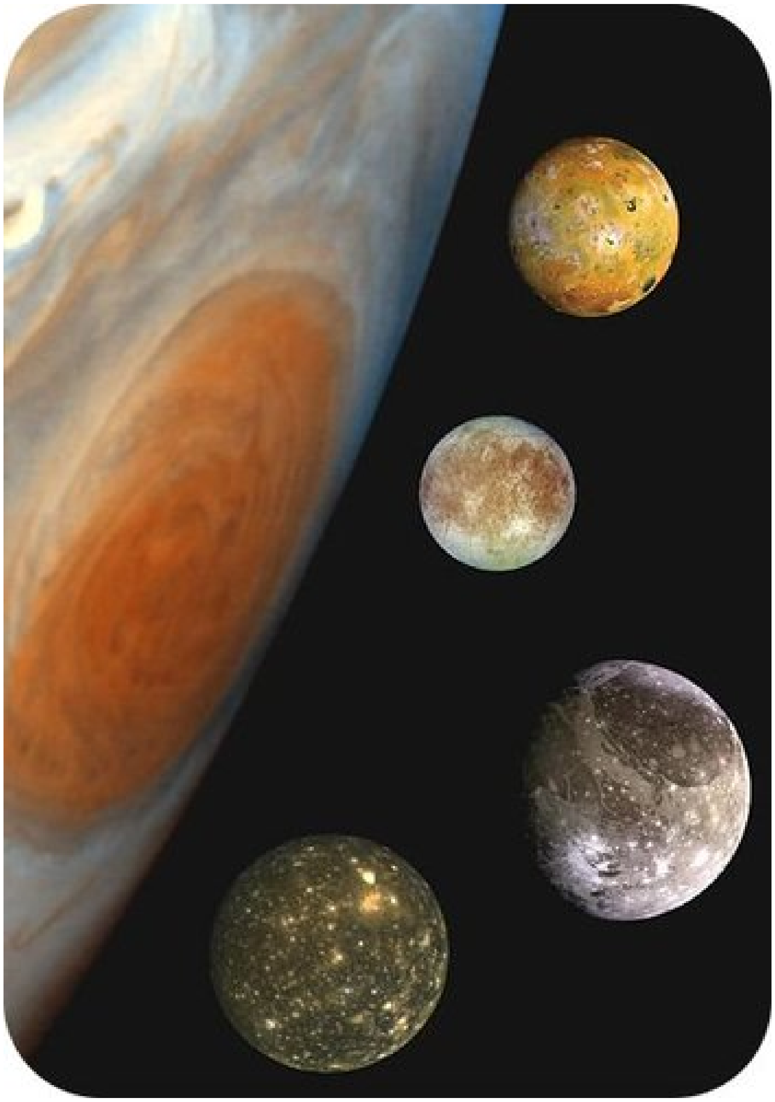


FIGURE 14.30
This composite image shows the four Galilean moons and their sizes relative to the Great Red Spot. From top to bottom, the moons are Io, Europa, Ganymede, and Callisto. Jupiter's Great Red Spot is in the background. Sizes are to scale.

Vocabulary

- **Galilean moons**: The four largest moons of Jupiter discovered by Galileo.
- **Great Red Spot**: An enormous, oval-shaped, long-lived storm on Jupiter.

Summary

- Jupiter is mostly hydrogen with some helium, and may contain a small rocky core.
- Jupiter has a thick atmosphere containing the Great Red Spot, a storm that has been going for at least 300 years.
- One of Jupiter's moons, Europa, appears to have a liquid ocean beneath the surface due to tidal forces from the massive planet; this ocean could be a place for life.

Practice

Use this resource to answer the questions that follow.

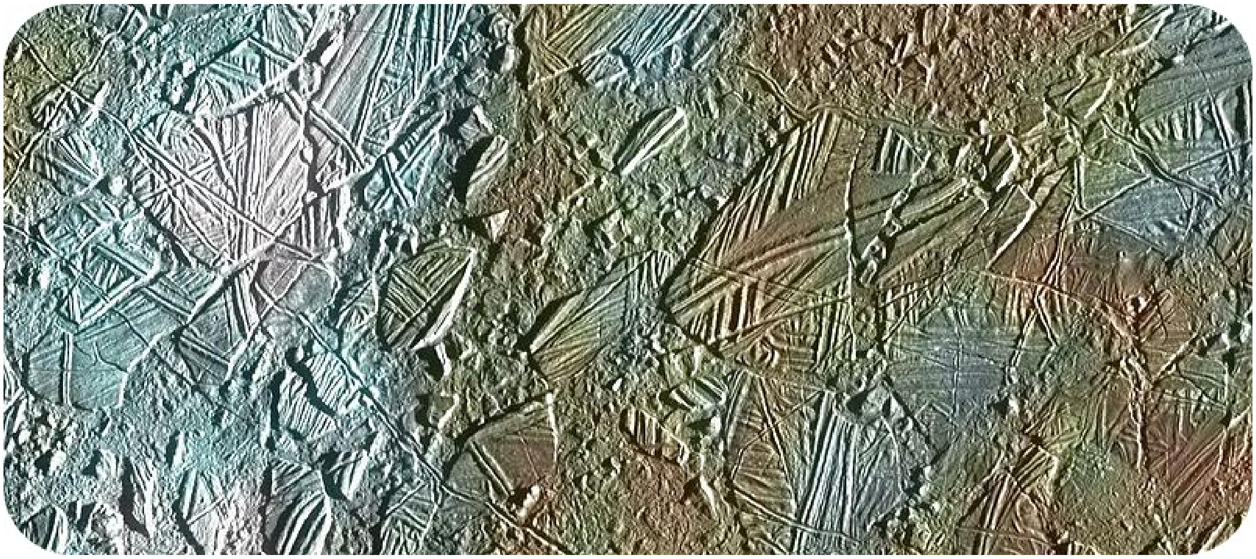


FIGURE 14.31

An enhanced color image of a portion of Europa's icy surface. The surface ice may have motions similar to plate tectonics on Earth.

http://www.youtube.com/watch?v=KcGCJwcmx2o

MEDIA

Click image to the left for more content.

1. How does the mass of Jupiter compare to Earth?
2. How quickly does it rotate on its axis?
3. What makes the different bands on the planet?
4. What is happening to the Giant Red Spot?
5. What two elements make up the majority of Jupiter?
6. What happened to the Comet Shoemaker-Levy 9?
7. How many moons does Jupiter have?
8. What is unique about Ganymede?
9. Describe Jupiter's ring system.
10. What causes the auroras on Jupiter?

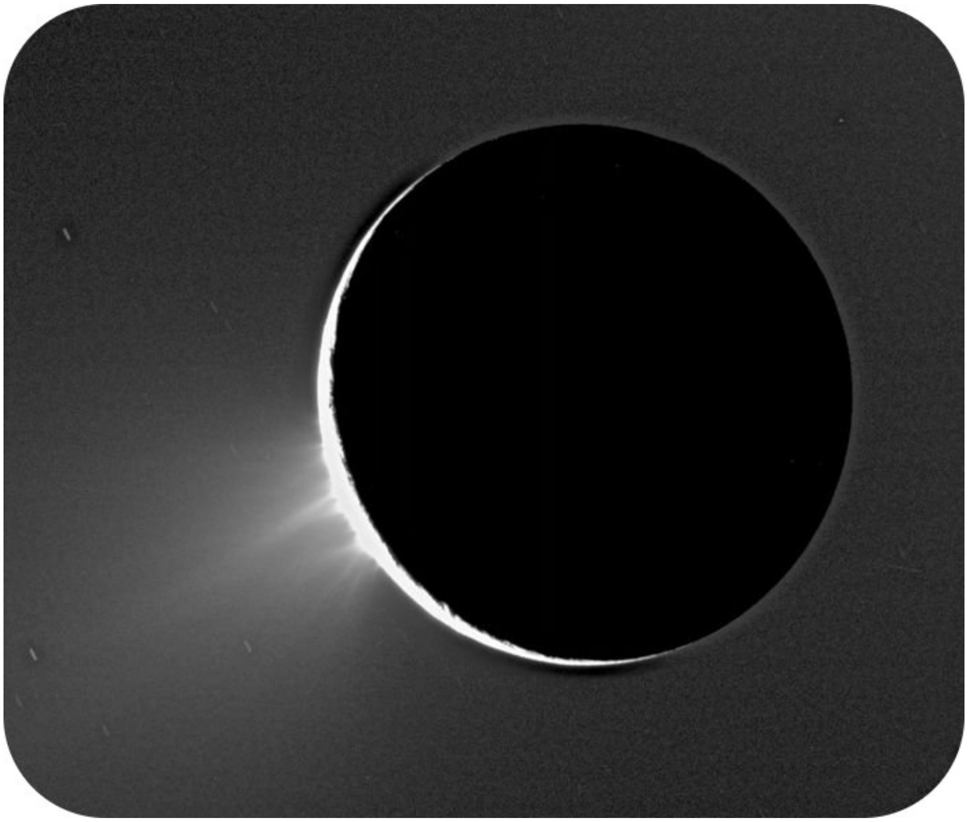
Want to know more about Jupiter? See https://www.windows2universe.org/jupiter/jupiter.html.

Review

1. Why is the Great Red Spot thought to be a storm?
2. What is Jupiter made of?
3. Why is Europa one of the few locations in the solar system where scientists think there could possibly be life?

14.12 Saturn

- Describe the characteristics of Saturn.



Is there life elsewhere in the Solar System?

Saturn's moon, Enceladus, may be the most habitable spot in the solar system, other than Earth, for life as we know it. These plumes indicate the presence of water and the internal heat to create liquid water. Is there life? No one knows yet.

Saturn

Saturn, shown in **Figure** 14.32, is famous for its beautiful rings. Although all the gas giants have rings, only Saturn's can be easily seen from Earth. In Roman mythology, Saturn was the father of Jupiter.

Saturn's mass is about 95 times the mass of Earth, and its volume is 755 times Earth's volume, making it the second largest planet in the solar system. Saturn is also the least dense planet in the solar system. It is less dense than water. What would happen if you had a large enough bathtub to put Saturn in? Saturn would float! Saturn orbits the Sun once about every 30 Earth years.

Like Jupiter, Saturn is made mostly of hydrogen and helium gases in the outer layers and liquids at greater depths. The upper atmosphere has clouds in bands of different colors. These rotate rapidly around the planet, but there seems to be less turbulence and fewer storms on Saturn than on Jupiter. One interesting phenomenon that has been observed in the storms on Saturn is the presence of thunder and lightning (see video, below). The planet likely has a small rocky and metallic core.

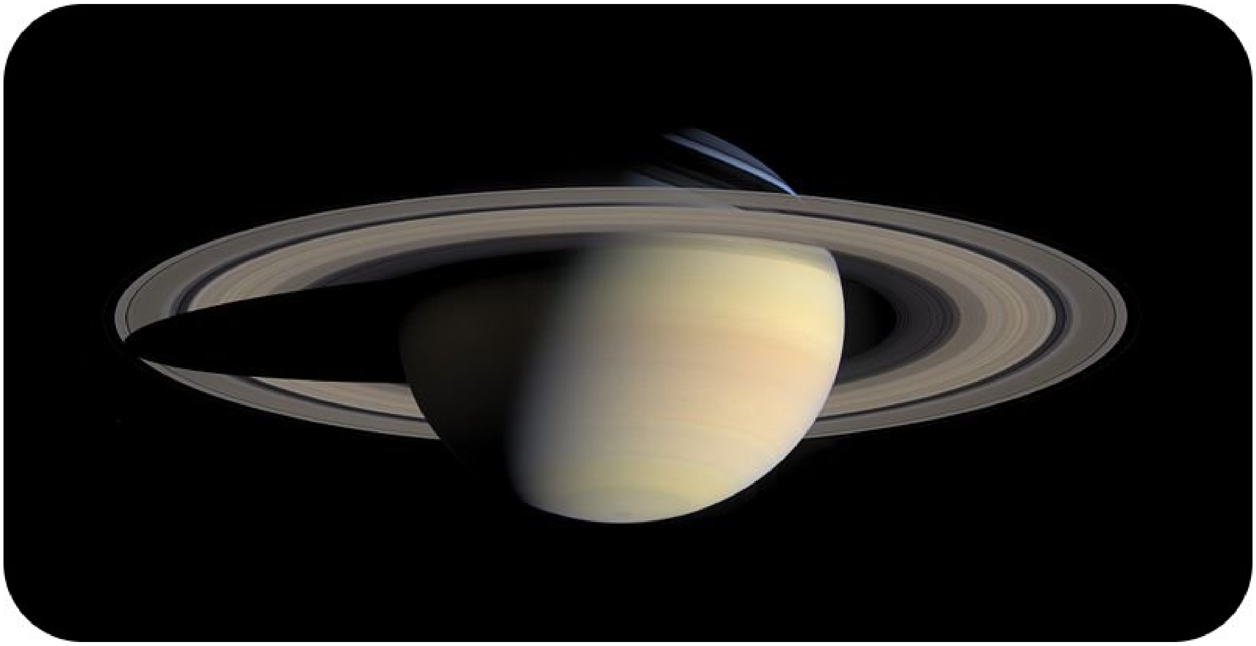


FIGURE 14.32
This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2008

Cassini scientists waited years for the right conditions to produce the first movie that shows lightning on another planet, Saturn: http://saturn.jpl.nasa.gov/video/videodetails/?videoID=210.

More videos from the Cassini mission are indexed here: http://saturn.jpl.nasa.gov/video/.

Saturn's Rings

In 1610, Galileo first observed Saturn's rings with his telescope, but he thought they might be two large moons, one on either side of the planet. In 1659, the Dutch astronomer Christian Huygens realized that the features were rings (**Figure** 14.33).

Saturn's rings circle the planet's equator and appear tilted because Saturn itself is tilted about 27 degrees. The rings do not touch the planet.

The Voyager 1 and 2 spacecraft in 1980 and 1981 sent back detailed pictures of Saturn, its rings, and some of its moons. Saturn's rings are made of particles of water and ice, with some dust and rocks (**Figure** 14.34). There are several gaps in the rings that scientists think have originated because the material was cleared out by the gravitational pull within the rings, or by the gravitational forces of Saturn and of moons outside the rings.

The rings were likely formed by the breakup of one of Saturn's moons or from material that never accreted into the planet when Saturn originally formed.

An animation of dark spokes in Saturn's rings is seen here: http://en.wikipedia.org/wiki/File:Saturn_ring_spokes_PIA11144_300px_secs15.5to23_20080926.ogv. The spokes appear seasonally and their origin is as yet unknown.

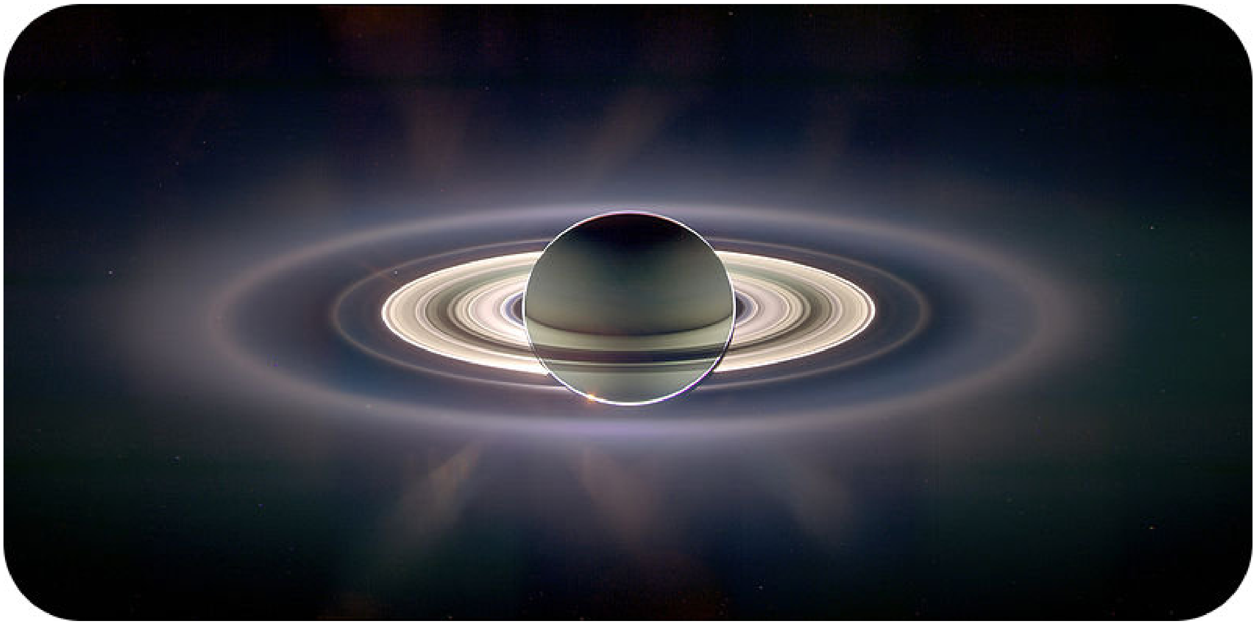


FIGURE 14.33
A color-exaggerated mosaic of Saturn and its rings taken by Cassini as Saturn eclipses the Sun.

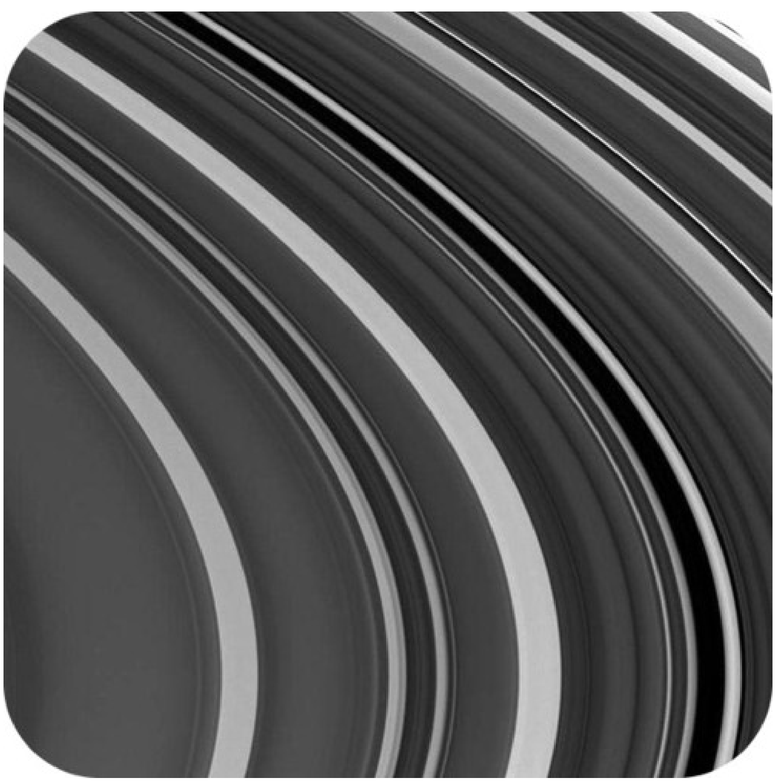


FIGURE 14.34
A close-up of Saturn's outer C ring showing areas with higher particle concentration and gaps.

Saturn's Moons

Most of Saturn's moons are very small, and only seven are large enough for gravity to have made them spherical. Only Titan is larger than Earth's Moon at about 1.5 times its size. Titan is even larger than the planet Mercury.

Scientists are interested in Titan because its atmosphere is similar to what Earth's was like before life developed. Nitrogen is dominant and methane is the second most abundant gas. Titan may have a layer of liquid water and ammonia under a layer of surface ice. Lakes of liquid methane (CH_4) and ethane (C_2H_6) are found on Titan's surface. Although conditions are similar enough to those of early Earth for scientists to speculate that extremely primitive life may exist on Titan, the extreme cold and lack of carbon dioxide make it unlikely (**Figure** 14.35).

