KMHS

Earth Science



Ch. 1: What is Earth Science?



The journey to better understanding Earth begins here with an exploration of how scientists learn about the natural world and introduces you to the study of Earth science.

Courtesy of NASA. earthobservatory.nasa.gov/IOTD/view.php?id=42805. Public Domain.

Earth science is the study of our home planet and all of its components: its lands, waters, atmosphere, and interior. In this book, some chapters are devoted to the processes that shape the lands and impact people. Other chapters depict the processes of the atmosphere and its relationship to the planet's surface and all our living creatures. For as long as people have been on the planet, humans have had to live within Earth's boundaries. Now human life is having a profound effect on the planet. Several chapters are devoted to the effect people have on the planet. Chapters at the end of the book will explore the universe beyond Earth: planets and their satellites, stars, galaxies, and beyond.

Section 1

The Nature of Science

1.1 The Nature of Science

Lesson Objectives

- Identify the goal of science.
- Explain the importance of asking questions.
- Describe how scientists study the natural world.
- Explain how and why scientists collect data.
- Describe the three major types of scientific models.
- Explain how a scientific theory differs from a hypothesis.
- Describe appropriate safety precautions inside and outside the science laboratory.

Vocabulary

- closed system
- conceptual model
- control
- dependent variable
- hypothesis
- independent variable
- mathematical model
- model
- open system
- physical model
- scientific method
- system
- theory

Introduction

This video helps to show what we will be studying this year In Earth Science.

Science is a path to gaining knowledge about the natural world. The study of science also includes the body of knowledge that has been collected through scientific inquiry.

To conduct a scientific investigation, scientists ask testable questions. To answer those questions, they make systematic observations and carefully collect relevant evidence. Then they use logical reasoning and some imagination to develop hypotheses and explanations. Finally, scientists design and conduct experiments based on their hypotheses.

Goal of Science

Scientists seek to understand the natural world. Scientists begin with a question and then try to answer the question with evidence and logic. A scientific question must be testable. It does not rely on faith or opinion. Our understanding of natural Earth processes help us to understand why earthquakes occur where they do and to understand the consequences of adding excess greenhouse gases to our atmosphere.

Scientific research may be done to build knowledge or to solve problems. Scientific discoveries may lead to technological advances. Pure research often aids in the development of applied research. Sometimes the results of pure research may be applied long after the pure research was completed. Sometimes something

unexpected is discovered while scientists are conducting their research.

Scientists describe what they see, whether in nature or in a laboratory. Science is the realm of facts and observations. However, science does not make moral judgments, such as “It is bad that the volcano erupted” and opinions are not relevant to scientific inquiry. Scientists might enjoy studying tornadoes, but their opinion that tornadoes are exciting is not important to learning about them. Scientists increase our technological knowledge, but science does not determine how or if we use that knowledge. Scientists learned to build an atomic bomb, but scientists didn't decide whether or when to use it. Scientists have accumulated data on warming temperatures. Their models have shown the likely causes of this warming. But although scientists are largely in agreement on the causes of global warming, they can't force politicians or individuals to pass laws or change behaviors.

For science to work, scientists must make some assumptions. The rules of nature, whether simple or complex, are the same everywhere in the universe. Natural events, structures, and landforms have natural causes. Evidence from the natural world can be used to learn about those causes. The objects and events in nature can be understood through careful, systematic study. Scientific ideas can change if we gather new data or learn more. An idea, even one that is accepted today, may need to be changed slightly or be entirely replaced if new evidence is found that contradicts it. Scientific knowledge can withstand the test of time. Accepted ideas in science become more reliable as they survive more tests.

Scientific Method

You have probably learned that the **scientific method** is the way scientists approach their work. The scientific method is a series of steps that help to investigate a question. Scientists use data and evidence gathered from observations, experience, or experiments to answer their questions.

But scientific inquiry rarely proceeds in the same sequence of steps outlined by the scientific method. For example, the order of the steps might change because more questions arise from the data that is collected. Still, to come to verifiable conclusions, logical, repeatable steps of the scientific method must be followed, as seen in the **Figure** below .



Figure 1.1

The basic sequence followed in the scientific method.

This video of *The Scientific Method Made Easy* explains scientific method succinctly and well **(1a, 1b, 1c, 1d, 1f, 1g, 1j, 1k - I&E Stand)** : http://www.youtube.com/watch?v=zcavPAFiG14&feature=related (9:54).



Click on the image above for more content

Questions

The most important thing a scientist can do is to ask questions.

- Why is the sky blue?
- Why does California have many earthquakes while Kansas does not?
- Why does Earth have so many varied life forms but other planets in the solar system do not?