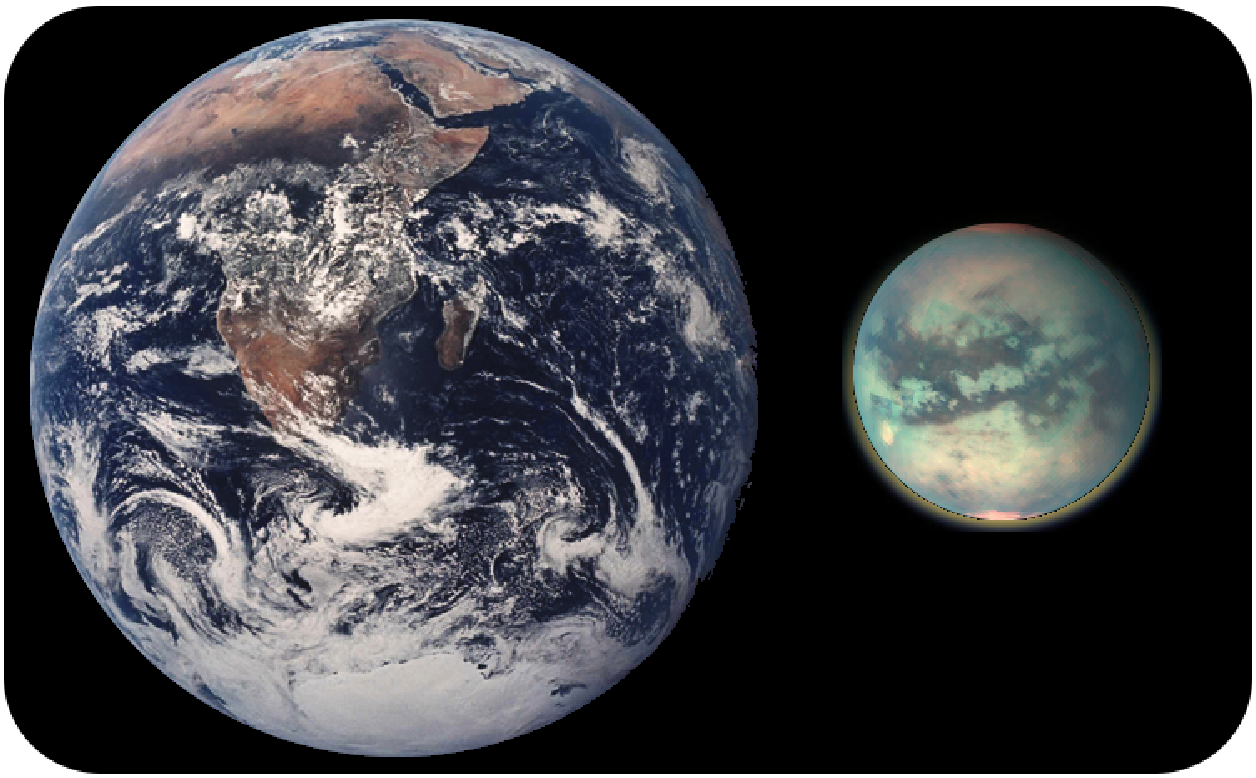


FIGURE 14.35

This composite image compares Saturn's largest moon, Titan (right) to Earth (left).

An incredible virtual tour of Titan as learned from Cassini-Huygens is in this video: http://saturn.jpl.nasa.gov/multimedia/flash/Titan/index.html.

Saturn's tiny moon, Enceladus, is also the subject of a video: http://saturn.jpl.nasa.gov/multimedia/flash/Enceladus/enceladus.html.

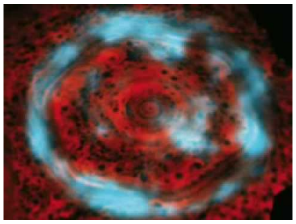
Summary

- Like Jupiter, Saturn is made of hydrogen and helium.
- Saturn's rings are composed of water and ice, with some dust and rock.
- Titan has an atmosphere dominated by nitrogen and methane, and may have liquid water beneath the ice.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=km58rDEdbjk



MEDIA

Click image to the left for more content.

1. What is the density of Saturn?
2. What is Saturn's temperature and what does this mean?
3. What did Cassini discover about Saturn?
4. How many moons does Saturn have?
5. Explain the theories about how Saturn got its rings?
6. What are Shepherds?
7. What is the Hexagon storm?

Want to know more about Saturn? See https://www.windows2universe.org/saturn/saturn.html.

Review

1. What features of Enceladus lead scientists to think that the moon could have life?
2. What caused Saturn's rings to form?
3. What features of Titan make it a possible location for life, but why do scientists think that this is unlikely?

14.13 Uranus

- Describe the characteristics of Uranus.

Uranus was the father of Saturn.

Uranus is an icy blue-green ball named for the ancient Greek god of the heavens. The planet's satellites are named for the characters of Shakespeare and Alexander Pope.

Uranus

Uranus (YOOR-uh-nuhs) is named for the Greek god of the sky (**Figure ??**). From Earth, Uranus is so faint that it was unnoticed by ancient observers. William Herschel first discovered the planet in 1781.

Although Uranus is very large, it is extremely far away, about 2.8 billion km (1.8 billion mi) from the Sun. Light from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

Uranus has a mass about 14 times the mass of Earth, but it is much less dense than Earth. Gravity at the surface of Uranus is weaker than on Earth's surface, so if you were at the top of the clouds on Uranus, you would weigh about 10% less than what you weigh on Earth.

An Icy Blue-Green Ball

Like Jupiter and Saturn, Uranus is composed mainly of hydrogen and helium, with an outer gas layer that gives way to liquid on the inside. Uranus has a higher percentage of icy materials, such as water, ammonia (NH_3), and methane (CH_4), than Jupiter and Saturn.

When sunlight reflects off Uranus, clouds of methane filter out red light, giving the planet a blue-green color. There are bands of clouds in the atmosphere of Uranus, but they are hard to see in normal light, so the planet looks like a plain blue ball.

The Sideways Planet

Most of the planets in the solar system rotate on their axes in the same direction that they move around the Sun. Uranus, though, is tilted on its side, so its axis is almost parallel to its orbit. In other words, it rotates like a top that was turned so that it was spinning parallel to the floor. Scientists think that Uranus was probably knocked over by a collision with another planet-sized object billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings (**Figure** 14.36). The rings circle the planet's equator, but because Uranus is tilted on its side, the rings are almost perpendicular to the planet's orbit.

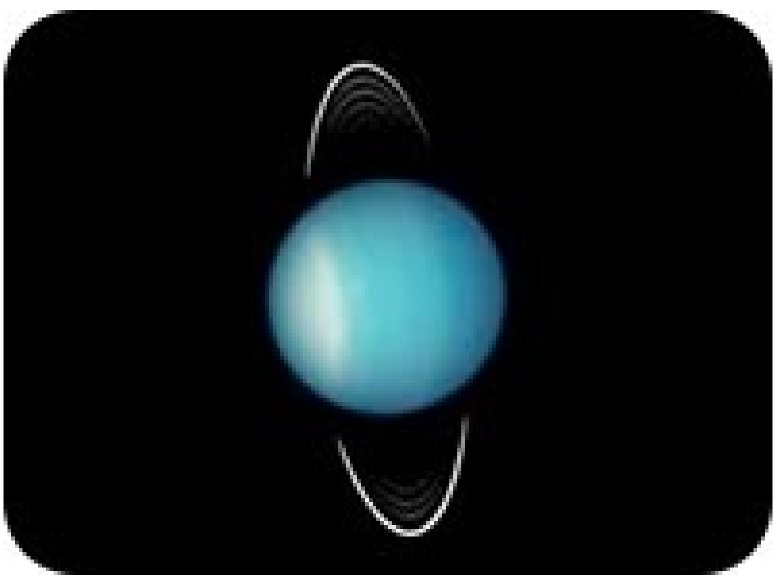


FIGURE 14.36

This image from the Hubble Space Telescope shows the faint rings of Uranus. The planet is tilted on its side, so the rings are nearly vertical.

Uranus has 27 known moons and all but a few of them are named for characters from the plays of William Shakespeare. The five biggest moons of Uranus — Miranda, Ariel, Umbriel, Titania, and Oberon — are shown in **Figure** 14.37.

Summary

- Uranus is composed of hydrogen and helium, but methane clouds filter red light and give the planet a blue-green color.
- The rotational axis of Uranus is tilted almost parallel to its orbit.

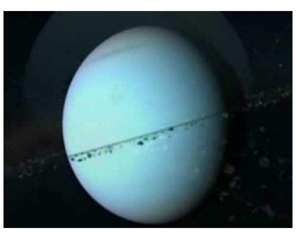
FIGURE 14.37
These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus.

- Uranus has rings that are nearly perpendicular to the planet's orbit.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=scvVpjRT-4M



MEDIA
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1. When was Uranus discovered? Who found Uranus?
2. How many moons does Uranus have?
3. How long does it take Uranus to orbit the Sun?
4. How does Uranus differ from the other large planets?
5. Why does Uranus appear blue-green?
6. Describe Uranus' composition.
7. Describe the axis of Uranus? What does it mean?
8. How long is a day on Uranus?
9. Explain how the Uranus' rings were discovered.
10. How many rings does Uranus have?

Want to know more about Uranus? See https://www.windows2universe.org/uranus/uranus.html.

Review

1. Why would you weigh only 90% of your Earth weight on Uranus?
2. Why is Uranus tilted on its side?
3. Describe the structure of Uranus.

14.14 Neptune

- Describe the characteristics of Neptune.

How do you think Neptune got its name?

Because of its blue color, Neptune was named for the Roman god of the sea. This statue of Neptune is at the Trevi Fountain in Rome.

Neptune

Neptune, shown in **Figure** 14.38, is the only major planet that can't be seen from Earth without a telescope. Scientists predicted the existence of Neptune before it was discovered because Uranus did not always appear exactly where it should appear. They knew that the gravitational pull of another planet beyond Uranus must be affecting Uranus' orbit.

Neptune was discovered in 1846, in the position that had been predicted, and it was named Neptune for the Roman god of the sea because of its bluish color.

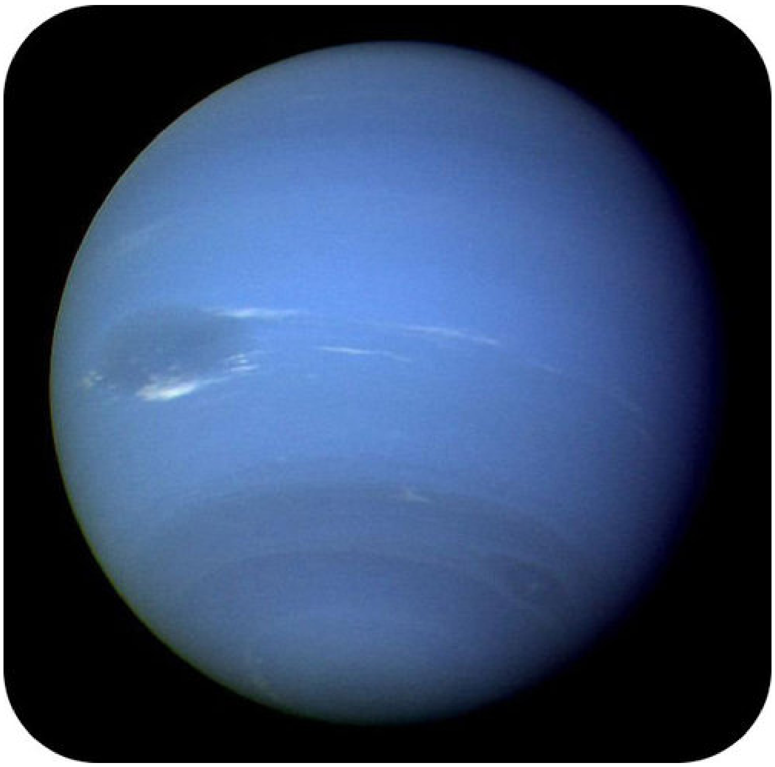


FIGURE 14.38

This image of Neptune was taken by Voyager 2 in 1989. The Great Dark Spot seen on the left center in the picture has since disappeared, but a similar dark spot has appeared on another part of the planet.

In many respects, Neptune is similar to Uranus (**Figure** 14.39). Neptune has slightly more mass than Uranus, but it is slightly smaller in size. Neptune is much farther from the Sun, at nearly 4.5 billion km (2.8 billion mi). The planet's slow orbit means that it takes 165 Earth years to go once around the Sun.

Extremes of Cold and Wind

Neptune's blue color is mostly because of frozen methane (CH_4). When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot, which scientists named the Great Dark Spot, south of the equator. When the Hubble Space Telescope took pictures of Neptune in 1994, the Great Dark Spot had disappeared, but another dark spot had appeared north of the equator. Astronomers think that both of these spots represent gaps in the methane clouds on Neptune.

The changing appearance of Neptune is caused by its turbulent atmosphere. The winds on Neptune are stronger than on any other planet in the solar system, reaching speeds of 1,100 km/h (700 mi/h), close to the speed of sound. This extreme weather surprised astronomers, since the planet receives little energy from the Sun to power weather systems. Neptune's core is 7000°C (12,632°C) which means that it produces more energy than it receives from the Sun. Neptune is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about

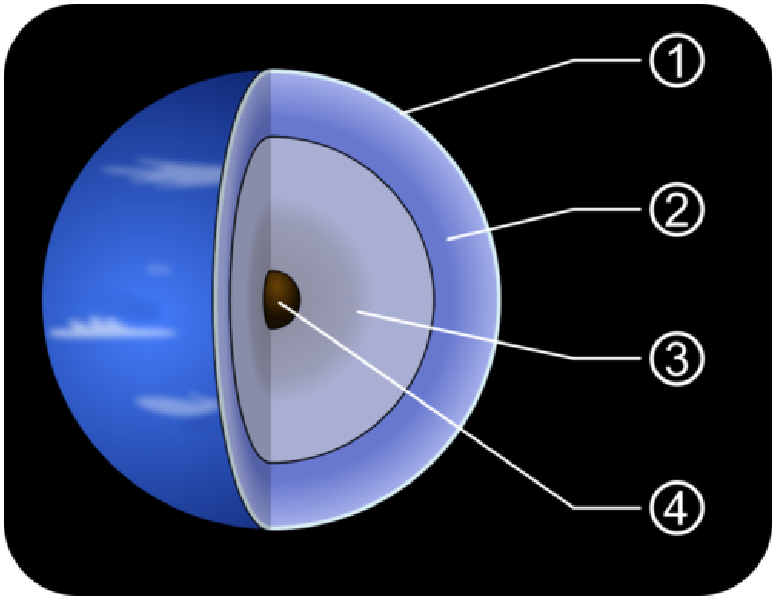


FIGURE 14.39
Neptune's composition is that of a gas giant: (1) upper atmosphere, (2) atmosphere composed of hydrogen, helium and methane gas, (3) mantle of water, ammonia and methane ice, (4) core of rock and ice.

-218°C (-360°F).

Neptune's Rings and Moons

Neptune has faint rings of ice and dust that may change or disappear in fairly short time frames.

Neptune has 13 known moons. Triton, shown in **Figure** 14.40, is the only one of them that has enough mass to be spherical in shape. Triton orbits in the direction opposite to the orbit of Neptune. Scientists think Triton did not form around Neptune, but instead was captured by Neptune's gravity as it passed by.

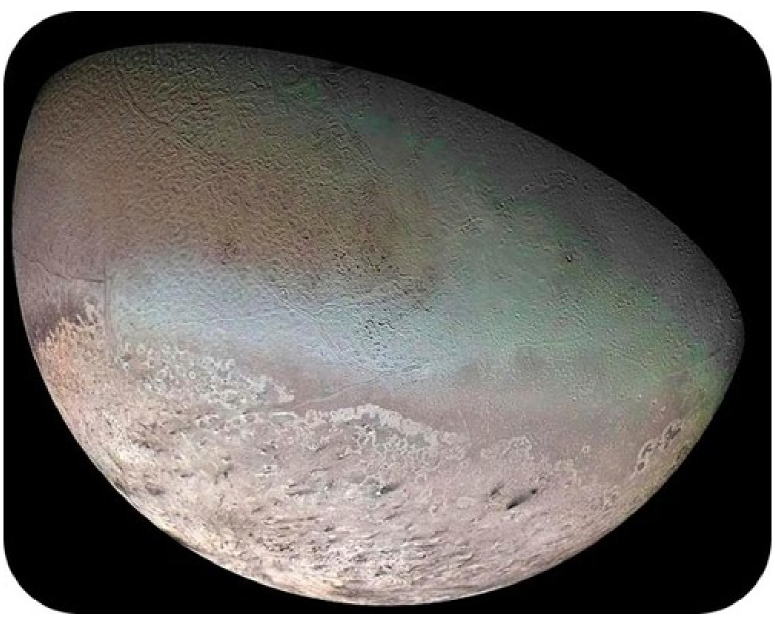


FIGURE 14.40
This image of Triton, Neptune's largest moon, was taken by Voyager 2 in 1989.

Fly by Neptune's moon Triton by watching this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath#playerTop.

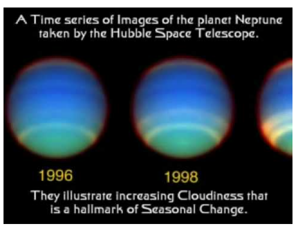
Summary

- Neptune is so far from Earth that it can't be seen without a telescope.
- Neptune has a turbulent atmosphere, which changes the planet's appearance. The blue color is due to frozen methane.
- Neptune has 13 moons, including Triton, which orbits in the opposite direction from Neptune.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=76xz74X4ivw



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1. Explain how Neptune was discovered.
2. How many moons does Neptune have?
3. Why is Triton unique?
4. How cold is Neptune?
5. Explain why Neptune is blue in color.
6. How long does each season last on Neptune?
7. What is the Great Dark Spot?
8. What causes the wind storms on Neptune?
9. How many rings does Neptune have?
10. What happened to the Great Dark Spot?

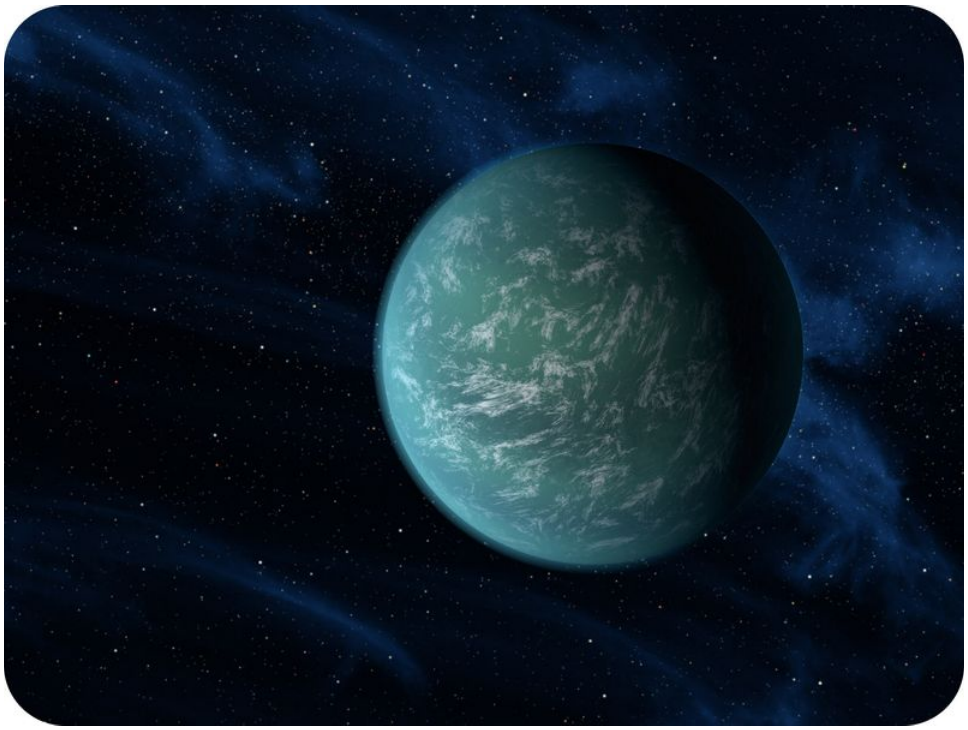
Want to know more about Neptune? See https://www.windows2universe.org/neptune/neptune.html.

Review

1. Why did scientists think that there was a planet beyond Uranus before it could be spotted in a telescope?
2. What is the structure of Neptune?
3. What causes the dark spots in Neptune's appearance? Why do they come and go?

14.15 Exoplanets

- Define exoplanet.
- Explain how scientists locate exoplanets.



Is there life on other planets?

Newly discovered planet Kepler-22b is the habitable zone of a sun-like star. This means that the planet could have liquid water, which is necessary for life on Earth. Even though this is the most Earth-like planet yet, the chances that it harbors life are slim. But there are likely many more Earth-like planets in the universe.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun. These are called "extrasolar planets" or simply **exoplanets** (see **Figure** 14.41). Exoplanets are not in our solar system, but are found in other solar systems.

Some extrasolar planets have been directly imaged, but most have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet or, sometimes, another star orbiting the star.

An animation showing how the orbit of a smaller body, such as a planet or small star, can be identified by the effect it has on the orbit of a larger star is seen here from above: http://upload.wikimedia.org/wikipedia/commons/5/59/Orbit3.gif. This is in line with the plane of the system: http://en.wikipedia.org/wiki/File:Dopspec-inline.gif.

A planet may also be identified by measuring a star's brightness over time. A temporary, periodic decrease in light

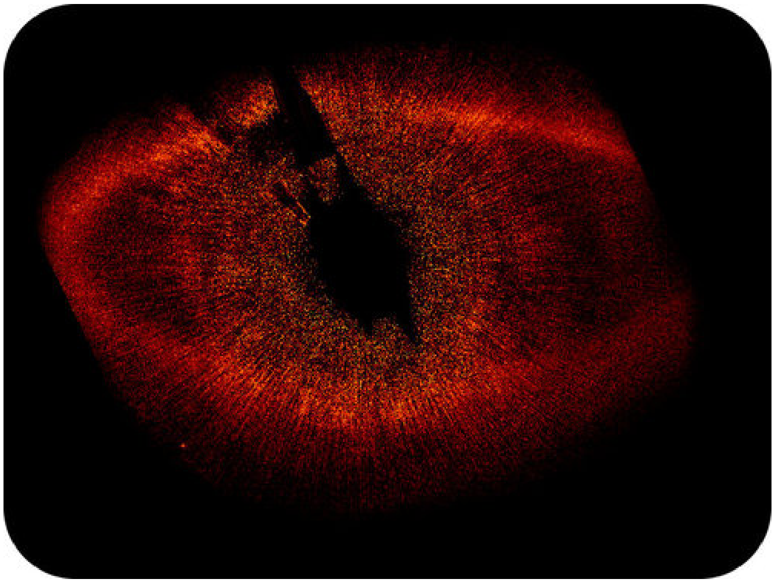
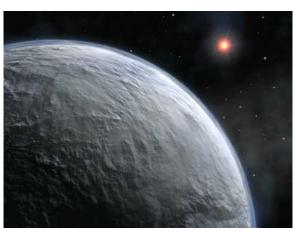


FIGURE 14.41
The extrasolar planet Fomalhaut is surrounded by a large disk of gas. The disk is not centered on the planet, suggesting that another planet may be pulling on the gas as well.

emitted from a star can occur when a planet crosses in front of, or "transits," the star it is orbiting, momentarily blocking out some of the starlight.

More than 700 extrasolar planets have been identified and confirmed and the rate of discovery is increasing rapidly.

Extrasolar Planet from the ESA discusses extrasolar planets and particularly a planetary system very similar to our solar system **(1g)**: http://www.youtube.com/watch?v=ouJahDONTWc (3:29).



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An introduction to extrasolar planets from NASA is available at **(1g)**: http://www.youtube.com/watch?feature=player_profilepage#38;v=oeeZCHDNTvQ (3:14).

MEDIA
Click image to the left for more content.

According to NASA, a statistical analysis shows that the Milky Way galaxy contains 100 million planets. That's a lot of exoplanets!

http://science.kqed.org/quest/audio/exoplanets/

MEDIA
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Hundreds of exoplanets have now been discovered. To learn something about how planet hunters find these balls of rock they usually can't even see, watch this QUEST video at http://www.kqed.org/quest/television/the-planet-hunters.

MEDIA
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Vocabulary

- **exoplanet**: Short for extrasolar planet. A planet that exists in a solar system different from our own.

Summary

- Now that scientists know how to identify extrasolar planets, the numbers of confirmed examples are increasing rapidly.
- An exoplanet may decrease a star's brightness as it passes in front of it.
- The gravitational pull of a planet may be detected in the slight motion of a star.

Practice

Use this resource to answer the questions that follow.

http://planetquest.jpl.nasa.gov/page/methods

1. How many total exoplanets have been found? How many have been confirmed?
2. What are the sizes of the exoplanets that have been found so far?
3. What are the challenges to finding exoplanets?
4. List the methods for detecting planets.
5. Why is direct imaging of exoplanets so difficult?

Review

1. What is an exoplanet?
2. Where are explanets located? How are exoplanets discovered?
3. Why are scientists so interested in exoplanets?

14.16 Asteroids

- Describe asteroids and the asteroid belt.
- Explain what affects asteroids may have on Earth and other planets.

Could human life end with an asteroid?

Asteroid impacts have played an enormous role in creating Earth and in altering the course of the evolution of life. It is most likely that an asteroid impact brought the end of the dinosaurs and many other lifeforms at the end of the Mesozoic. Could one asteroid do it again?

Asteroids

Asteroids are very small, rocky bodies that orbit the Sun. "Asteroid" means "star-like," and in a telescope, asteroids look like points of light, just like stars. Asteroids are irregularly shaped because they do not have enough gravity to become round. They are also too small to maintain an atmosphere, and without internal heat they are not geologically active (**Figure** 14.42). Collisions with other bodies may break up the asteroid or create craters on its surface.

Asteroid impacts have had dramatic impacts on the shaping of the planets, including Earth. Early impacts caused the planets to grow as they cleared their portions of space. An impact with an asteroid about the size of Mars caused fragments of Earth to fly into space and ultimately create the Moon. Asteroid impacts are linked to mass extinctions throughout Earth's history.

FIGURE 14.42
In 1991, Asteroid 951 Gaspra was the first asteroid photographed at close range. Gaspra is a medium-sized asteroid, measuring about 19 by 12 by 11 km (12 by 7.5 by 7 mi).

The Asteroid Belt

Hundreds of thousands of asteroids have been discovered in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month. The majority of the asteroids are found in between the orbits of Mars and Jupiter, in a region called the **asteroid belt**, as shown in **Figure** 14.43. Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's Moon.

Scientists think that the bodies in the asteroid belt formed during the formation of the solar system. The asteroids might have come together to make a single planet, but they were pulled apart by the intense gravity of Jupiter.

Near-Earth Asteroids

More than 4,500 asteroids cross Earth's orbit; they are **near-Earth asteroids**. Between 500 and 1,000 of these are over 1 km in diameter.

Any object whose orbit crosses Earth's can collide with Earth, and many asteroids do. On average, each year a rock about 5–10 m in diameter hits Earth (**Figure** 14.44). Since past asteroid impacts have been implicated in mass extinctions, astronomers are always on the lookout for new asteroids, and follow the known near-Earth asteroids closely, so they can predict a possible collision as early as possible.

Asteroid Missions

Scientists are interested in asteroids because they are representatives of the earliest solar system (**Figure** 14.45). Eventually asteroids could be mined for rare minerals or for construction projects in space. A few missions have studied asteroids directly. NASA's DAWN mission will be exploring asteroid Vesta in 2011 and 2012 and dwarf planet Ceres in 2015.

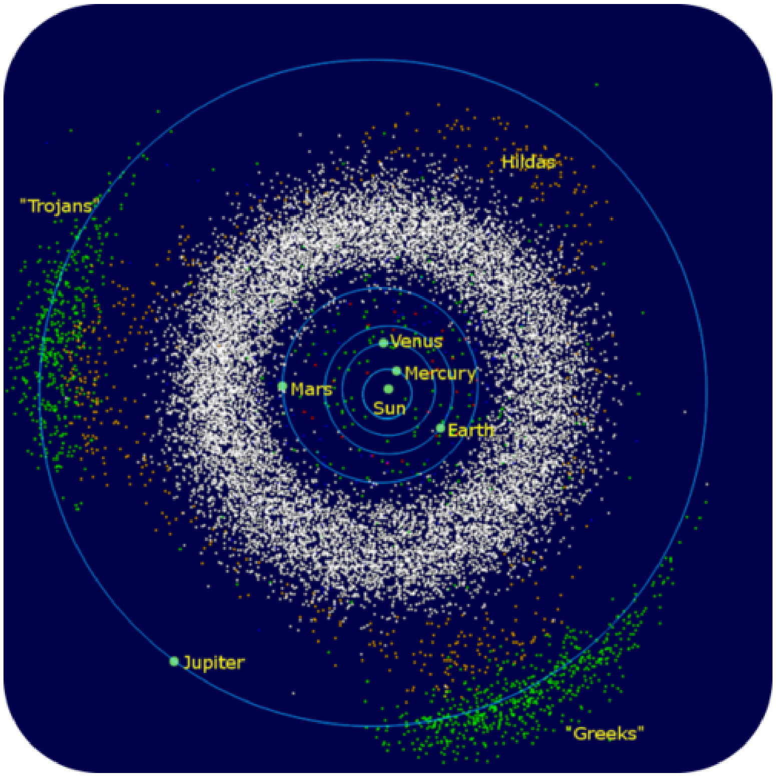

FIGURE 14.43
The white dots in the figure are asteroids in the main asteroid belt. Other groups of asteroids closer to Jupiter are called the Hildas (orange), the Trojans (green), and the Greeks (also green).

FIGURE 14.44
A painting of what an asteroid a few kilometers across might look like as it strikes Earth.

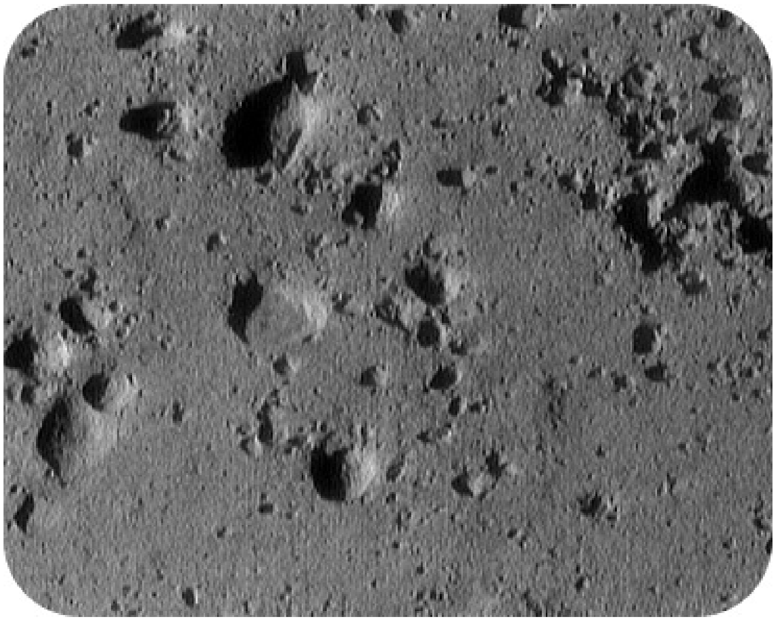

FIGURE 14.45
The NEAR Shoemaker probe took this photo as it was about to land on 433 Eros in 2001.

KQED: Asteroid Hunters

Thousands of objects, including comets and asteroids, are zooming around our solar system; some could be on a collision course with Earth. QUEST explores how these Near Earth Objects are being tracked and what scientists are saying should be done to prevent a deadly impact. Learn more at: http://science.kqed.org/quest/video/asteroid-hunters/

MEDIA
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Vocabulary

- **asteroid**: Rocky objects larger than a few hundred meters that orbit the Sun.
- **asteroid belt**: Region between the orbits of Mars and Jupiter where many asteroids are found.
- **near-Earth asteroid**: Asteroids that orbit relatively close to Earth.

Summary

- Asteroids are small rocky bodies that orbit the Sun and sometimes strike Earth.
- Most asteroids reside in the asteroid belt, between Mars and Jupiter.
- Near-earth asteroids are the ones most likely to strike Earth, and scientists are always looking out for a large one that may impact our planet and cause problems.

Practice

Use these resources to answer the questions that follow.

https://www.windows2universe.org/our_solar_system/asteroids.html#38;edu=high

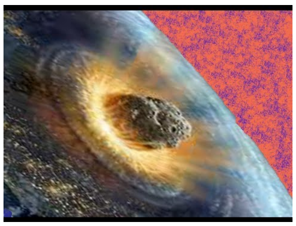
1. What are asteroids?

2. Where are most asteroids found?

Go to the Asteroid Table.

3. What is the largest asteroid and when was it discovered?

http://www.youtube.com/watch?v=02menVmEN60



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4. What has NEOWISE determined?

5. How many of the asteroids have been cataloged?

6. How are the asteroids detected?

7. What type of telescope is being used?

Review

1. What is the reason there is a belt of asteroids between Mars and Jupiter?

2. Why do scientists look for asteroids that might strike our planet?

3. What do scientists hope to learn from missions to visit asteroids?

14.17 Comets

- Describe the characteristics of comets and explain where they come from.

Why do comets have tails?

The ball of white in the lower left portion of the image is a comet, Comet Holmes. Comets do not have tails out in space, only when they are close to the Sun. The spiral shaped light in the image is the Andromeda Galaxy.

Comets

Comets are small, icy objects that have very elliptical orbits around the Sun. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun. Early in Earth's history, comets may have brought water and other substances to Earth during collisions.

Comet tails form the outer layers of ice melt and evaporate as the comet flies close to the Sun. The ice from the comet vaporizes and forms a glowing coma, which reflects light from the Sun. Radiation and particles streaming from the Sun push this gas and dust into a long tail that always points away from the Sun (**Figure** 14.46). Comets appear for only a short time when they are near the Sun, then seem to disappear again as they move back to the outer solar system.

FIGURE 14.46

Comet Hale-Bopp, also called the Great Comet of 1997, shone brightly for several months in 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun.

The time between one appearance of a comet and the next is called the comet's period. Halley's comet, with a period of 75 years, will next be seen in 2061. The first mention of the comet in historical records may go back as much as two millennia.

Where Comets Come From

Short-period comets, with periods of about 200 years or less, come from a region beyond the orbit of Neptune called the **Kuiper belt** (pronounced "KI-per"). It contains not only comets, but also asteroids and at least two dwarf planets.

Comets with periods as long as thousands or even millions of years come from a very distant region of the solar system called the Oort cloud, about 50,000 — 100,000 AU from the Sun (50,000 – 100,000 times the distance from the Sun to Earth).

Vocabulary

- **comet**: A small, icy, dusty object with a bright tail in orbit around the Sun.
- **Kuiper belt**: A region beyond the orbit of Neptune that contains millions of frozen objects.

Summary

- Comets are icy objects that have very elliptical orbits around the Sun.
- Comet tails form as ice vaporizes and glows in the Sun's light.
- Short-period comets come from the Kuiper belt beyond Neptune, and long-period comets come from the Oort cloud far out away from the Sun.

Practice

Use these resources to answer the questions that follow.

https://www.windows2universe.org/comets/comets.html#38;edu=high

1. What are comets?

2. What happens to comets when they get close to the Sun?

3. What happened to comet Shoemaker-Levy?

4. Why is Hale-Bopp unique?

http://www.windows2universe.org/comets/comet_model_interactive.html

5. What do you observe about the comet at it orbits around the Sun?

Review

1. Why do comets only have tails when they are near the Sun?

2. Where is the Kuiper belt and what is found in it?

3. Why does Halley's comet appear to earthlings every 75 years?

14.18 Meteors

- Define and describe meteors, meteoroids, and meteorites.

Is a shooting star really a star flying across the sky?

When a meteor shoots through the atmosphere it burns and glows. When we look up and see one, we call it a shooting star. When Earth travels through the debris left by a comet's tail, we see a meteor shower.

Meteors

A **meteor**, such as in **Figure** 14.47, is a streak of light across the sky. People call them shooting stars but they are actually small pieces of matter burning up as they enter Earth's atmosphere from space.

Meteors are called **meteoroids** before they reach Earth's atmosphere. Meteoroids are smaller than asteroids and range from the size of boulders down to the size of tiny sand grains. Still smaller objects are called interplanetary dust. When Earth passes through a cluster of meteoroids, there is a **meteor shower**. These clusters are often remnants left behind by comet tails.

Meteorites

Although most meteors burn up in the atmosphere, larger meteoroids may strike the Earth's surface to create a **meteorite**. Meteorites are valuable to scientists because they provide clues about our solar system. Many meteorites are from asteroids that formed when the solar system formed (**Figure** 14.48). A few meteorites are made of rocky material that is thought to have come from Mars when an asteroid impact shot material off the Martian surface and into space.

FIGURE 14.47
A meteor streaks across the sky to the right of the Milky Way.

FIGURE 14.48
A lunar meteorite originates on the Moon and strikes Earth.

Vocabulary

- **meteor**: Material from outer space that burns up as it enters Earth's atmosphere.
- **meteor shower**: An area of frequent meteors appearing to originate in a particular part of the sky
- **meteorite**: Fragments of planetary bodies such as moons, planets, asteroids, and comets that strike Earth.

- **meteoroid**: A small rock in interplanetary space that has not yet entered Earth's atmosphere.

Summary

- A meteor that strikes Earth's surface is a meteorite.
- Many meteorites are remnants of the earliest material that formed in the solar system.
- Shooting stars are meteors that burn up in Earth's atmosphere.

Practice

Use these resources to answer the questions that follow. http://www.windows2universe.org/our_solar_system/meteors/meteors.html#38;edu=high

1. What are meteors?

2. What happens to most meteors?

3. What are fireballs?

4. Explain the difference between meteors, meteoroids, and meteorites.

http://stardate.org/nightsky/meteors

5. When is the next meteor shower?

6. What causes a meteor shower?

Review

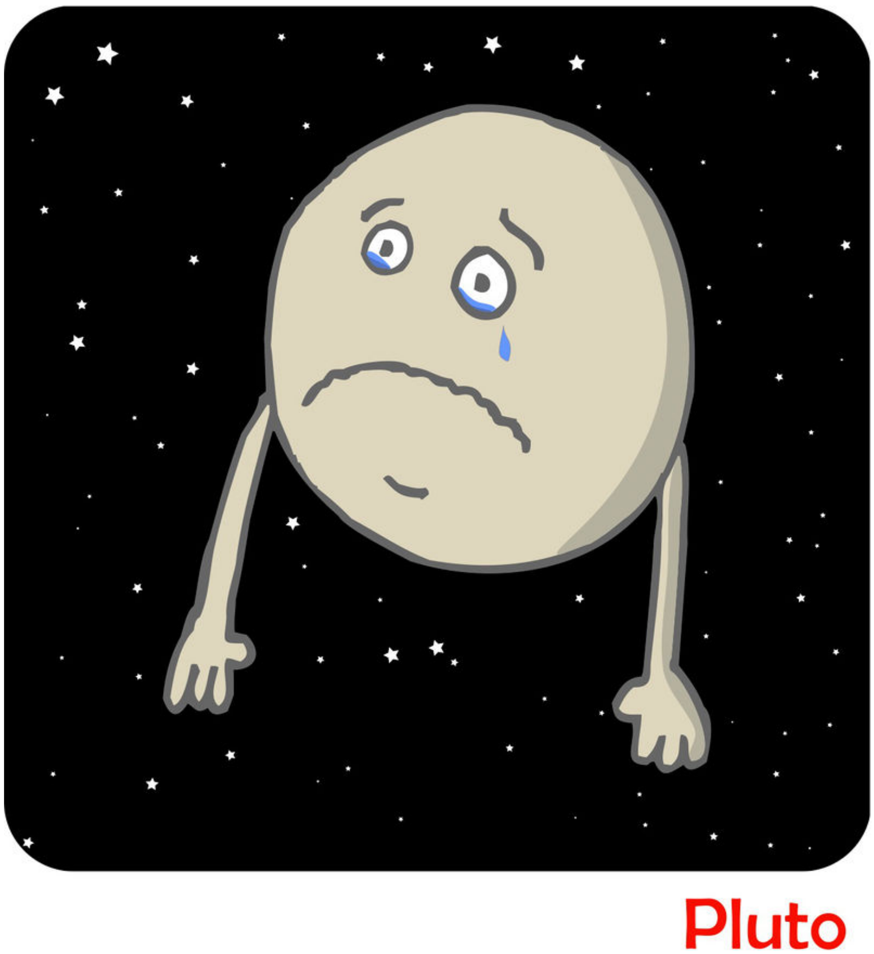
1. The Perseid meteor shower appears every August. Why is the shower so regular in its appearance?