Earth science can answer testable questions about the natural world. What makes a question impossible to test? Some untestable questions are whether ghosts exist or whether there is life after death.

A testable question might be about how to reduce soil erosion on a farm (**Figure** below). A farmer has heard of a planting method called “no-till farming.” Using this process eliminates the need for plowing the land. The farmer's question is: Will no-till farming reduce the erosion of the farmland?



Figure 1.2

Soil erosion on a farm.

Research

To answer a question, a scientist first finds out what is already known about the topic by reading books and magazines, searching the Internet, and talking to experts. This information will allow the scientist to create a good experimental design. If this question has

already been answered, the research may be enough or it may lead to new questions.

Example: The farmer researches no-till farming on the Internet, at the library, at the local farming supply store, and elsewhere. He learns about various farming methods, as illustrated in the **Figure** below . He learns what type of fertilizer is best to use and what the best crop spacing would be. From his research he learns that no-till farming can be a way to reduce carbon dioxide emissions into the atmosphere, which helps in the fight against global warming.



Figure 1.3

The farmer researches farming methods.

Hypothesis

With the information collected from background research, the scientist creates a plausible explanation for the question. This is a **hypothesis** . The hypothesis must directly relate to the question and must be testable. Having a hypothesis guides a scientist in designing experiments and interpreting data.

Example: The farmer's hypothesis is this: No-till farming will decrease soil erosion on hills of similar steepness as compared to the traditional farming technique because there will be fewer disturbances to the soil.

Data Collection

To support or refute a hypothesis, the scientist must collect data. A great deal of logic and effort goes into designing tests to collect data so the data can answer scientific questions. Data is usually collected by experiment or observation. Sometimes improvements in technology will allow new tests to better address a hypothesis.

Observation is used to collect data when it is not possible for practical or ethical reasons to perform experiments. Written descriptions are qualitative data based on observations. This data may also be used to answer questions. Scientists use many different types of instruments to make quantitative measurements. Electron microscopes can be used to explore tiny objects or telescopes to learn about the universe. Probes make observations where it is too dangerous or too impractical for scientists to go. Data from the probes travels through cables or through space to a computer where it is manipulated by scientists (**Figure** below).



Figure 1.4

Scientists routinely travel to the bottom of the ocean in research submersibles to observe and collect samples.

Experiments may involve chemicals and test tubes, or they may require advanced technologies like a high-powered electron microscope or radio telescope. Atmospheric scientists may collect data by analyzing the gases present in gas samples, and geochemists may perform chemical analyses on rock samples.

A good experiment must have one factor that can be manipulated or changed. This is the **independent variable** . The rest of the factors must remain the same. They are the experimental **controls** . The outcome of the experiment, or what changes as a result of the experiment, is the **dependent variable** . The dependent variable "depends" on the independent variable.

Example: The farmer conducts an experiment on two separate hills. The hills have similar steepness and receive similar amounts of sunshine. On one, the farmer uses a traditional farming technique that includes plowing. On the other, he uses a no-till technique, spacing plants farther apart and using specialized equipment for planting. The plants on both hillsides receive identical amounts of water and fertilizer. The farmer measures plant growth on both hillsides (**Figure** below).



Figure 1.5

A farmer takes careful measurements in the field.

In this experiment:

- What is the independent variable?
- What are the experimental controls?
- What is the dependent variable?

The independent variable is the farming technique—either traditional or no-till—because that is what is being manipulated. For a fair comparison of the two farming techniques, the two hills must have the same slope and the same amount of fertilizer and

water. These are the experimental controls. The amount of erosion is the dependent variable. It is what the farmer is measuring.

During an experiment, scientists make many measurements. Data in the form of numbers is quantitative. Data gathered from advanced equipment usually goes directly into a computer, or the scientist may put the data into a spreadsheet. The data then can be manipulated. Charts and tables display data and should be clearly labeled.

Statistical analysis makes more effective use of data by allowing scientists to show relationships between different categories of data. Statistics can make sense of the variability in a data set. Graphs help scientists to visually understand the relationships between data. Pictures are created so that other people who are interested can see the relationships easily.

In just about every human endeavor, errors are unavoidable. In a scientific experiment, this is called experimental error. What are the sources of experimental errors? Systematic errors may be inherent in the experimental setup so that the numbers are always skewed in one direction. For example, a scale may always measure one-half ounce high. The error will disappear if the scale is recalibrated. 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 type of error, many measurements are taken and then averaged.

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 and the inconsistent data point can be thrown out.

Conclusions

Scientists study graphs, tables, diagrams, images, descriptions, and all other available data to draw a conclusion from their experiments. Is there an answer to the question based on the results of the experiment? Was the hypothesis supported?