2. What are the similarities and differences between meteors, meteoroids, and meteorites?

3. Why are meteors known as shooting stars?

14.19 Dwarf Planets

- Identify our solar system's five dwarf planets.
- Describe the characteristics of dwarf planets.
- Compare and contrast planets and dwarf planets.



What is, and what is not, a planet?

Pluto just didn't fit the criteria for a planet, so it was placed in a new category with others of its kind, dwarf planets. So what is a planet, and what is Pluto?

What is a Planet?

In 2006, the International Astronomical Union decided that there were too many questions surrounding what could be called a planet, and so refined the definition of a planet.

According to the new definition, a planet must:

- Orbit a star.
- Be big enough that its own gravity causes it to be shaped as a sphere.

- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, astronomers refined the definition of a dwarf planet in 2006.

According to the IAU, a dwarf planet must:

- Orbit a star.
- Have enough mass to be nearly spherical.
- Not have cleared the area around its orbit of smaller objects.
- Not be a moon.

Pluto

The reclassification of Pluto to the new category dwarf planet stirred up a great deal of controversy. How the classification of Pluto has evolved is an interesting story in science.

From the time it was discovered in 1930 until the early 2000s, Pluto was considered the ninth planet. When astronomers first located Pluto, the telescopes were not as good, so Pluto and its moon, Charon, were seen as one much larger object (**Figure** 14.49). With better telescopes, astronomers realized that Pluto was much smaller than they had thought.

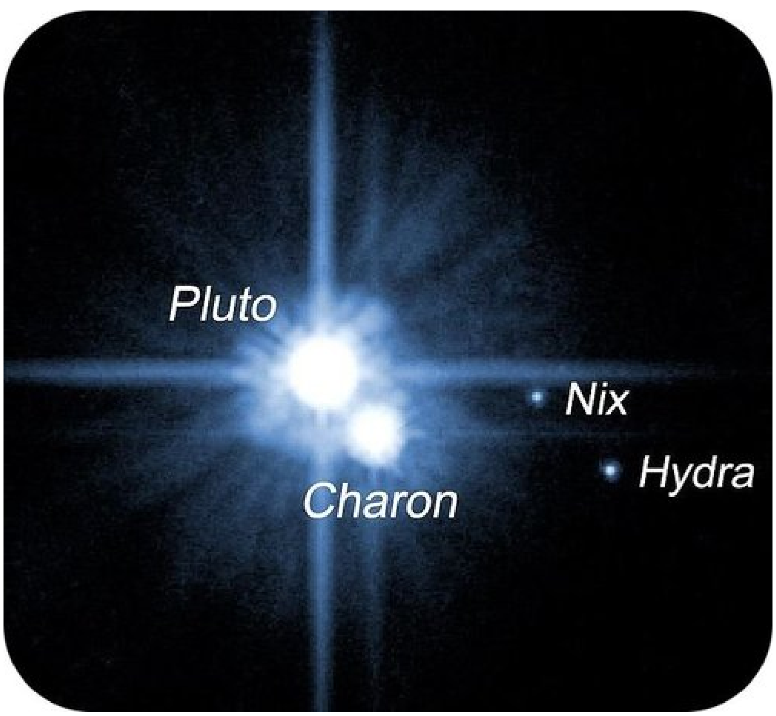


FIGURE 14.49
Pluto and its moon, Charon, are actually two objects.

Better technology also allowed astronomers to discover many smaller objects like Pluto that orbit the Sun. One of them, Eris, discovered in 2005, is even larger than Pluto.

Even when it was considered a planet, Pluto was an oddball. Unlike the other outer planets in the solar system, which are all gas giants, it is small, icy, and rocky. With a diameter of about 2,400 km, it is only about one-fifth the mass of Earth's Moon. Pluto's orbit is tilted relative to the other planets and is shaped like a long, narrow ellipse. Pluto's orbit sometimes even passes inside Neptune's orbit.

In 1992, Pluto's orbit was recognized to be part of the Kuiper belt. With more than 200 million Kuiper belt objects, Pluto has failed the test of clearing other bodies out its orbit.

From what you've read above, do you think Pluto should be called a planet? Why are people hesitant to take away Pluto's planetary status? Is Pluto a dwarf planet?

A video showing why Pluto isn't a planet any more: http://www.youtube.com/watch?v=FqX2YdnwtRc.

Pluto has three moons of its own. The largest, Charon, is big enough that the Pluto-Charon system is sometimes considered to be a double dwarf planet (**Figure** 14.51). Two smaller moons, Nix and Hydra, were discovered in 2005. But having moons is not enough to make an object a planet.

Pluto and the other dwarf planets, besides Ceres, are found orbiting out beyond Neptune.

Ceres

Ceres is by far the closest dwarf planet to the Sun; it resides between Mars and Jupiter. Ceres is the largest object in the asteroid belt (**Figure** 14.50). Before 2006, Ceres was considered the largest of the asteroids, with only about 1.3% of the mass of the Earth's Moon. But unlike the asteroids, Ceres has enough mass that its gravity causes it to be shaped like a sphere. Like Pluto, Ceres is rocky.

Is Ceres a planet? How does it match the criteria above? Ceres orbits the Sun, is round, and is not a moon. As part of the asteroid belt, its orbit is full of other smaller bodies, so Ceres fails the fourth criterion for being a planet.

FIGURE 14.50
This composite image compares the size of the dwarf planet Ceres to Earth and the Moon.

Makemake

Makemake is the third largest and second brightest dwarf planet we have discovered so far (**Figure** 14.51). With a diameter estimated to be between 1,300 and 1,900 km, it is about three-quarters the size of Pluto. Makemake orbits the Sun in 310 years at a distance between 38.5 to 53 AU. It is thought to be made of methane, ethane, and nitrogen ices.

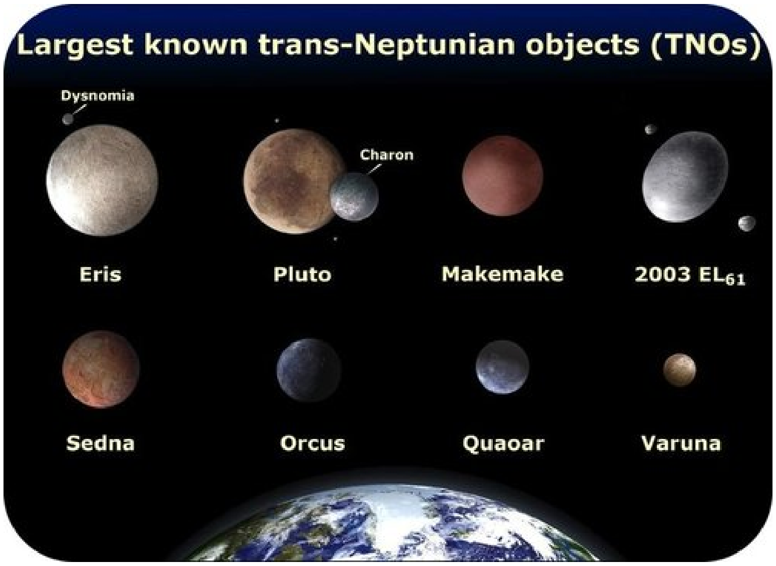


FIGURE 14.51
Largest Known Trans-Neptunian Objects. Makemake is named after the deity that created humanity in the mythology of the people of Easter Island.

Eris

Eris is the largest known dwarf planet in the solar system — it has about 27% more mass than Pluto. The object was not discovered until 2003 because it is about three times farther from the Sun than Pluto, and almost 100 times farther from the Sun than Earth is. For a short time Eris was considered the "tenth planet" in the solar system, but its discovery helped to prompt astronomers to better define planets and dwarf planets in 2006. Eris also has a small moon, Dysnomia, that orbits it once about every 16 days.

Astronomers know there may be other dwarf planets in the outer reaches of the solar system. Haumea was made a dwarf planet in 2008, so the total number of dwarf planets is now five. Quaoar, Varuna, and Orcus may be added to the list of dwarf planets in the future. We still have a lot to discover and explore.

Vocabulary

- **dwarf planet**: A planet-like object that has not cleared its orbit of other objects.

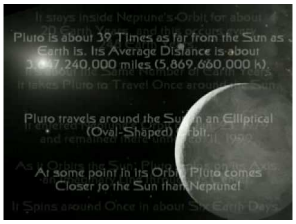
Summary

- There are currently five dwarf planets in our solar system: Pluto, Eris, Haumea, Makemake, and Ceres.
- Most dwarf planets are similar to planets, except that they haven't cleared their space of debris.
- Pluto was thought to be larger than it is because its large moon made the dwarf planet look bigger than it is.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=IECe5dP-GqU



MEDIA

Click image to the left for more content.

1. Who discovered Pluto? When?
2. When was Pluto demoted to a dwarf planet?
3. Why don't scientists know much about Pluto?
4. What is odd about Pluto's orbit?
5. How many moons does Pluto have?
6. What spacecraft is on its way to Pluto? When will it get there?

http://www.windows2universe.org/our_solar_system/dwarf_planets/dwarf_planets.html#38;edu=high

7. List the other four dwarf planets.
8. What is the criteria for a body to be called a dwarf planet?

Review

1. Why isn't Pluto still a planet? Why do some people still insist that it is?
2. Why did people think that Pluto was a planet in the decades after its discovery?
3. If Pluto is a dwarf planet, are any other of the eight planets in our solar system at risk of losing their planetary status?

Summary

At the center of the solar system is our star, the Sun. Solar energy is the result of the fusion of hydrogen and helium. The Sun is not just a featureless ball of gas, but has three internal layers and an atmosphere. We see the surface features, like sunspots, which have an affect on Earth. Eight planets orbit the Sun; the small, dense, rocky four nearer the Sun, and the large, gaseous four further away. Mercury is the smallest planet; it is closest to the Sun so it is extremely hot in most locations. Venus, the second planet out and the closest to Earth, has a thick, carbon dioxide-rich atmosphere with a large greenhouse effect and so is also very hot. Earth, the third rock from the Sun, is the only one of the inner planets with a large moon. The red planet, Mars, is the most earth-like, with channels where water once flowed and large volcanoes. The four gas planets — Jupiter, Saturn, Uranus, and Neptune — are composed of hydrogen, helium, and some methane and other gases. All have rings and moons. The other objects in the solar system are the five dwarf planets, which include Pluto, plus the asteroids, and comets. An object that strikes Earth is a meteorite. Increasing numbers of planets are now being found in other solar systems; they are called extrasolar planets or exoplanets.

14.20 References

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CHAPTER 15 Beyond the Solar System

Chapter Outline

Introduction

To infinity and beyond!

Astronomy has advanced by leaps and bounds in the past few decades. Tools like the Hubble Space Telescope have allowed astronomers to see and understand things that they'd never even dreamed of. As recently as a century ago, no one knew that there was anything out there beyond our galaxy. Now we can see fantastic images of pinwheels, sombreros, towers, and many other shapes. In this concept we will explore a tiny bit of what is beyond our solar system and even beyond our galaxy. The questions asked by the scientists who study these features are often profound: How did the universe begin? How will it end? Are we alone?

15.1 Star Constellations

- Define constellation.
- Explain the difference between apparent and real distances.

How did astrology come to be?

Ancient Babylonian astronomers created the Zodiac, a circle that divides the ecliptic into twelve 30-degree zones. Each zone contains a constellation, many of them animals. Horoscopes based on these astrological signs first appeared in Ptolemaic Egypt in around 50 BC. These early people used astrology to explain things that are now much better explained by science.

Stars

When you look at the sky on a clear night, you can see dozens, perhaps even hundreds, of tiny points of light. Almost every one of these points of light is a **star**, a giant ball of glowing gas at a very, very high temperature. Stars differ in size, temperature, and age, but they all appear to be made up of the same elements and to behave according to the same principles.

Constellations

People of many different cultures, including the Greeks, identified patterns of stars in the sky. We call these patterns **constellations**. **Figure** 15.1 shows one of the most easily recognized constellations.

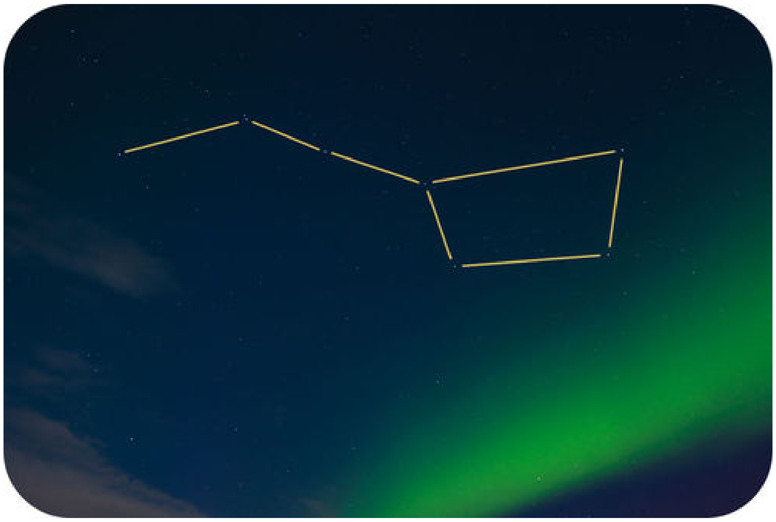


FIGURE 15.1
In this image the Big Dipper is outlined and shown next to the Aurora borealis near Fairbanks, Alaska.

Why do the patterns in constellations and in groups or clusters of stars, called **asterisms**, stay the same night after night? Although the stars move across the sky, they stay in the same patterns. This is because the apparent nightly motion of the stars is actually caused by the rotation of Earth on its axis. The patterns also shift in the sky with the seasons as Earth revolves around the Sun. As a result, people in a particular location can see different constellations in the winter than in the summer. For example, in the Northern Hemisphere Orion is a prominent constellation in the winter sky, but not in the summer sky. This is the annual traverse of the constellations.

Apparent Versus Real Distances

Although the stars in a constellation appear close together as we see them in our night sky, they are not at all close together out in space. In the constellation Orion, the stars visible to the naked eye are at distances ranging from just 26 light-years (which is relatively close to Earth) to several thousand light-years away.

Astrology

There is no reason to think that the alignment of the stars has anything to do with events that happen on Earth. The constellations were defined by people who noticed that patterns could be made from stars, but the patterns do not reflect any characteristics of the stars themselves. When scientific tests are done to provide evidence in support of astrological ideas, the tests fail. When a scientific idea fails, it is abandoned or modified. Astrologers do not change or abandon their ideas.

Vocabulary

- **asterism**: A group or cluster of stars that appear close together in the sky.
- **constellation**: A group of stars that appear to form a pattern in the sky. Most often these stars are unrelated and are not near each other in space. Constellations are used to locate objects in space.
- **star**: A glowing sphere of gases that produces light through nuclear fusion reactions.

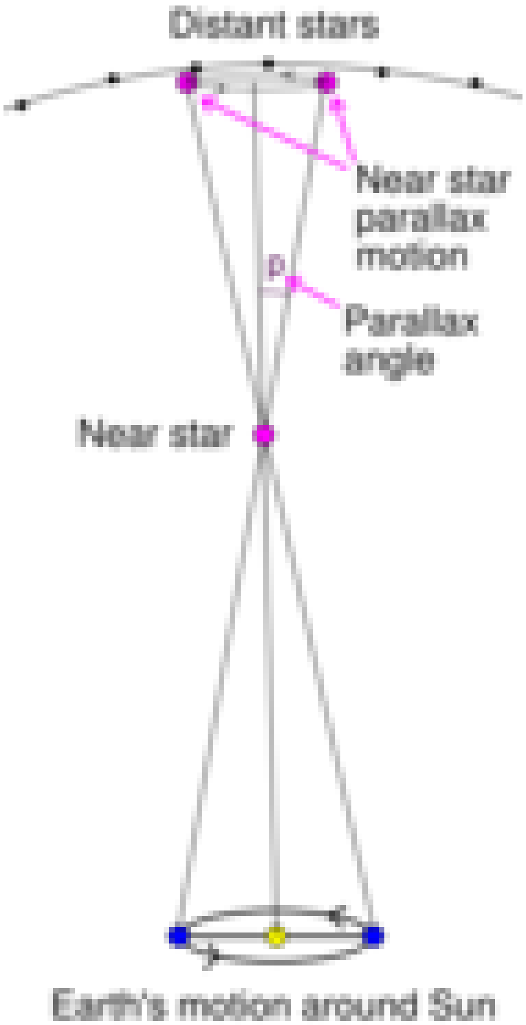


FIGURE 15.2
How parallax works.

Summary

- The points of light in the night sky are stars that are balls of gas undergoing nuclear fusion.
- Constellations are patterns of stars that are usually not near each other but are the result of chance.
- Stars in a constellation may be fairly close together, but are more likely extremely far apart.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=QXeEAQtC75g

MEDIA
Click image to the left for more content.

1. What are constellations?
2. How many constellations are there?

http://www.windows2universe.org/the_universe/Constellations/constnavi.html

3. What are the two groups of constellations? Define each.

http://www.windows2universe.org/the_universe/Constellations/circumpolar.html

4. List the constellations that are always visible in the Northern Hemisphere.
5. Why is Ursa Major unique?

Review

1. Why are constellations so important to people when they think about stars?
2. Are constellations useful?
3. What is astrology? How is it different from astronomy?

15.2 Star Power

- Describe nuclear fusion and explain its relationship to the shining of stars.

What's Marilyn Monroe doing in a science book?

Marilyn Monroe (on the right) was a famous movie star, even a superstar. Movie stars shine brightly — and in some cases, as with Marilyn, die young. Stars also shine brightly, then die. Their power, like that of an atom bomb, comes from nuclear fusion.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy. The Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a **nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** 15.3).

FIGURE 15.3
A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (**Figure** 15.4).

Particle Accelerators

In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** 15.5). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

The CERN Particle Accelerator presented in this video is the world's largest and most powerful particle accelerator and can boost subatomic particles to energy levels that simulate conditions in the stars and in the early history of the universe before stars formed **(2e)**: http://www.youtube.com/watch?v=sxAxV7g3yf8 (6:16).

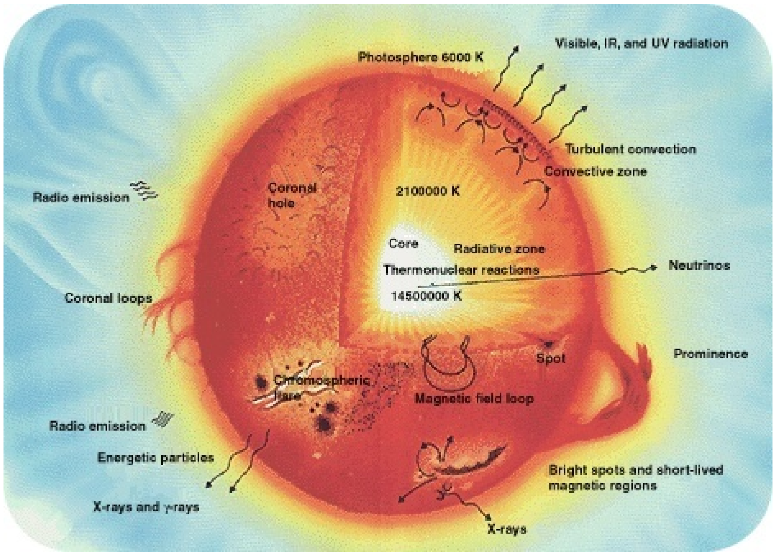
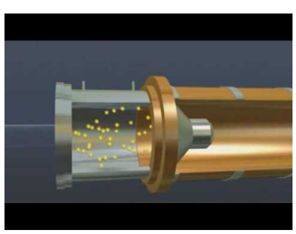


FIGURE 15.4
A diagram of a star like the Sun.

FIGURE 15.5
The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).



MEDIA
Click image to the left for more content.

Vocabulary

- **nuclear fusion reaction**: When nuclei of two atoms fuse together, giving off tremendous amounts of energy.

Summary

- In a nuclear fusion reaction, two nuclei combine to form a larger nucleus.

- The energy from fusion reactions keeps the star from collapsing from its own gravity.
- Particle accelerators simulate reactions at the cores of stars.

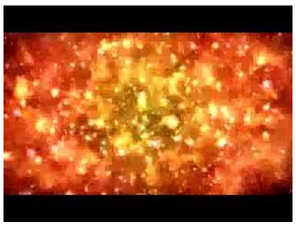
Practice

Use these resources to answer the questions that follow.

http://www.atomicarchive.com/Movies/Movie5.shtml

1. What two molecules does nuclear fusion begin with?
2. What is produced from nuclear fusion?

http://www.youtube.com/watch?v=uKqvjEE0wFg



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3. How do stars begin their lives?
4. What causes hydrogen fusion?
5. What occurs when the star runs out of hydrogen?
6. What is the last element created in a star? Why?
7. When does a star die?
8. What does a supernova create?

Review

1. What type of fusion reaction takes place in most stars?
2. What do scientists learn from particle accelerators?
3. Why don't stars collapse on themselves?

15.3 Star Classification

- Describe how scientists classify stars.
- Explain the relationship between the color of a star and its temperature.

Why are the stars in Orion's Belt different colors?

The ancient Greeks thought this group of stars looked like a hunter, so they named it Orion after their mythical hunter. The line of three stars at the center is "Orion's Belt." The many different colors of stars reflect the star's temperature. The bright, red star in the upper left, named Betelgeuse (pronounced BET-ul-juice), is not as hot than the blue star in the lower right, named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black, but with added heat will start to glow a dull red. With more heat, the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (**Figure** 15.6).

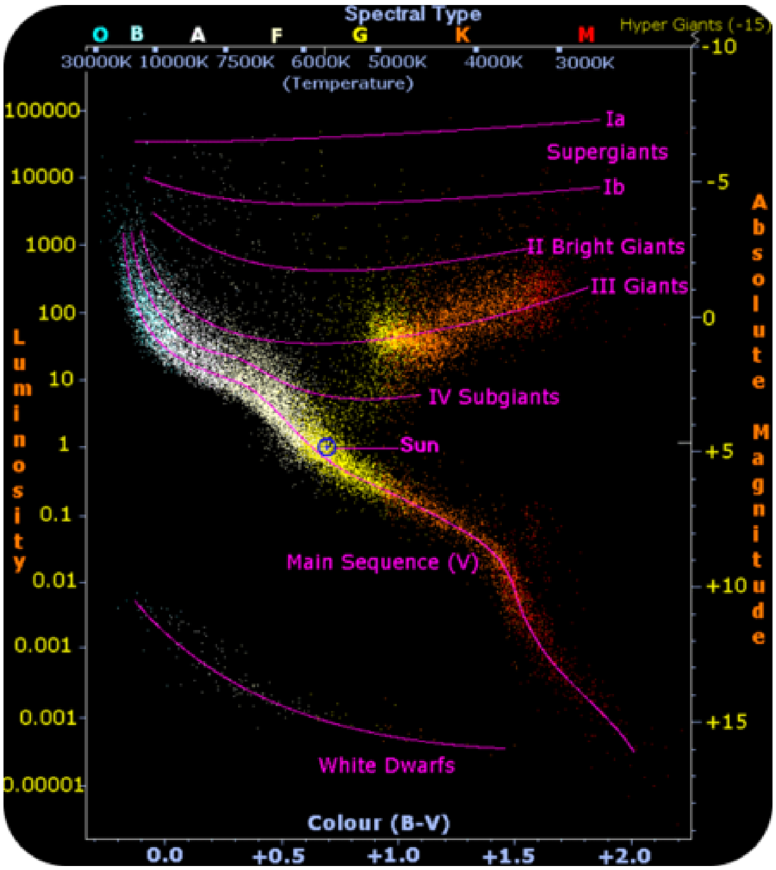


FIGURE 15.6

A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

Classifying Stars by Color

Color is the most common way to classify stars. **Table** 15.1 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

TABLE 15.1: Classification of Stars By Color and Temperature

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi

TABLE 15.1: (continued)

Class	Color	Temperature Range	Sample Star
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

(*Sources*: http://en.wikipedia.org/wiki/Stellar_classification; http://en.wikipedia.org/wiki/Star, License: GNU-FDL)

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. **Figure** 15.7 shows a typical star of each class, with the colors about the same as you would see in the sky.

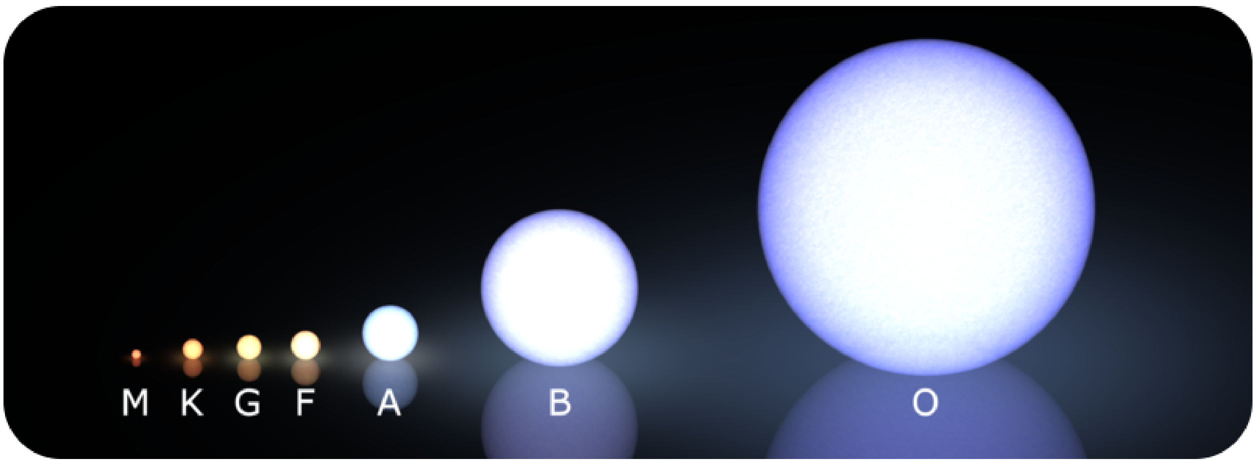


FIGURE 15.7

Typical stars by class, color, and size. For most stars, size is related to class and to color. The colors are approximately as they appear in the sky.

Summary

- Stars are classified by color, which correlates with temperature.
- A Hertzsprung-Russell diagram is used to learn about the characteristics of a star.
- Red stars are the coolest and blue are the hottest in a continuum ranging from 2000 K to more than 30,000 K.

Practice

Use this resource to answer the questions that follow.

http://www.enchantedlearning.com/subjects/astronomy/stars/startypes.shtml

1. How are stars classified?
2. What is the Hertzsprung - Russell diagram?
3. What are most stars?
4. What is our star? Be specific.
5. Define luminosity.

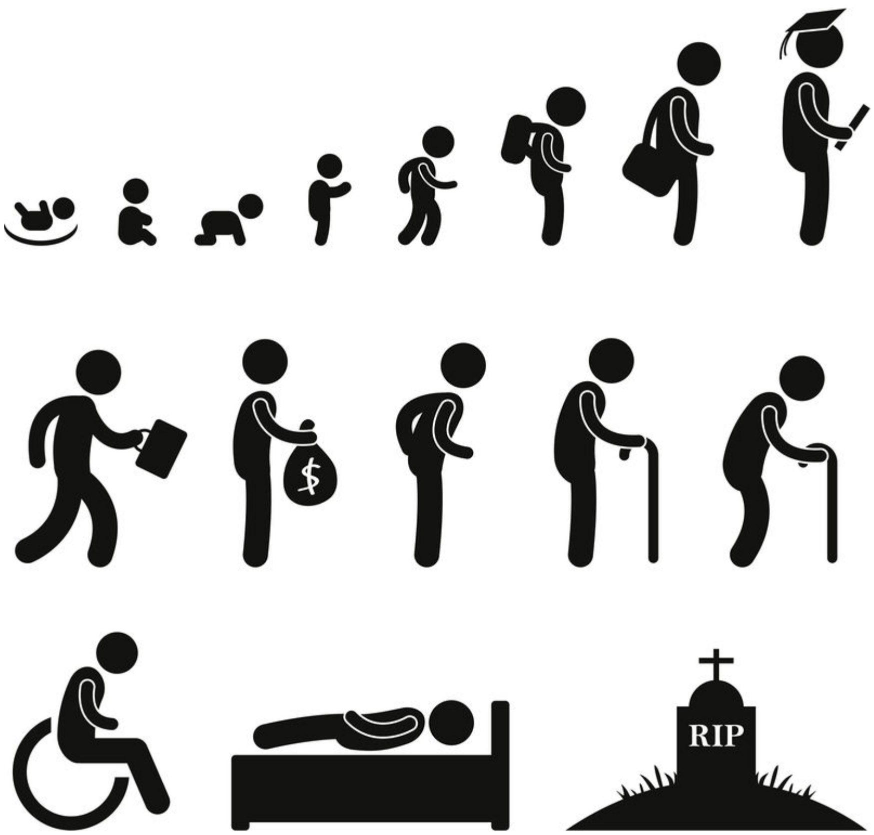
6. What is the Yerkes classification scheme?
7. Describe main sequence stars.
8. Explain the difference between a red and blue giant star.
9. What is a a white dwarf?
10. What is a brown dwarf?

Review

1. What information is contained in a Hertzsprung-Russell diagram?
2. What is the order of star colors from coolest to hottest? How is that related to size?
3. Why do stars that are different colors appear in the same constellation?

15.4 Life Cycles of Stars

- Describe the main stages in the life cycle of stars, including formation and main sequence.
- Describe the differences in the life cycles of different types of stars.
- Explain the relationship between a star's life cycle and its size.



What changes do stars undergo in their lifetimes?

Stars have a life cycle, just like people: they are born, grow, change over time, and eventually grow old and die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in "Concept The Solar System," stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** 15.8.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html and http://hurricanes.nasa.gov/universe/science/stars.html.

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence star**. This term comes from the Hertzsprung-Russell diagram shown above. For stars on the main

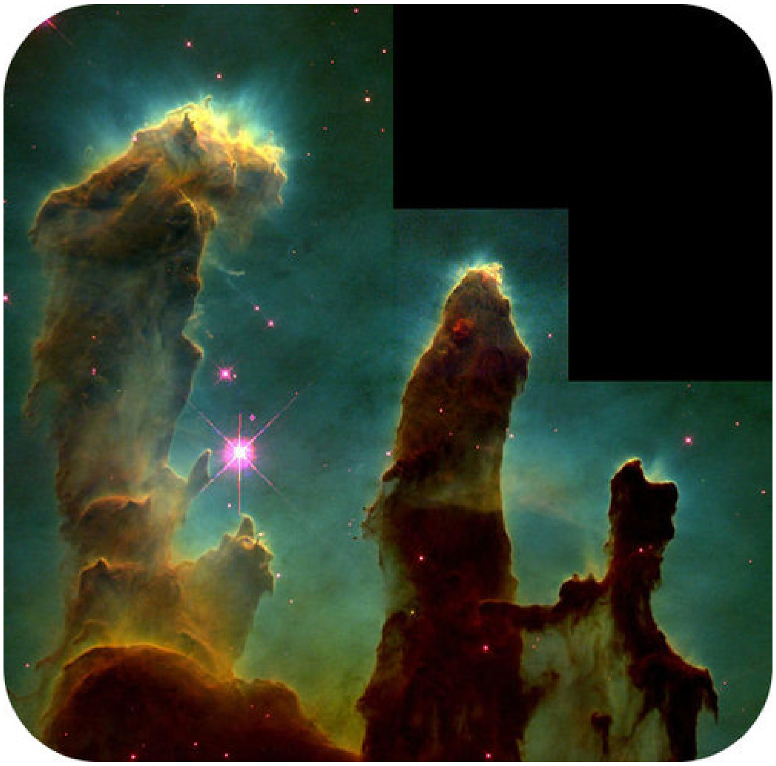


FIGURE 15.8
The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

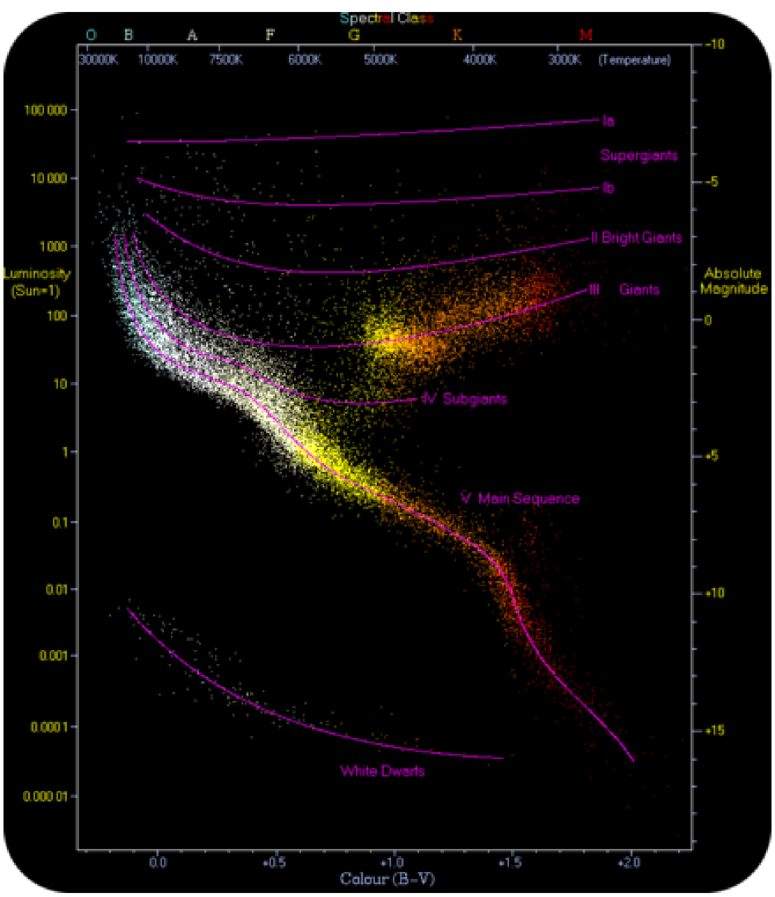


FIGURE 15.9

sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force of nuclear fusion in its core. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years (**Figure** 15.10). Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

FIGURE 15.10
Our Sun is a medium-sized star in about the middle of its main sequence life.

The fate of the Sun and inner planets is explored in this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath.

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is in a transitional phase. When the light elements are mostly used up, the star can no longer resist gravity and starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** 15.11). A white dwarf will ultimately fade out.

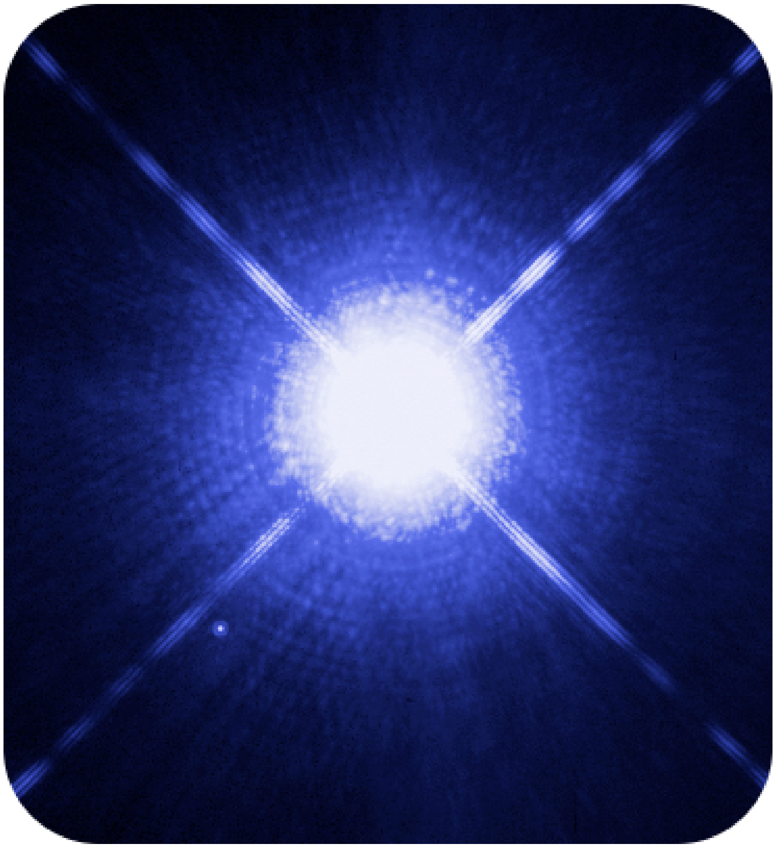


FIGURE 15.11

Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (**Figure** 15.12).

Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces, so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (**Figure** 15.13). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=0J8srN24pSQ#38;feature=fvw.

Neutron Stars

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (**Figure** 15.14). A neutron star is more massive than the Sun, but only a few kilometers in diameter. A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

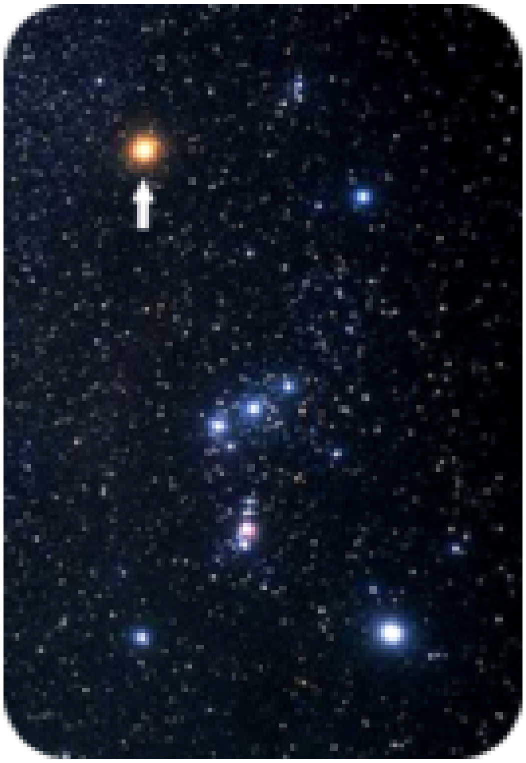


FIGURE 15.12
The red star Betelgeuse in Orion is a red supergiant.