Some experiments completely support a hypothesis and some do not. If a hypothesis is shown to be wrong, the experiment was not a failure. All experimental results contribute to knowledge. Experiments that do or do not support a hypothesis may lead to even more questions and more experiments.

Example: After a year, the farmer finds that erosion on the traditionally farmed hill is 2.2 times greater than erosion on the no-till hill. The plants on the no-till plots are taller and the soil moisture is higher. The farmer decides to convert to no-till farming for future crops. The farmer continues researching to see what other factors may help reduce erosion.

Theory

As scientists conduct experiments and make observations to test a hypothesis, over time they collect a lot of data. If a hypothesis explains all the data and none of the data contradicts the hypothesis, the hypothesis becomes a **theory** .

A scientific theory is supported by many observations and has no major inconsistencies. A theory must be constantly tested and revised. Once a theory has been developed, it can be used to predict behavior. A theory provides a model of reality that is simpler than the phenomenon itself. Even a theory can be overthrown 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.

Watch this video to understand the difference between hypothesis and theory **(1f - I&E Stand.)** : http://www.youtube.com/watch?v=jdWMcMW54fA (6:39).



Click on the image above for more content

Science does not prove anything beyond a shadow of a doubt. Scientists seek evidence that supports or refutes an idea. If there is no significant evidence to refute an idea and a lot of evidence to support it, the idea is accepted. The more lines of evidence that support an idea, the more likely it will stand the test of time. The value of a theory is when scientists can use it to offer reliable explanations and make accurate predictions.

Scientific Models

A system, such as Earth's surface or climate, can be very complex and can be difficult for scientists to work with. Instead, scientists may create **models** to represent the real system that they are interested in studying.

Models are a useful tool in science. They help scientists efficiently demonstrate ideas and create hypotheses. Models are used to make predictions and conduct experiments without all of the difficulties of using real-life objects. Could you imagine trying to explain a plant cell by only using a real plant cell or trying to predict the next alignment of planets by only looking at them? But models have limitations that should be considered before any prediction is believed or any conclusion is seen as fact.

Models are simpler than real life representations of objects or systems. One benefit to using a model is that it can be manipulated and adjusted far more easily than real systems. Models help scientists understand, analyze, and make predictions about systems that would be impossible to study without using models. The simplicity of a model, which makes it easier to use than the actual system, is also the reason why models have limitations. One problem with a simpler model is that it may not predict the behavior of the real system very accurately.

Scientists must validate their ideas by testing. If a model is designed to predict the future, it may not be possible to wait long enough to see if the prediction was accurate. One way to test a model is to use a time in the past as the starting point and then have the model 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.

There are three types of models used by scientists.

1. Physical Models

Physical models are physical representations of the subject being studied. These models are typically smaller and simpler than the thing they are modeling, but they contain some of the important elements. A map or a globe are physical models of Earth and are smaller and much simpler than the real thing (**Figure** below).



Figure 1.6

The Unisphere in Queens, New York is a physical model of Earth but is very different from the real thing.

Conceptual Models

A **conceptual model** ties together many ideas in an attempt to explain a phenomenon. A conceptual model uses what is known and must be able to incorporate new knowledge as it is acquired (**Figure** below). For example, a lot of data supports the idea that the Moon formed when a Mars-sized planet hit Earth, flinging a great deal of debris and gas into orbit that eventually coalesced to create the Moon. A good working idea is a conceptual model.



Figure 1.7

A collision showing a giant meteor striking the Earth.

Mathematical Models

A **mathematical model** is an equation or set of equations that takes many factors or variables into account. Mathematical models are usually complex and often cannot account for not all possible factors (**Figure** below). These models may be used to predict complex events such as the location and strength of a hurricane.