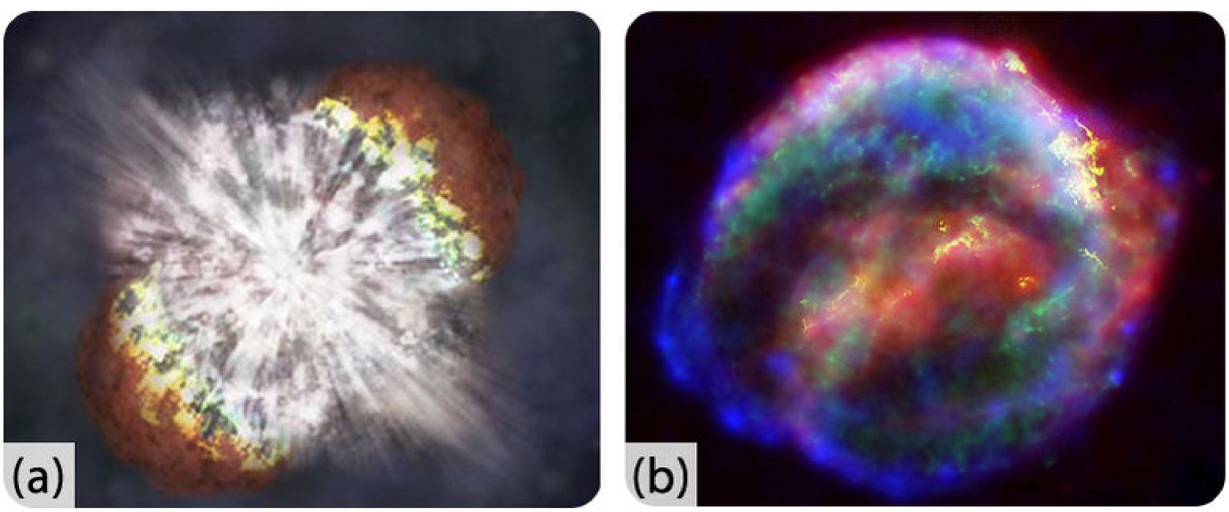


FIGURE 15.13
(a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus, in the night sky.

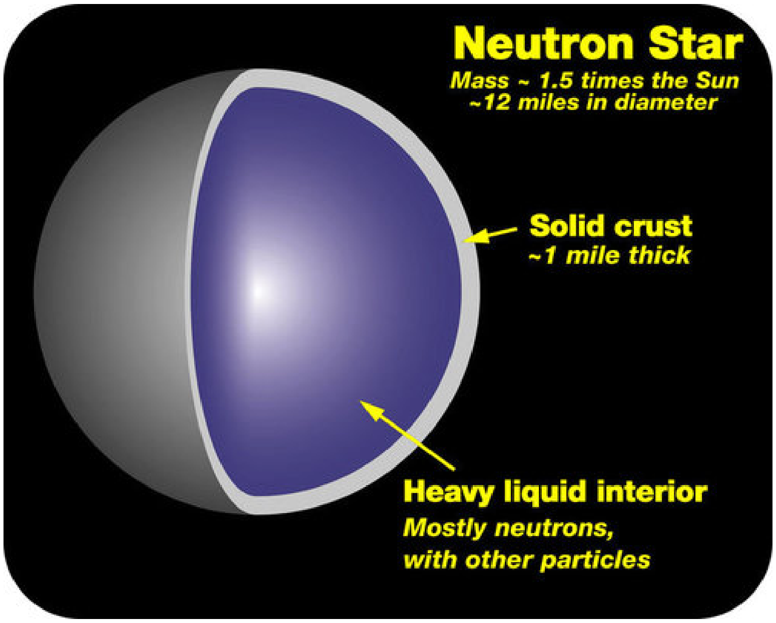


FIGURE 15.14
After a supernova, the remaining core may end up as a neutron star.

Black Hole

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop.

A video about black holes is seen on Space.com: http://www.space.com/common/media/video/player.php?videoRef=black_holes.

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die **(2f)**: http://www.youtube.com/watch?v=H8Jz6FU5D1A (3:11).

MEDIA
Click image to the left for more content.

A video of neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).

MEDIA
Click image to the left for more content.

Vocabulary

- **black hole**: The super dense core left after a supergiant explodes as a supernova.
- **main sequence star**: A star that is fusing hydrogen atoms to helium; a star in the main portion of its "life."
- **neutron star**: The remnant of a massive star after it explodes as a supernova.
- **red giant**: Stage in a star's development when the inner helium core contracts while the outer layers of hydrogen expand.
- **supernova**: A tremendous explosion that occurs when the core of a star is mostly iron.
- **white dwarf**: A small to mid-sized star that has collapsed.

Summary

- Stars spend most of their lives on the main sequence, fusing hydrogen into helium for energy.
- As stars burn up their hydrogen and fuse helium into larger atoms they begin to collapse and become red giants. When the helium is gone they become white dwarfs.
- When a massive star has no more elements left to fuse it explodes as a supernova, from which the chemical elements heavier than lithium form.
- An extremely massive core will collapse after a supernova explosion to become a black hole, which is black because no light can escape it.

Practice

Use this resource to answer the questions that follow.

http://www.odec.ca/projects/2002/wongj/public_html/animations.html

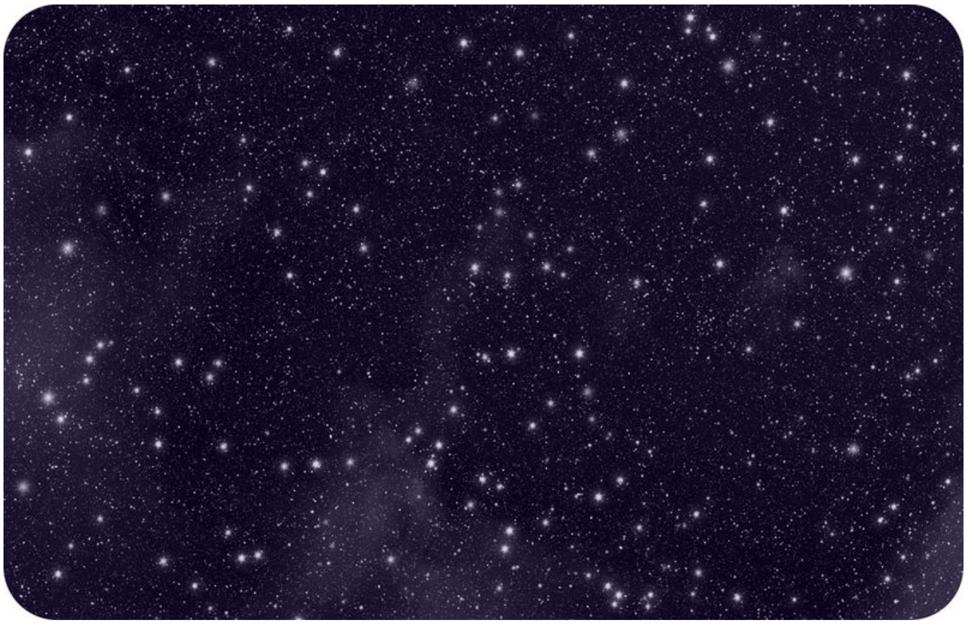
1. What is the birthplace of stars?
2. What is formed in the birthplace of stars?
3. Describe the main sequence star.
4. What causes a red giant to form?
5. Why does a red giant core collapse?
6. What does a red giant become?
7. What happens to a white dwarf?
8. What is the structure of high mass stars?
9. What happens as this star ages?
10. What do neon and magnesium fuse into?
11. How is an iron core produced?
12. What do high mass stars become?

Review

1. Why do some stars become red giants and others become supernovae?
2. Why are supernovae crucial to the evolution of the universe?
3. How does a star become a black hole? What are the characteristics of a black hole?

15.5 Distance Between Stars

- Define parallax and explain how astronomers use parallax to measure distances to stars.



How far is that star?

How can you measure the distance of an object that is too far away to measure? What if you don't know the size of the object or the size or distance of any other objects like it? That is the problem facing astronomers when they try to measure the distances to stars.

Parallax

Distances to stars that are relatively close to us can be measured using **parallax**. Parallax is an apparent shift in position that takes place when the position of the observer changes.

To see an example of parallax, try holding your finger about 1 foot (30 cm) in front of your eyes. Now, while focusing on your finger, close one eye and then the other. Alternate back and forth between eyes, and pay attention to how your finger appears to move. The shift in position of your finger is an example of parallax. Now try moving your finger closer to your eyes, and repeat the experiment. Do you notice any difference? The closer your finger is to your eyes, the greater the position changes because of parallax.

As **Figure** 15.15 shows, astronomers use this same principle to measure the distance to stars. Instead of a finger, they focus on a star, and instead of switching back and forth between eyes, they switch between the biggest possible differences in observing position. To do this, an astronomer first looks at the star from one position and notes where the star is relative to more distant stars. Now where will the astronomer go to make an observation the greatest possible distance from the first observation? In six months, after Earth moves from one side of its orbit around the Sun to the other side, the astronomer looks at the star again. This time parallax causes the star to appear in a different position relative to more distant stars. From the size of this shift, astronomers can calculate the distance to the star.

For more about parallax, visit http://starchild.gsfc.nasa.gov/docs/StarChild/questions/parallax.html and http://imagine.gsfc.nasa.gov/YBA/HTCas-size/parallax1-more.html.

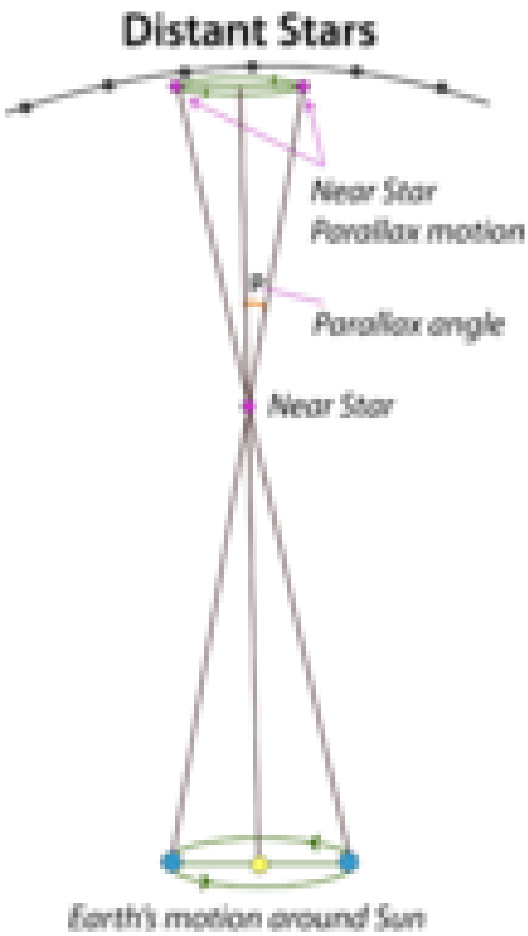


FIGURE 15.15
Parallax is used to measure the distance to stars that are relatively nearby.

A parallax exercise is seen here: http://www.astro.ubc.ca/ scharein/a311/Sim/new-parallax/Parallax.html.

Other Methods

Even with the most precise instruments available, parallax is too small to measure the distance to stars that are more than a few hundred light years away. For these more distant stars, astronomers must use more indirect methods of determining distance. Most of these methods involve determining how bright the star they are looking at really is. For example, if the star has properties similar to the Sun, then it should be about as bright as the Sun. The astronomer compares the observed brightness to the expected brightness.

Vocabulary

- **parallax**: A method used by astronomers to calculate the distance to nearby stars, using the apparent shift relative to distant stars.

Summary

- Parallax is the apparent shift in position of an object due to a change in the position of an observer.
- Parallax is useful for determining distances of stars that are a few hundred light years from Earth.
- Brightness is used to determine the distances of stars that are further away.

Practice

Use these resources to answer the questions that follow.

http://www.astro.ubc.ca/ scharein/a311/Sim/new-parallax/Parallax.html

1. What is parallax?

2. Describe what occurs when you run the animation.

http://www.universetoday.com/47182/stellar-parallax/

3. What is the farthest apart two locations on Earth's orbit can be?

4. What has produced the most accurate parallax measurements to date?

5. What will Gaia measure?

Review

1. Why is parallax only good for measuring the distances of stars that are no more than a few hundred light years away?

2. Explain the process that you would use to determine the distance to a star that was about 100 light years away.

3. How do astronomers determine the distance to a star that is further than a few hundred light years away?

15.6 Galaxies

- Define galaxy, and describe types of galaxies.

What's happening with those galaxies?

Find a clear night sky and get out a good pair of binoculars or a telescope. You can see this feature (although not quite as well). The Whirlpool galaxy has an enhanced spiral structure due to its interactions with its companion galaxy NGC 5195.

Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars. Every star that is visible in the night sky is part of the Milky Way Galaxy. To the naked eye, the closest major galaxy — the Andromeda Galaxy, shown in **Figure** 15.16 — looks like only a dim, fuzzy spot. But that fuzzy spot contains one trillion — 1,000,000,000,000 — stars!

Galaxies are divided into three types according to shape: spiral galaxies, elliptical galaxies, and irregular galaxies.

Spiral Galaxies

Spiral galaxies spin, so they appear as a rotating disk of stars and dust, with a bulge in the middle, like the Sombrero Galaxy shown in **Figure** 15.17. Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** 15.17) and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.

Elliptical Galaxies

Figure 15.18 shows a typical egg-shaped **elliptical galaxy**. The smallest elliptical galaxies are as small as some

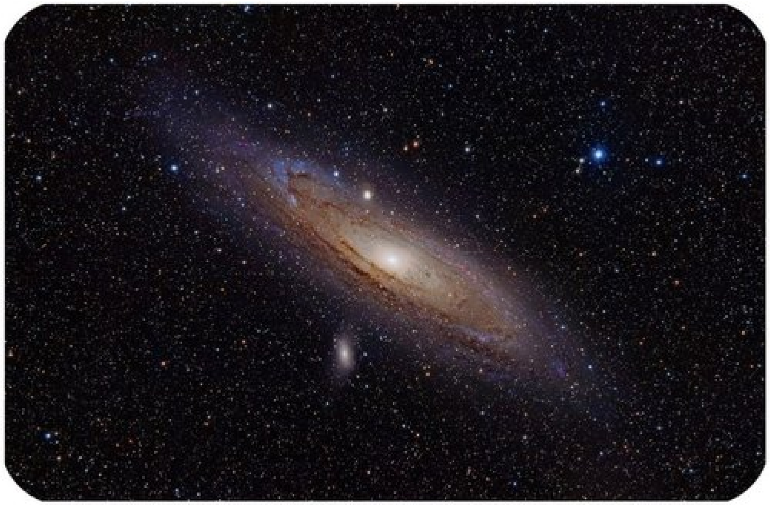


FIGURE 15.16
The Andromeda Galaxy is a large spiral galaxy similar to the Milky Way.

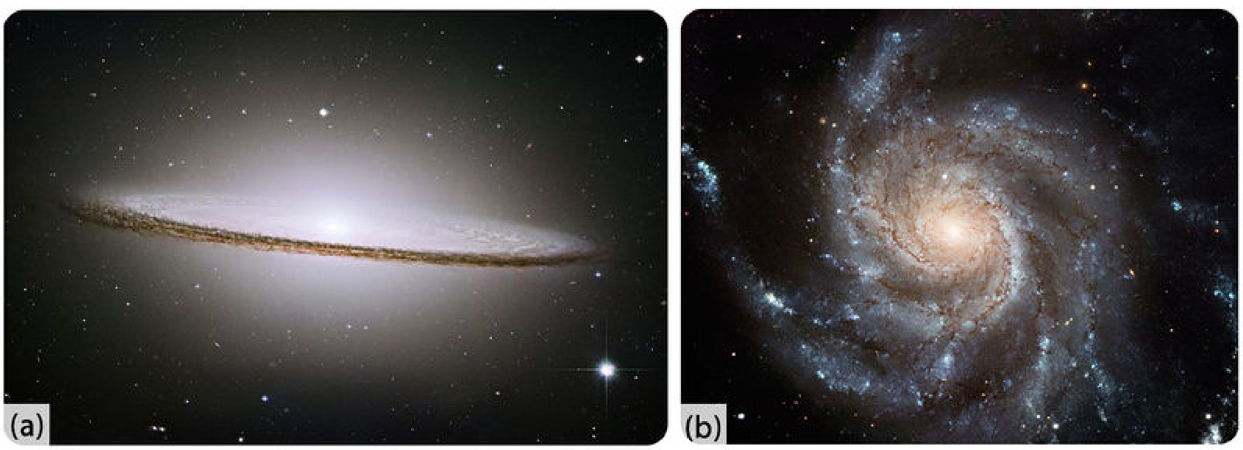


FIGURE 15.17
(a) The Sombrero Galaxy is a spiral galaxy that we see from the side so the disk and central bulge are visible. (b) The Pinwheel Galaxy is a spiral galaxy that we see face-on so we can see the spiral arms. Because they contain lots of young stars, spiral arms tend to be blue.

globular clusters. Giant elliptical galaxies, on the other hand, can contain over a trillion stars. Elliptical galaxies are reddish to yellowish in color because they contain mostly old stars.

Most elliptical galaxies contain very little gas and dust because the gas and dust have already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** 15.19, contain lots of dust. Why might some elliptical galaxies contain dust?

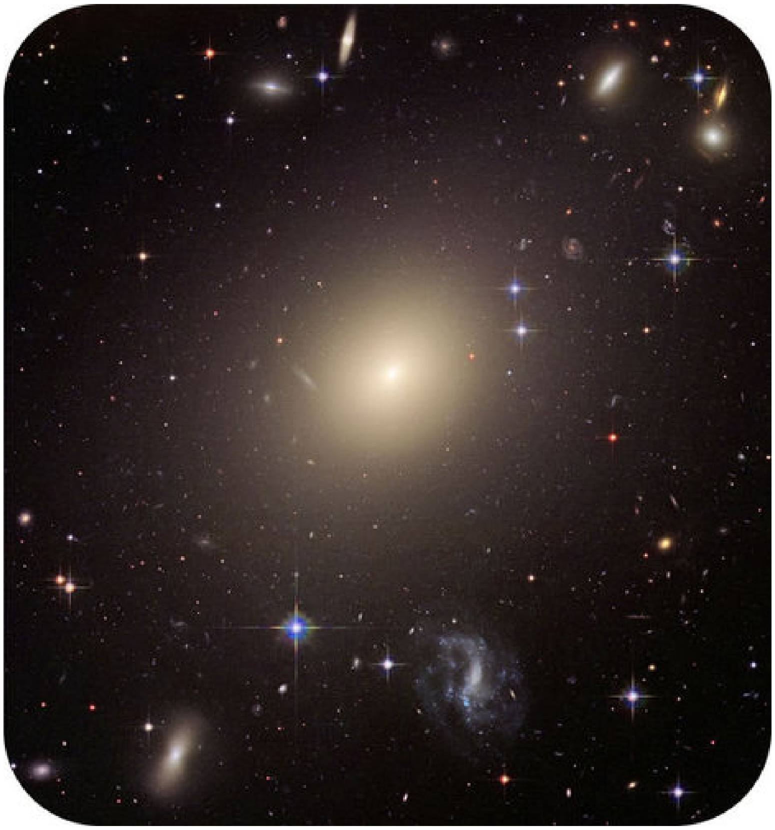


FIGURE 15.18
The large, reddish-yellow object in the middle of this figure is a typical elliptical galaxy. What other types of galaxies can you find in the figure?

FIGURE 15.19
Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

Irregular Galaxies

Is the galaxy in **Figure** 15.20 a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. How might an irregular galaxy form? Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy.

FIGURE 15.20
This galaxy, called NGC 1427A, has neither a spiral nor an elliptical shape.

Dwarf Galaxies

Dwarf galaxies are small galaxies containing only a few million to a few billion stars. Dwarf galaxies are the most common type in the universe. However, because they are relatively small and dim, we don't see as many dwarf galaxies from Earth. Most dwarf galaxies are irregular in shape. However, there are also dwarf elliptical galaxies and dwarf spiral galaxies.