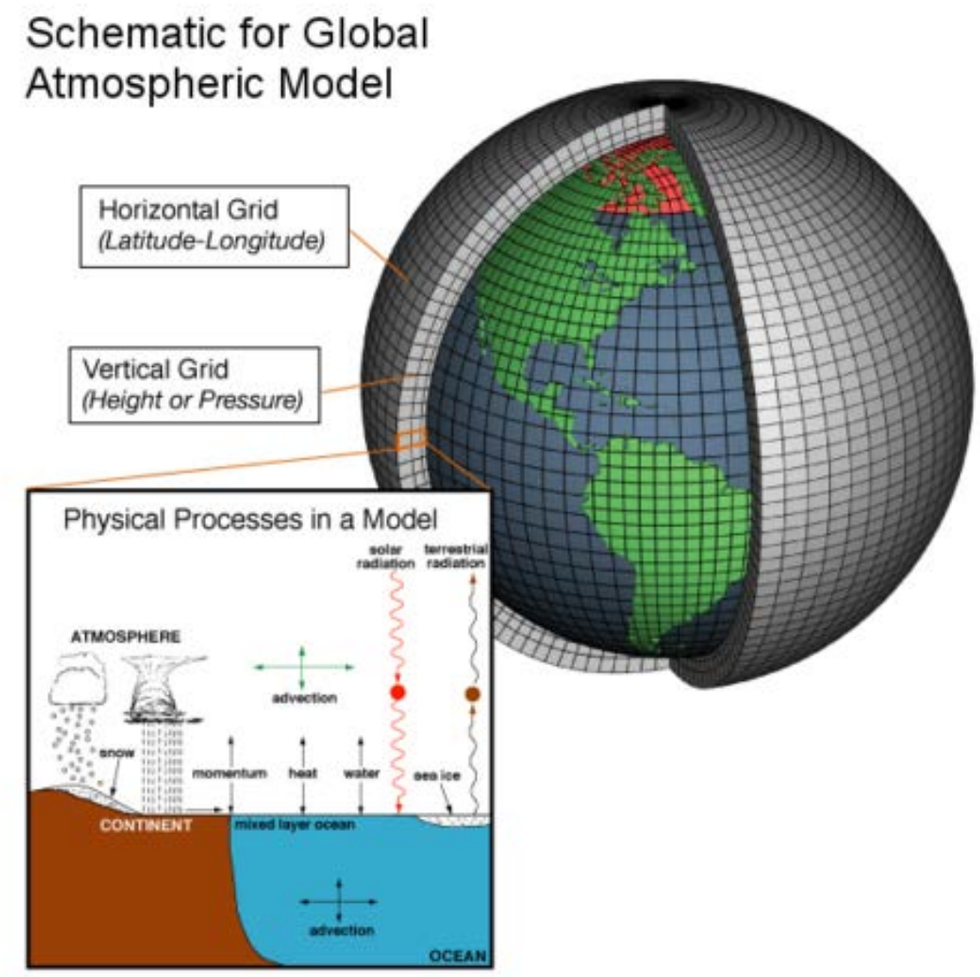


Figure 1.8

This climate model accounts for only a few factors in a small region of Earth. The best climate models are so complex that they must be created on supercomputers, and even they are simple compared to Earth's climate.

Modeling climate change is very complex because the model must take into account factors such as temperature, ice density, snow fall, and humidity. Many factors affect each other: If higher temperatures cause the amount of snow to decrease, the land surface is less able to reflect sunlight and temperature will increase more.

Systems

Systems are a kind of model. A system can be defined as a part of the universe that can be studied separately. In addition to this quality of being able to be studied separately, system models also include time as a variable; that is, we now measure things in real time and make models to describe what happened in the past and what might happen in the future. Scientists often describe the natural world by using models such as open and closed systems.

In a **closed system** , energy, such as sunlight, may enter, but matter doesn't enter or leave. An example of a closed system would be a sealed glass jar of iced tea. Energy, in the form of light, can enter. Energy can leave, too, as heat passes out through the glass walls of the jar. But if the jar is tipped over, the tea stays in. As a closed sytem, the jar of tea doesn't share matter with its surroundings.

In an **open system** , the system and its surroundings freely exchange both energy and matter. For example, the jar of iced tea would become an open system of the lid of the jar were to be removed, allowing some of the tea to evaporate. If a lemon slice were added, new matter would enter the system.

An island is a natural example of an open system. Sunlight (energy) strikes the island, warming it. The island returns some of the energy to the atmosphere in the form of heat. Rain (matter) falls on the island. The rain runs off, possibly carrying sediment (another type of matter) into the waters around it. The island exchanges matter and energy with its surroundings.

Earth system science is a means by which all the flows of energy and matter in and out of an open system are measured and related to all other open systems. Scientists consider Earth to be an essentially closed system. Earth receives radiant energy from the Sun and reflects much of it back into space (an exchange of energy). Earth is not an entirely closed system, however. The atmosphere loses hydrogen atoms to space and meteorites enter the atmosphere from space. Overall, however, Earth's mass remains constant. One consequence of Earth being an essentially closed system is that the planet's resources are finite: new matter is not going to form, and whatever matter exits on Earth is not going away.

The Importance of Community in Science

Scientific discovery is best when it is the work of a community of scientists. For a hypothesis to be fully accepted, the work of many scientists must support it. The scientific process has built-in checks and balances. In general, the scientific community does a good job of monitoring itself. While new ideas are often criticized, if continued investigation supports them, they will eventually become accepted.

Although each scientist may perform experiments in her lab alone or with a few helpers, she will write up her results and present her work to the community of scientists in her field (**Figure** below). Initially, she may present her data and conclusions at a scientific conference where she will talk with other scientists about those results.



Figure 1.9

High school students share their research results to NASA scientists at a poster session.

Using what she's learned, she will write a professional paper to be published in a scientific journal (**Figure** below). Before publication, several scientists will review the paper – called peer review – to suggest changes and then recommend or deny the paper for publication. Once it is published, other scientists in her field will learn about the work and will incorporate the results into their own research. They will try to replicate her results to prove whether the results are correct or incorrect. In this way, science builds toward a greater understanding of nature.



Figure 1.10

A peer-reviewed scientific journal.

The 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 Foundation 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. Considering all the scientific research that is done, there are few incidences of scientific dishonesty, yet these are often reported with great vehemence by the media. Often this causes the public to mistrust scientists in ways that are unnecessary. Scientists who do not have scientific integrity are strongly condemned by the scientific community.

Lesson Summary

- The goal of science is to ask and answer testable questions.
- Scientists use a sequence of logical steps, called the scientific method, which involves making observations, forming a hypothesis, testing that hypothesis, and forming a conclusion.
- Physical, conceptual, and mathematical models help scientists to discuss and understand scientific information and concepts.
- A scientific theory is a hypothesis that has been repeatedly tested and has not been proven false.

Review Questions

1. Write a list of five interesting scientific questions. Is each one testable?
2. A scientist was studying the effects of oil contamination on ocean seaweed. He thought that oil runoff from storm drains would keep seaweed from growing normally, so he decided to do an experiment. He filled two aquarium tanks of equal size with water and monitored the dissolved oxygen and temperature in each to be sure that they were equal. He introduced some motor oil into one tank and then measured the growth of seaweed in each tank. In the tank with no oil, the average growth was 2.57 cm. The average growth of the seaweed in the tank with oil was 2.37 cm. Based on this experiment:
    a. What was the question that the scientist started with?

b.What was his hypothesis?
c.Identify the independent variable, the dependent variable, and the experimental control(s).
d.What did the data show?
e.Can he be certain of his conclusion? How can he make his conclusion firmer?

3.Explain three types of scientific models. What is one advantage and one disadvantage of each?
4.Identify or design five of your own safety symbols, based on your knowledge of safety procedures in a science laboratory.
5.Design your own experiment based on one of your questions from question 1 above. Include the question, hypothesis, and independent and dependent variables. You may want to work with your teacher or a group.

•What types of models have you had experience with? What did you learn from them?
•What situations are both necessary and dangerous for scientists to study? What precautions do you think they should use when they study them?
•How does the scientific meaning of the word theory differ from the common usage? Can you find an example in the media of where the word was used incorrectly in a scientific story? The misuse of the word theory is rampant in the media and in daily life.

Further Reading / Supplemental Links

•An extremely good and detailed explanation of what science is and how it is done: http://undsci.berkeley.edu/article/0_0_0/us101contents_01 .
•BrainPOP features in-depth discussions of scientific inquiry, including text and movies: http://www.brainpop.com/science/ .
•An example of the use of scientific method to study greenhouse gases and tree growth is found here: http://forest.mtu.edu/kidscorner/face_nf.html . Or one to study the relationship of foot pain to the weather: http://www.brooklyn.cuny.edu/bc/ahp/AVC/SciMeth/VCB_SM_HP.html .

Points to Consider

Section 2

Earth Science and Its

Earth Science and Its Branches

Vocabulary

- Astronomy
- atmosphere
- biosphere
- climatology
- geology
- geosphere
- hydrosphere
- meteorology
- oceanography

Lesson Objectives

- Define and describe Earth science as a general field with many branches.
- Identify the field of geology as a branch of Earth science dealing with the solid Earth.
- Describe oceanography as a branch of Earth science that has several subdivisions that deal with the various aspects of the ocean.
- Define meteorology as a branch of Earth science that deals with the atmosphere.
- Understand that astronomy is an extension of Earth science that examines other parts of the solar system and universe.
- List some of the other branches of Earth science, and how they relate to the study of the Earth.

Introduction

Earth science is made of many branches of knowledge concerning all aspects of the Earth system. The main branches are geology, meteorology, climatology, oceanography, and environmental science. Astronomy uses principles understood from Earth to learn about the solar system, galaxy, and universe.