Look back at the picture of the elliptical galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Images from the Hubble Space Telescope are seen in this video: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop.

Vocabulary

- **dwarf galaxy**: A small galaxy containing a few million to a few billion stars.
- **elliptical galaxy**: An oval or egg shaped galaxy with older stars and little gas and dust.

- **galaxy**: A very large group of stars held together by gravity; few million to a few billion stars.
- **irregular galaxy**: A galaxy that is neither spiral nor elliptical.
- **spiral arm**: Regions of gas and dust plus young stars that wind outward from the central area bulge.
- **spiral galaxy**: A rotating type of galaxy with a central bulge and spiral arms with stars, gas and dust.

Summary

- A galaxy is composed of millions to billions of stars.
- Galaxies can be spiral, elliptical or irregular. Dwarf galaxies are smaller, but are more common than other galaxies.
- Galaxies that have lots of dust and gas are locations where stars are forming.

Practice

Use this resource to answer the questions that follow.

http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/galaxytypes.htm

1. List the different types of galaxies.
2. What determines the type of galaxy?
3. What is the bulge?
4. What is the disk?
5. Describe elliptical galaxies.
6. Describe irregular galaxies.

Review

1. What makes a galaxy different from other galaxies or types of astronomical objects?
2. What makes irregular galaxies take an irregular shape?
3. How do dwarf galaxies interact with other galaxies?

15.7 Milky Way

- Describe the characteristics of the Milky Way Galaxy and our solar system's location within it.

"The Milky Way is nothing else but a mass of innumerable stars planted together in clusters." — Galileo Galilei

It's sad that there is so much light pollution in most cities that many people have never seen the Milky Way. On a clear night away from lights the view is of a bright white river of stars. You don't need a telescope or even binoculars to see it. The view of the Milky Way is so bright because you're looking at the stars in your own galaxy.

The Milky Way Galaxy

The **Milky Way Galaxy**, which is our galaxy. The Milky Way is made of millions of stars along with a lot of gas and dust. It looks different from other galaxies because we are looking at the main disk from within the galaxy. Astronomers estimate that the Milky Way contains 200 to 400 billion stars.

Shape and Size

Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars (**Figure** 15.21).

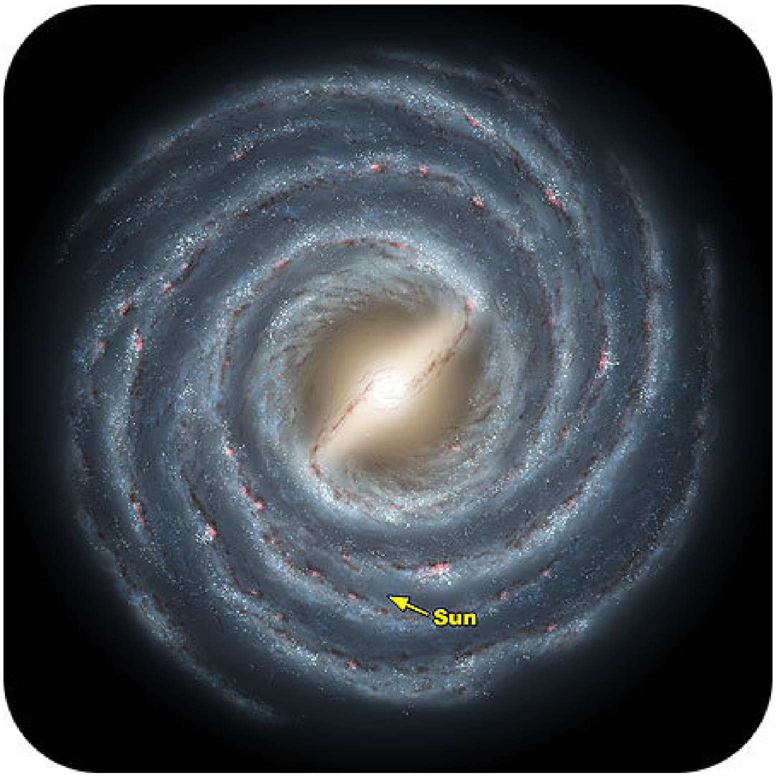


FIGURE 15.21
An artist's rendition of what astronomers think the Milky Way Galaxy would look like seen from above. The Sun is located approximately where the arrow points.

Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk.

What evidence do astronomers find that lets them know that the Milky Way is a spiral galaxy?

1. The shape of the galaxy as we see it (**Figure** 15.22).

2. The velocities of stars and gas in the galaxy show a rotational motion.

3. The gases, color, and dust are typical of spiral galaxies.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also contains old stars and globular clusters. Astronomers have discovered that there is a gigantic black hole at the center of the galaxy.

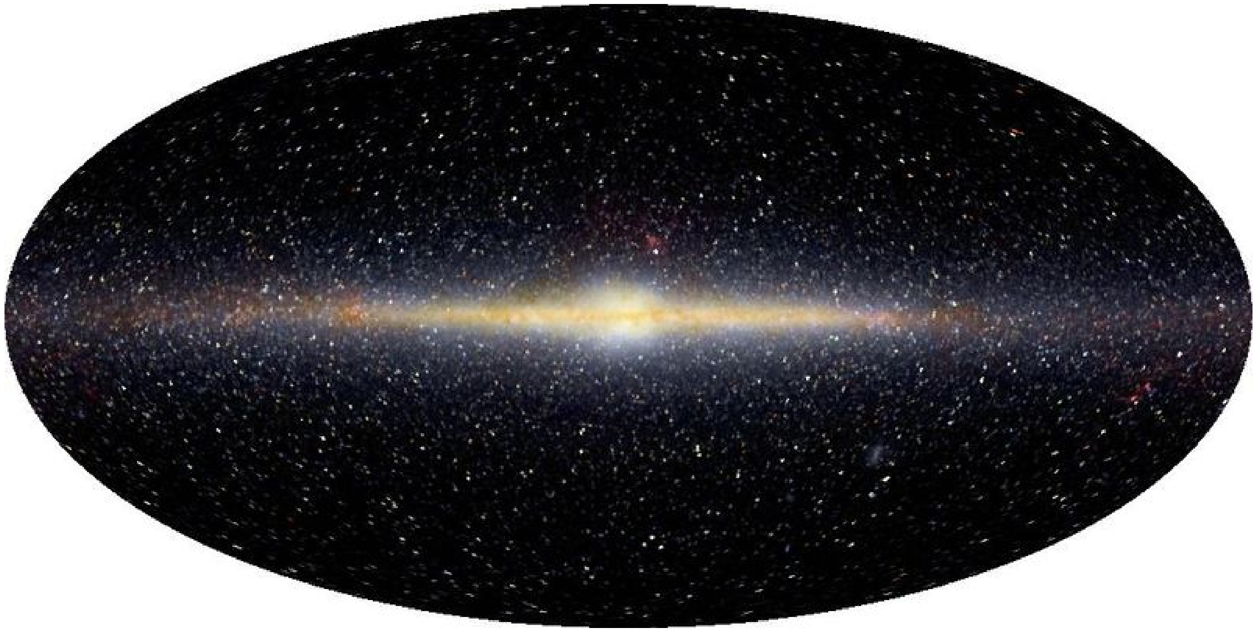


FIGURE 15.22
An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

The Milky Way Galaxy is a big place. If our solar system were the size of your fist, the Galaxy's disk would still be wider than the entire United States!

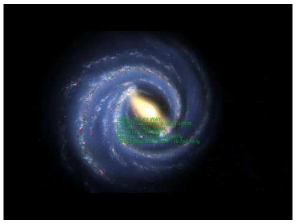
A video closeup of the Milky Way Galaxy is seen here: http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTopjjj.

Where We Are

Our solar system, including the Sun, Earth, and all the other planets, is within one of the spiral arms in the disk of the Milky Way Galaxy. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.

Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago. Astronomers have recently discovered that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, although a black hole cannot be seen.

This video describes the solar system in which we live. It is located in an outer edge of the Milky Way galaxy, which spans 100,000 light years **(2a)**: http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).



MEDIA

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The Universe contains many billions of stars and there are many billions of galaxies. Our home, the Milky Way galaxy, is only one **(2a, 2b)**: http://www.youtube.com/watch?v=eRJvB3hM7K0#38;feature=related (5:59).

MEDIA

Click image to the left for more content.

Vocabulary

- **Milky Way Galaxy**: The spiral galaxy in which Earth and our solar system reside.

Summary

- We view the Milky Way Galaxy from within so it looks like a river of stars.
- From outside the galaxy, the Milky Way would appear as a spiral.
- A supermassive black hole resides at the center of the galaxy, just like within most other galaxies.

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/the_universe/Milkyway.html

1. What type of galaxy is our galaxy?

2. Where are we located in the galaxy?

3. How old is our galaxy?

http://www.windows2universe.org/kids_space/milky_way_ask.html

4. How wide is our galaxy?

5. How long does it take our solar system to revolve around the center of our galaxy?

6. How far away is the center of our galaxy?

7. Explain the Local Group.

Review

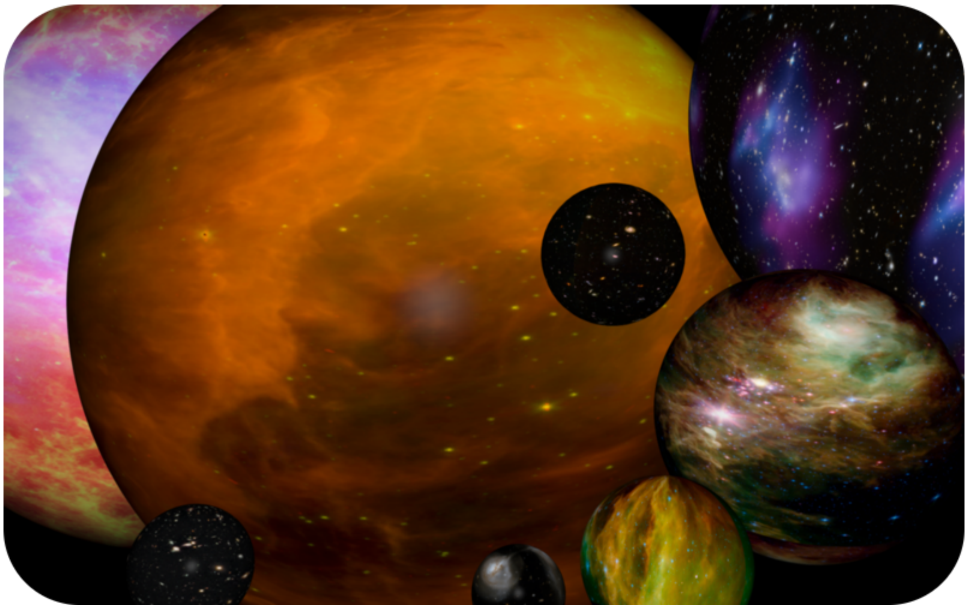
1. Why do astronomers think that the Milky Way is a spiral galaxy?

2. Where is Earth within the Milky Way Galaxy?

3. What are some of the features found within the Milky Way Galaxy?

15.8 Universe

- Define universe and describe the evolution of human understanding of the universe.



Is there more than one universe? Are there multiverses?

Some scientists think there may be more than one universe. This idea is called the multiverse hypothesis. This image is of a universe with different physical constants from our own.

The Universe

The study of the universe is called **cosmology**. Cosmologists study the structure and changes in the present universe. The **universe** contains all of the star systems, galaxies, gas, and dust, plus all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe includes all of space and time.

Evolution of Human Understanding of the Universe

What did the ancient Greeks recognize as the universe? In their model, the universe contained Earth at the center, the Sun, the Moon, five planets, and a sphere to which all the stars were attached. This idea held for many centuries until Galileo's telescope helped people recognize that Earth is not the center of the universe. They also found out that there are many more stars than were visible to the naked eye. All of those stars were in the Milky Way Galaxy.

In the early 20th century, an astronomer named Edwin Hubble **Figure** 15.23 discovered that what scientists called the Andromeda Nebula was actually over 2 million light years away — many times farther than the farthest distances that had ever been measured. Hubble realized that many of the objects that astronomers called nebulas were not actually clouds of gas, but were collections of millions or billions of stars — what we now call galaxies.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies — about the same number of galaxies as there are stars in the Milky Way Galaxy.

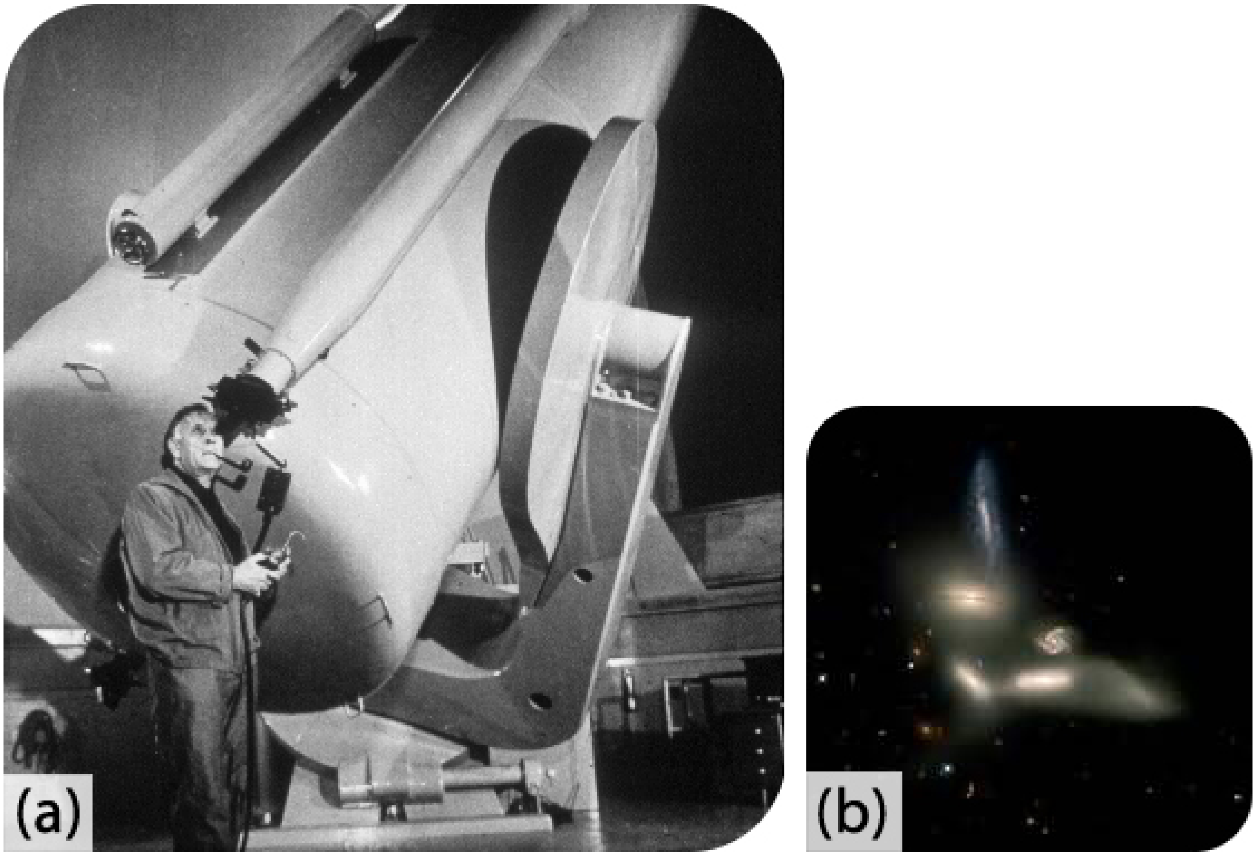


FIGURE 15.23

(a) Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California to show that some distant specks of light were galaxies. (b) Hubble's namesake space telescope spotted this six galaxy group. Edwin Hubble demonstrated the existence of galaxies.

Vocabulary

- **cosmology**: The study of the universe.
- **universe**: Everything that exists; all matter and energy; also includes all of space and time.

Summary

- The universe contains about a hundred billion galaxies.
- The idea of a universe has changed through human history.
- Edwin Hubble saw the enormity of space and determined that there was much more than our own galaxy.

Practice

Use these resources to answer the questions that follow.

http://www.aip.org/history/cosmology/ideas/hubble.htm

1. When did Hubble join the Mount Wilson Observatory?
2. What did Hubble accomplish at Mount Wilson?
3. What did Hubble learn from his observations?

http://www.newscientist.com/article/dn9988-instant-expert-cosmology.html

4. What is cosmology?
5. How can the red shift of galaxies be explained?
6. What is the discover of the expansion of the universe lead to?

Review

1. Why do astronomers study objects in space but cosmologists study the universe?
2. Why does the human idea of the universe continue to change?
3. Why did Edwin Hubble come up with the idea of a universe?

15.9 Expansion of the Universe

- Explain how astronomers use red-shift to determine that the universe is expanding.

What is Doppler Effect?

The sound of a siren on an emergency vehicle changes as it passes you: it shifts from higher to lower pitch. As the vehicle moves toward you, the sound waves are pushed together. As the vehicle moves past you, the waves are spread apart. Though redshift involves light instead of sound, a similar principle operates in both situations.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun — not on Earth — by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in **Figure** 15.24. This shift of absorption bands toward the red end of the spectrum is known as **redshift**.

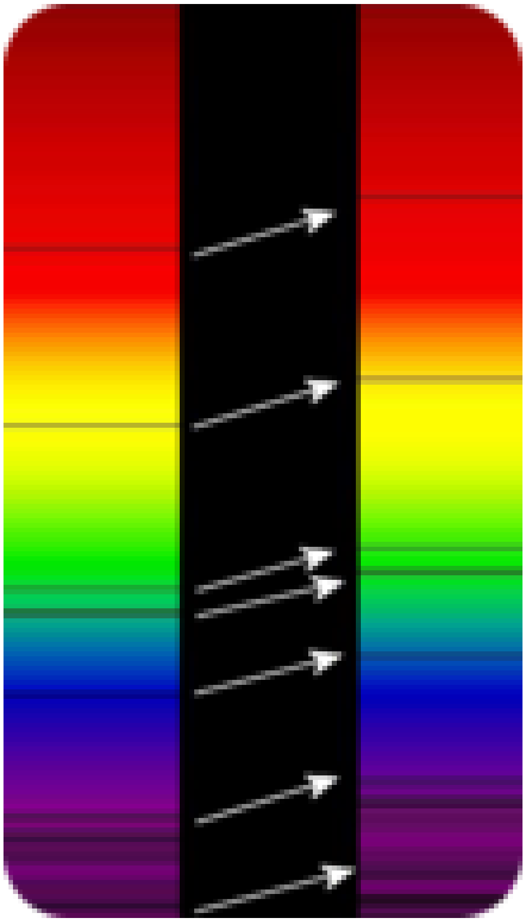


FIGURE 15.24
Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

Redshift occurs when the light source is moving away from the observer or when the space between the observer and the source is stretched. What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

An animation of Doppler Effect: http://projects.astro.illinois.edu/data/Doppler/index.html.