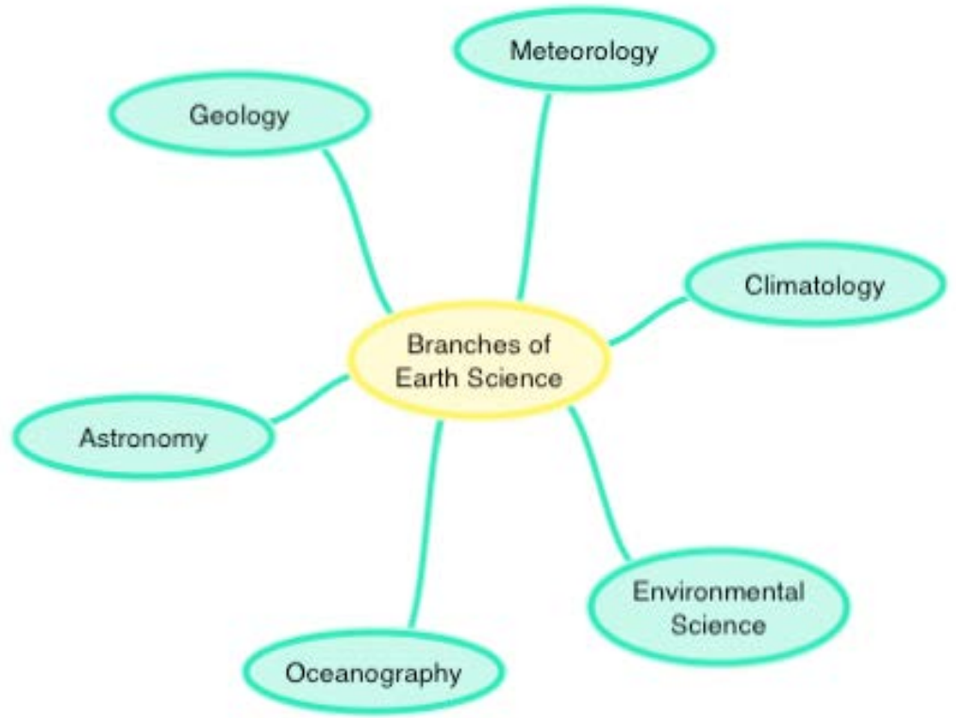


Figure 1.11

Overview of Earth Science

Only recently have humans begun to understand the complexity of our planet Earth. We have only known for a few hundred years that Earth is just a tiny part of an enormous galaxy, which in turn is a tiny part of an even greater universe.

Earth science deals with any and all aspects of the Earth: its lands, interior, atmosphere, and oceans. In all its wonder, Earth scientists seek to understand the beautiful sphere on which we live, shown in **Figure** below .



Figure 1.12

Earth as seen from Apollo 17.

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.

Geosphere

Geology is the study of the Earth's solid material and structures and the processes that create them. The earth itself- the rocks, mountains, the beaches, and all the ther physical features of the planet, except water--makes up the **geosphere** . 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.

Geology has many branches, only a few of which are described in **Figure** below . As you learn about each branch of geology, think of an interesting question that you might like to try to answer.



Figure 1.13

(a) Mineralogists study the composition and structure of minerals and may look for valuable minerals. (b) Planetary geologists study the geology of other planets. Lunar geologists study the Moon. (c) Seismologists study earthquakes and the geologic processes that create them. They monitor earthquakes worldwide to protect people and property. (d) Scientists interested in fossils are paleontologists.

Hydrosphere

The study of water and its movements, distribution and quality is hydrology. The **hydrosphere** contains all the water in the Earth system, including the water in the oceans, lakes, rivers and groundwater. The hydrosphere also includes the water locked up in ice and snow at the poles and in high mountains.

Most of Earth's water is salty. Only about 3 percent of the hydrosphere consists of fresh water, and most of that water (70 percent) is frozen, in the form of glacial ice. The remaining fresh water is found in groundwater, lakes, as soil moisture, as water vapor, and as river water. Of all the water in the hydrosphere, only about one half of one percent is useable freshwater.

All the water on Earth is continually recycled. The water you drank this morning may have irrigated a field last year, flowed through aqueducts during the time of the Roman Empire, or washed around the feet of a dinosaur standing at a river's edge millions of years ago.

Oceanography is more than just the hydrology of the oceans. Oceanography is the study of everything in the ocean environment, which covers about 70% of the Earth's surface (**Figure** below). Recent technology has allowed people and probes to venture to the deepest parts of the ocean, but still much of the ocean remains unexplored.



Figure 1.14

Physical oceanographers study the movements of ocean water such as currents, waves, and tides.

Marine geologists learn about the rocks and geologic processes of the ocean basins. An animation of underwater high-resolution sonar can be found here: http://oceanexplorer.noaa.gov/explorations/02fire/logs/jul06/media/abefly.html . Marine biologists study life in the oceans. (need plug-in)

Atmosphere

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 (**Figure** here).



Figure 1.15

Meteorologists forecast major storms to save lives and property.

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



Figure 1.16

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

The gaseous envelope surrounding Earth is the **atmosphere** . Composed of a mixture of gases, the atmosphere provides living things with oxygen and carbon dioxide. Other gases in the atmosphere absorb and altar rays from the sun, blocking potentially harmful radiation. Changing amounts of water vapor in the atmosphere results in areas of high or low humidity and influence the formation of clouds. Varying atmospheric pressure causes winds. Storms occur when water vapor, air pressure, and energy interact. The mix of gases in Earth's atmosphere supports the life forms that thrive on Earth's surface.

Biosphere

The interactions of the geosphere, atmosphere, and hydrosphere gave rise tot he conditions that support life. The living things on the planet compose the **biosphere** . Thebiosphere includes all living things, from single-celled protozoans to redwood trees to people. Human activities have changed the face of the geosphere, had an impact on the oceans,a nd altered the stmosphere. We are living proof that one sphere can affect another.

Environmental scientists study the effects people have on their environment, including the landscape, atmosphere, water, and living things (**Figure** here).



Figure 1.17

Every action people take has some effect on Earth's environment.



Figure 1.18

Interactions of Earth's four Spheres: atmosphere, hydrosphere, geosphere, and biosphere.

Astronomy

Astronomy is the study of the individual celestial bodies (excluding the earth) and of the universe as a whole. Astronomers are interested in outer space and the physical bodies beyond the Earth. They 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** here).



Figure 1.19

The Hubble Space Telescope.

Lesson 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.

Review Questions

1. What are three major branches of Earth science?
2. What branch of science deals with stars and galaxies beyond the Earth?
3. List some important functions of Earth scientists.

4.What is the focus of a meteorologist?
5.An astronomer has discovered a new planet. On the planet, she sees what appears to be a lava flow. With what type of scientist might she consult to help her figure it out?
6.An ecologist notices that an important coral reef is dying off. He believes that it has to do with some pollution from a local electric plant. What type of scientist might help him analyze the water for contamination?
7.Design an experiment that you could conduct in any branch of Earth science. Identify the independent variable and dependent variable. What safety precautions would you have to take?

Further Reading / Supplemental Links

•BrainPOP features in depth discussions of many topics in earth systems including text and movies: http://www.brainpop.com/science/earthsystem/ .
•USGS Online Lectures: Lectures 60-90 minutes long delivered by experts covering an enormous range of Earth science topics can provide detail on topics of interest to students and teachers. They can be found at http://education.usgs.gov/common/video_lectures.html .

Points to Consider

•Why is Earth science important?
•Which branch of Earth science would you most like to explore?
•What is the biggest problem that humans face today? Which Earth scientists may help us to solve the problem?
•How do the other branches of science impact Earth science?

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References

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11.Courtesy of Apollo 17 crew/NASA. Earth as seen from Apollo 17 . Public Domain
12.(a) JAVanfleet; (b) Courtesy of NASA; (c) Oleg Alexandrov; (d) Joanne Bourne; composite created by CK-12 Foundation. (a) https://commons.wikimedia.org/wiki/File:Clinohedrite2.jpg; (b) http://en.wikipedia.org/wiki/File:Moon-craters.jpg; (c) http://commons.wikimedia.org/wiki/File:Seismometer_at_Lick_Observatory.JPG; (d) http://www.flickr.com/photos/66992990@N00/116512454/sizes/l/ . (a) CC-BY 3.0; (b) Public Domain; (c) Public Domain; (d) CC-BY 2.0
13.Misty. http://www.flickr.com/photos/mistybushell/2161046983/sizes/o/ . CC-BY 2.0
14.Image courtesy of Jesse Allen/NASA's Earth Observatory. http://commons.wikimedia.org/wiki/File:Hurricane_Helene_2006.jpg . Public Domain
15.Walter Siegmund. http://en.wikipedia.org/wiki/File:Anacortes_Refinery_31911.JPG . CC-BY 2.5
16.Agunther. An example of a dam . CC-BY 3.0
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Ch. 2: The Universe, Galaxies and Stars



The Whirlpool Galaxy, also known as M51, is a spiral galaxy about 23 million light-years from Earth. Its interactions with the yellowish dwarf galaxy NGC 5195 are of interest to astronomers because the galaxies are near enough to Earth to be well-studied.

Decades ago astronomers could not tell if these two galaxies were just passing each other but radio astronomy has supplied astronomers with important data outlining their interactions. Using this data, astronomers have simulated the interaction. NGC 5195 came from behind and then passed through the main disk of M51 about 500 to 600 million years ago. The dwarf galaxy crossed the disk again between 50 and 100 million years ago and is now slightly behind M51. These interactions appear to have intensified the spiral arms that are the dominant characteristic of the Whirlpool Galaxy.