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 15.25 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also, the dots farther away from you on the balloon would move away faster than dots nearby.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is

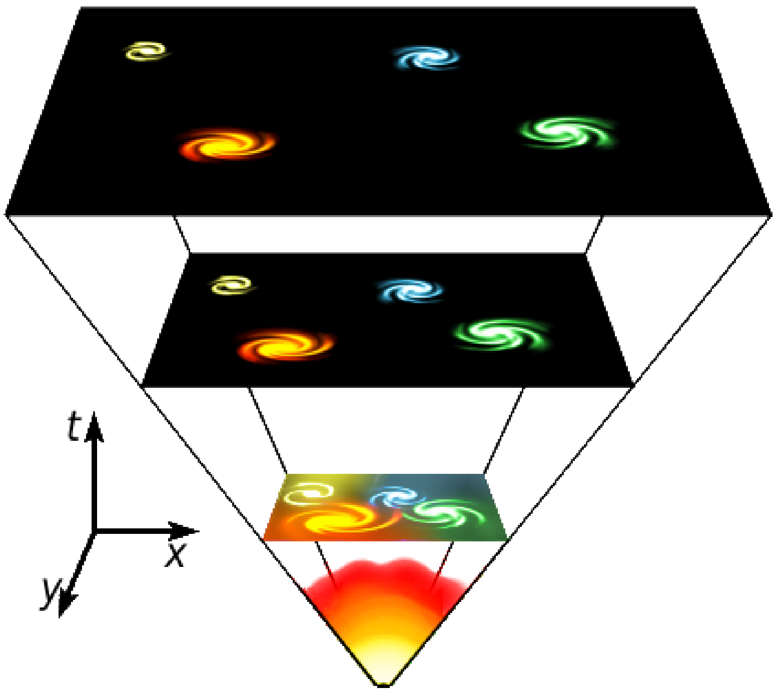


FIGURE 15.25
In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies, just as the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here: http://www.astro.ubc.ca/ scharein/a311/Sim/bang/BigBang.html.

One other difference between the universe and a balloon involves the actual size of the galaxies. On a balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size; only the space between the galaxies increases.

Vocabulary

- **redshift**: Shift of wavelengths of light towards the red end of the spectrum; happens as a light source moves away from us.

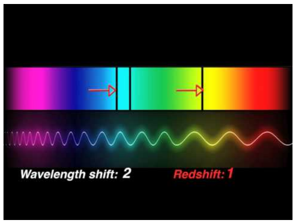
Summary

- Almost every galaxy is moving away from us.
- The spectrum from stars is shifted toward the red; this is known as red-shift and is evidence that the universe is expanding.
- Hubble's Law states that the farther away a galaxy is, the faster it is moving away from us.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=8FPVIV-LzYM



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1. What does dark energy do?
2. What are Cephied variables?
3. What are the Cephieds used for?
4. What happens to light as it reaches us?
5. What is the Doppler effect?
6. What is red shift?
7. What is Hubble's law?
8. What causes red shift?
9. How is red shift measured?
10. What is the successor for the Hubble Space Telescope? What will it allow scientists to do?

Review

1. How did Hubble determine that the universe is expanding?
2. How do astronomers determine the composition of distant stars?
3. What is the significance of the idea that the universe is expanding?

15.10 Big Bang

- Define Big Bang theory and explain its relationship to the expansion of the universe.
- Describe what occurred after the Big Bang.
- Describe evidence scientists have discovered to support Big Bang theory.

How did everything begin in the Big Bang?

If the universe is expanding, the next logical thought is that in the past it had to have been smaller. A point even. The time when the universe began is the explosion known as the Big Bang.

The Big Bang Theory

The **Big Bang theory** is the most widely accepted cosmological explanation of how the universe formed. If we start at the present and go back into the past, the universe is contracting — getting smaller and smaller. What is the end result of a contracting universe?

According to the Big Bang theory, the universe began about 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion — a big bang — caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion.

What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.

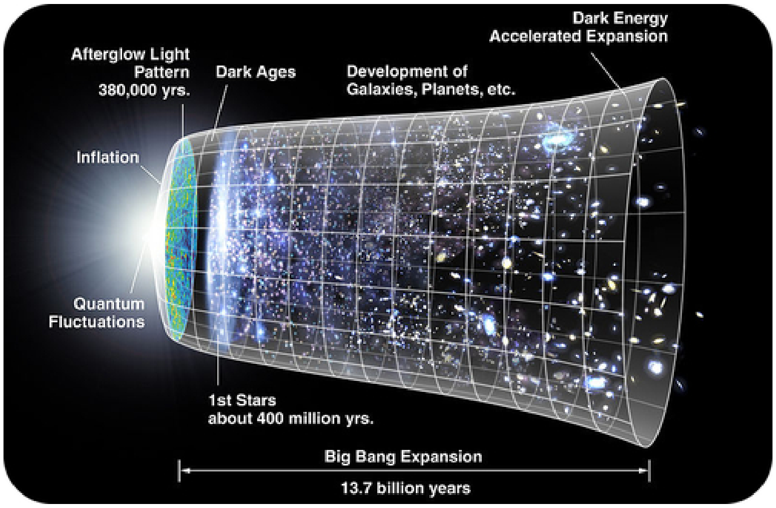

FIGURE 15.26
Timeline of the Big Bang and the expansion of the Universe.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those subatomic particles came together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion, and hydrogen nuclei were fused into helium nuclei. The first neutral atoms that included electrons did not form until about 380,000 years later.

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (**Figure** 15.27).

Background Radiation

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (**Figure** 15.28). This tiny amount of heat is left over from the Big Bang. Since nearly all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

An explanation of the Big Bang: http://dvice.com/archives/2009/08/big-bang-animat.php.

How we know about the early universe: http://www.youtube.com/watch?v=uihNu9Icaeo#38;feature=channel.

"History of the Universe," part 2: http://www.youtube.com/watch?v=bK6_p5a-Hbo#38;feature=channel.

"The Evidence for the Big Bang in 10 Little Minutes" provides a great deal of scientific evidence for the Big Bang **(2g)**: http://www.youtube.com/watch?v=uyCkADmNdNo (10:10).

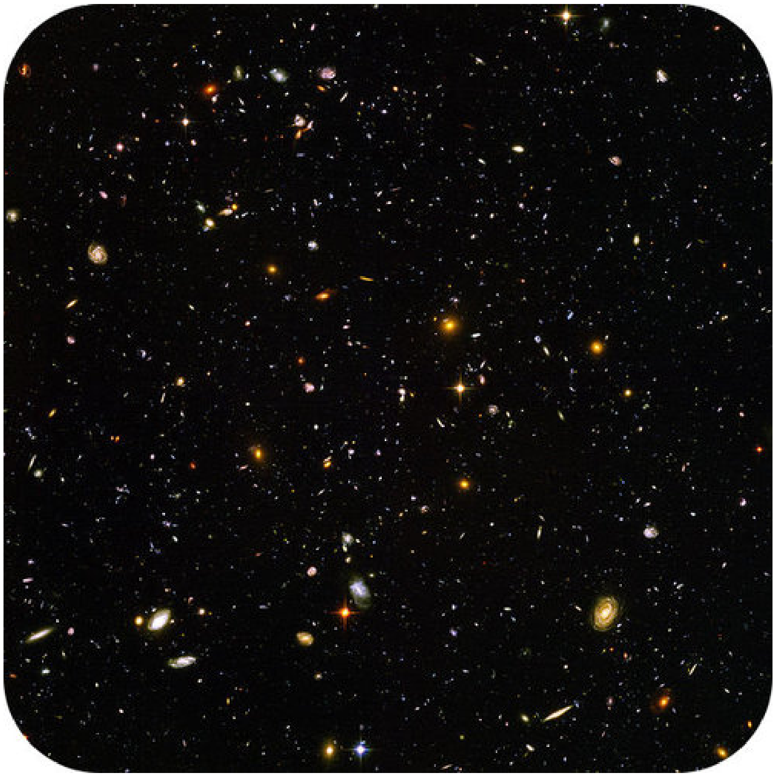

FIGURE 15.27
Images from very far away show what the universe was like not too long after the Big Bang.

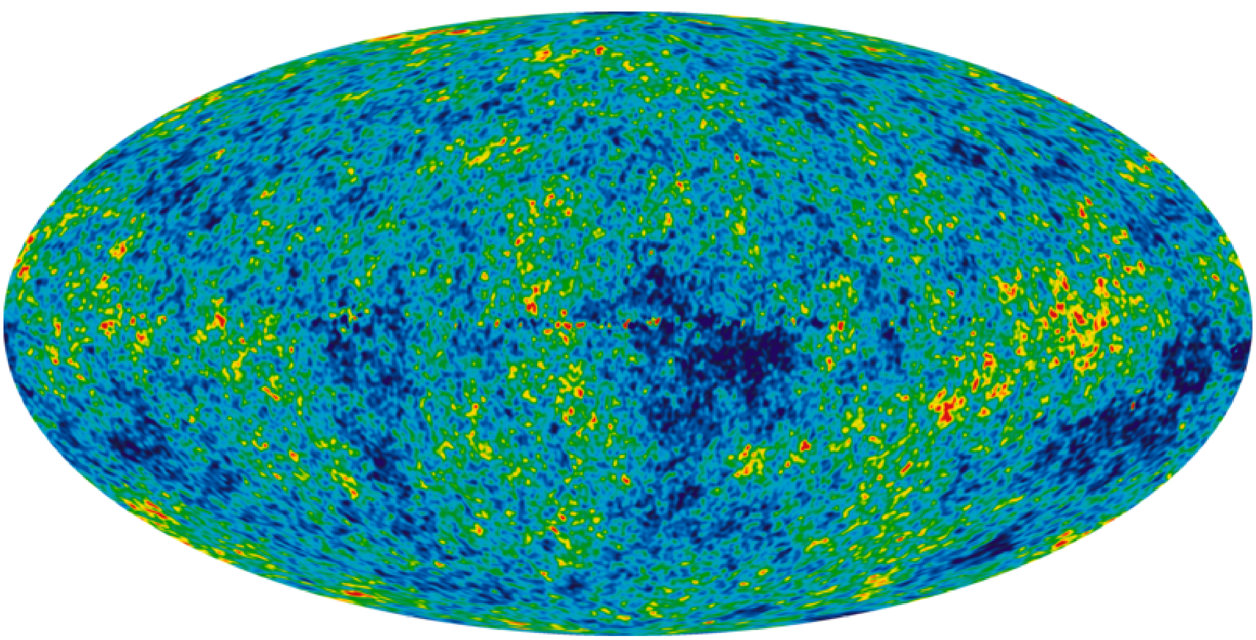

FIGURE 15.28
Background radiation in the universe was good evidence for the Big Bang theory.

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KQED: Nobel Laureate George Smoot and the Origin of the Universe

George Smoot, a scientist at Lawrence Berkeley National Lab, shared the 2006 Nobel Prize in Physics for his work on the origin of the universe. Using background radiation detected by the Cosmic Background Explorer Satellite (COBE), Smoot was able to make a picture of the universe when it was 12 hours old. Learn more at: http://science.kqed.org/quest/video/nobel-laureate-george-smoot-and-the-origin-of-the-universe/

Adobe Flash

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Vocabulary

- **Big Bang Theory**: The hypothesis that all matter and energy were at one time compresses into a very small volume; then there was an explosion that sent everything moving outward, causing the universe to expand.

Summary

- The Big Bang theory states that the universe began as a point and expanded outward.
- No one can know what came before the Big Bang because there is no remaining evidence.
- The tiny bit of background radiation in the universe is energy remaining from the Big Bang.

Practice

Use this resource to answer the questions that follow.

http://science.nationalgeographic.com/science/space/universe/origins-universe-article/

1. Explain the Big Bang Theory.

2. Who suggested the Big Bang Theory?

3. Who discovered cosmic microwave radiation?

4. What does cosmic microwave radiation indicate?

5. What questions are not answered with the Big Bang Theory?

Review

1. How is the idea that the universe started in a big bang a logical extension from a fact?

2. What evidence is there that the universe began in a big bang?

3. What happened in the first minutes after the Big Bang?

15.11 Dark Matter

- Define dark matter and dark energy.
- Describe evidence for and hypotheses about the existence of dark matter and dark energy and the roles they play in the universe.

Why is dark matter hot?

It's not hot in temperature; it's a hot topic in cosmology. Many lines of evidence support the Big Bang theory for explaining the formation of the universe. However, scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80%, is dark matter.

Dark matter emits no electromagnetic radiation, so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than they can see.

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** 15.29). To explain strong gravitational lensing, more matter than is observed must be present.

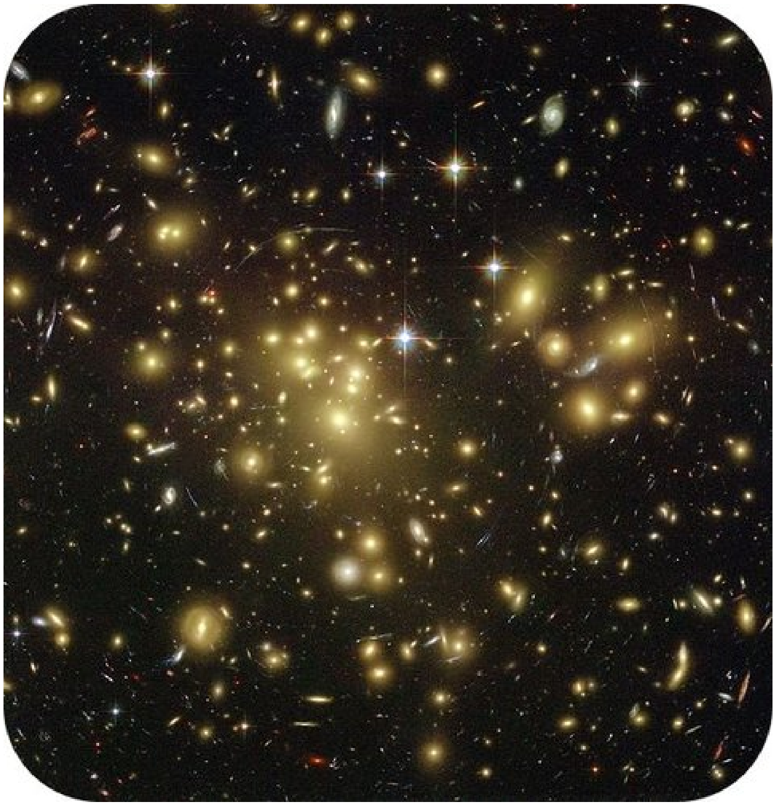


FIGURE 15.29

The arc around the galaxies at the center of this image is caused by gravitational lensing. The addition of gravitational pull from dark matter is required to explain this phenomenon.

With so little to go on, astronomers don't really know much about the nature of dark matter. One possibility is that it could just be ordinary matter that does not emit radiation in objects such as black holes, neutron stars, and brown dwarfs — objects larger than Jupiter but smaller than the smallest stars. But astronomers cannot find enough of these types of objects, which they have named MACHOs (massive astrophyiscal compact halo object), to account for all the dark matter, so they are thought to be only a small part of the total.

Another possibility is that the dark matter is very different from the ordinary matter we see. Some appear to be particles that have gravity, but don't otherwise appear to interact with other particles. Scientists call these theoretical particles WIMPs, which stands for Weakly Interactive Massive Particles.

Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOs and some type of exotic matter, such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

Dark Energy

Astronomers who study the expansion of the universe are interested in knowing the rate of that expansion. Is the rate fast enough to overcome the attractive pull of gravity?

- If yes, then the universe will expand forever, although the expansion will slow down over time.

- If no, then the universe would someday start to contract, and eventually get squeezed together in a big crunch, the opposite of the Big Bang.

Recently, astronomers have made a discovery that answers that question: the rate at which the universe is expanding is actually increasing. In other words, the universe is expanding faster now than ever before, and in the future it will expand even faster. So now astronomers think that the universe will keep expanding forever. But it also proposes a perplexing new question: what is causing the expansion of the universe to accelerate?

One possible hypothesis involves a new, hypothetical form of energy called **dark energy** (**Figure** 15.30). Some scientists think that dark energy makes up as much as 71% of the total energy content of the universe.

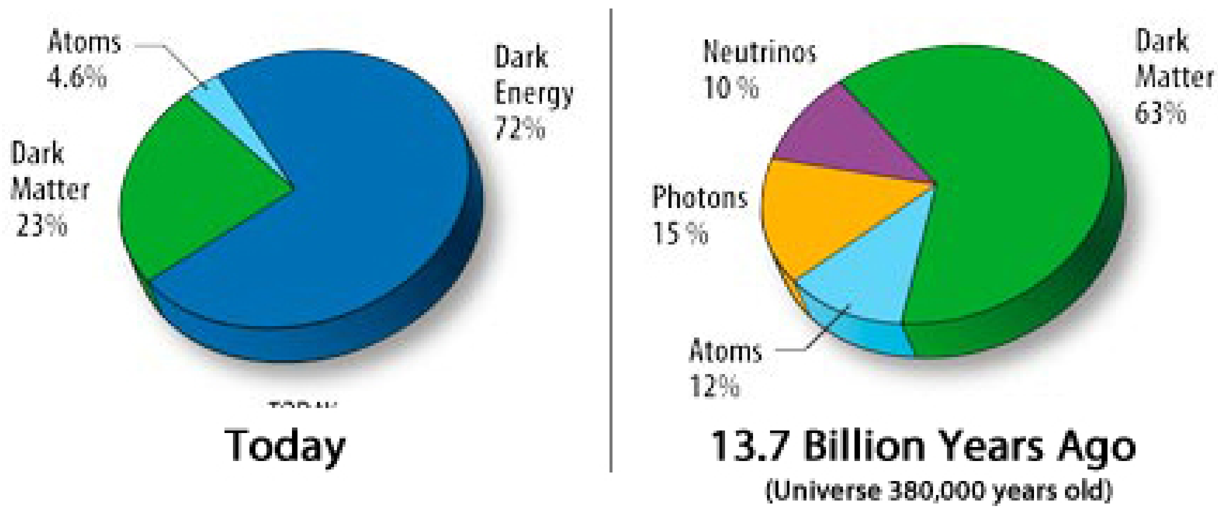


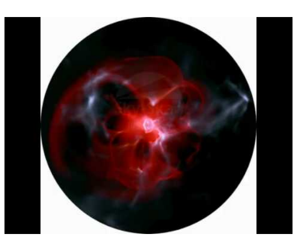
FIGURE 15.30

Today matter makes up a small percentage of the universe, but at the start of the universe it made up much more. Where did dark energy, if it even exists, come from?

Other scientists have other hypotheses about why the universe is continuing to expand; the causes of the universe's expansion is another unanswered question that scientists are researching.

A video explaining dark matter is here: http://www.youtube.com/watch?v=gCgTJ6ID6ZA.

This video looks at the origin of the universe, star formation, and the formation of the chemical elements in supernovas (**2c**): http://www.youtube.com/watch?v=8AKXpBeddu0#38;feature=related (8:30).



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KQED: Dark Energy

Meet one of the three winners of the 2011 Nobel Prize in Physics, Lawrence Berkeley Lab astrophysicist Saul Perlmutter. He explains how dark energy, which makes up 70 percent of the universe, is causing our universe to expand. Learn more at: http://science.kqed.org/quest/video/dark-energy/

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Click image to the left for more content.

Vocabulary

- **dark energy**: An as yet undiscovered form of energy that we cannot see.
- **dark matter**: Matter in the universe that doesn't emit light.

Summary

- Dark matter cannot be sensed by astronomers, but the effect of its gravity is seen on the motion of nearby objects.
- Dark matter may be a combination of WIMPs and MACHOs.
- Dark energy is still hypothetical, but if it exists it could be a significant portion of the energy of the universe.

Practice

Use this resource to answer the questions that follow.

http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

1. What do we know about dark energy?
2. How much of the universe is made up of dark energy?
3. How much of the universe is made up of dark matter?
4. What is dark matter?
5. What do we know about dark matter?

Review

1. Why can't scientists see dark matter? Since they can't see it, how do they know that it exists?
2. What are WIMPs and MACHOs and why are they important?
3. What might dark energy be and why is it important?

Summary

Stars have a life cycle that begins with birth, goes through middle age and ends in some sort of death. The exact path and the exact result depends on the size of the star. We can see different types of stars in the sky; they vary by size and brightness, which is how they are classified. Stars cluster in galaxies, which are fantastic structures in the sky. Our own sun and solar system lies within an arm of a spiral galaxy, the Milky Way. Scientists have used observations, measurements, and mathematical calculations to hypothesize an origin for the universe, known as the Big Bang. These scientists continue to learn new things about the universe. For example, dark matter and dark energy have only recently been discovered.

15.12 References

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