Astronomers are able to learn about objects unimaginably far away from Earth using telescopes that sense all wavelengths on the electromagnetic spectrum. Imagine what Galileo would do if he could see the images and data astronomers have available to them now.

Courtesy of NASA and European Space Agency. commons.wikimedia.org/wiki/File:Messier51_sRGB.jpg. Public Domain.

Section 1

The Universe

The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- Cosmic Microwave Background Radiation (CMB)
- cosmology
- dark energy
- dark matter
- Doppler Effect
- Hubble, Edwin
- Penzias and Wilson
- redshift
- universe

Introduction

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 allow people to 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** below) 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.

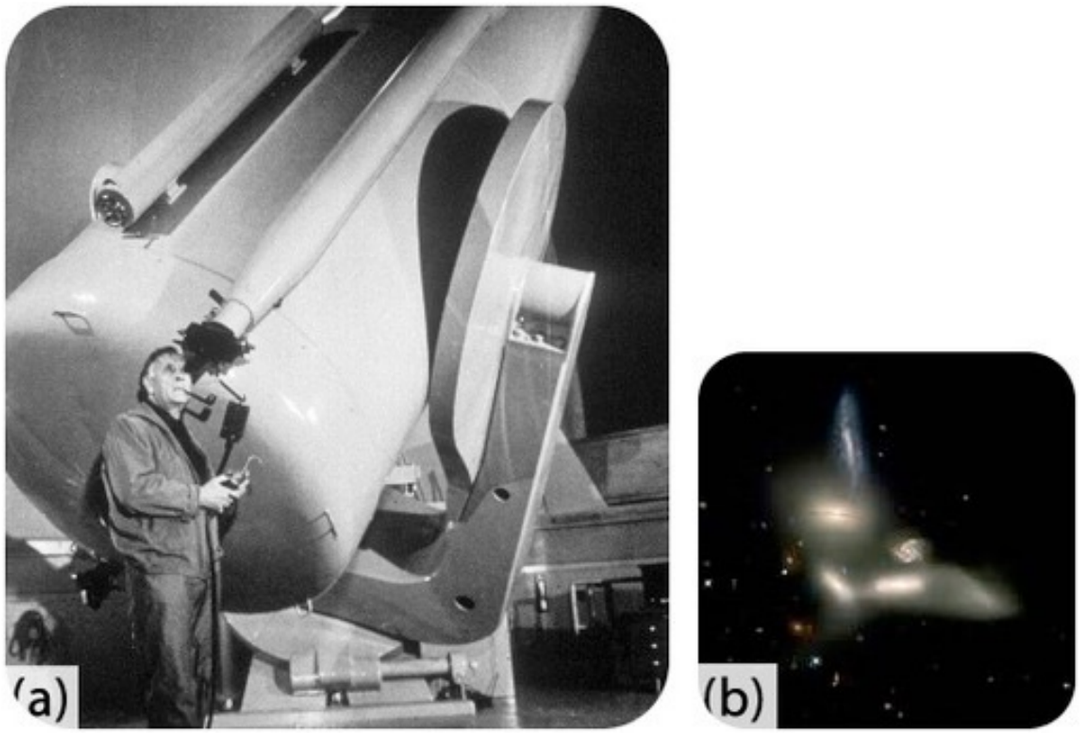


Figure 2.1

(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.

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.

Expansion of the Universe (First major discovery supporting the Big Bang Theory)

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** below . This shift of absorption bands toward the red end of the spectrum is known as **redshift** .

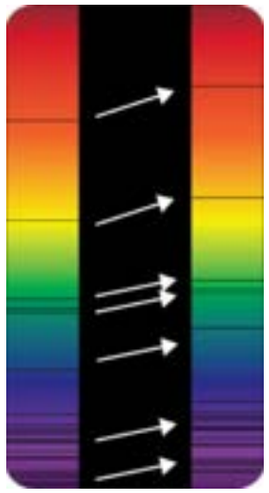


Figure 2.2

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.

Redshift can occur with other types of waves too. This phenomenon is called the **Doppler Effect** . An analogy to redshift is the noise a siren makes as it passes you. You may have noticed that an ambulance seems to lower the pitch of its siren after it passes you. The sound waves shift towards a lower pitch when the ambulance speeds away from you. Though redshift involves light instead of sound, a similar principle operates in both situations.

An animation of Doppler Effect http://projects.astro.illinois.edu/data/Doppler/index.html .

The Expanding Universe

So one of Edwin Hubble's first conclusions was that **almost every galaxy is moving away from our Milky Way Galaxy.** Then In 1929, Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a second 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 below 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.

Expansion of the Universe Diagram

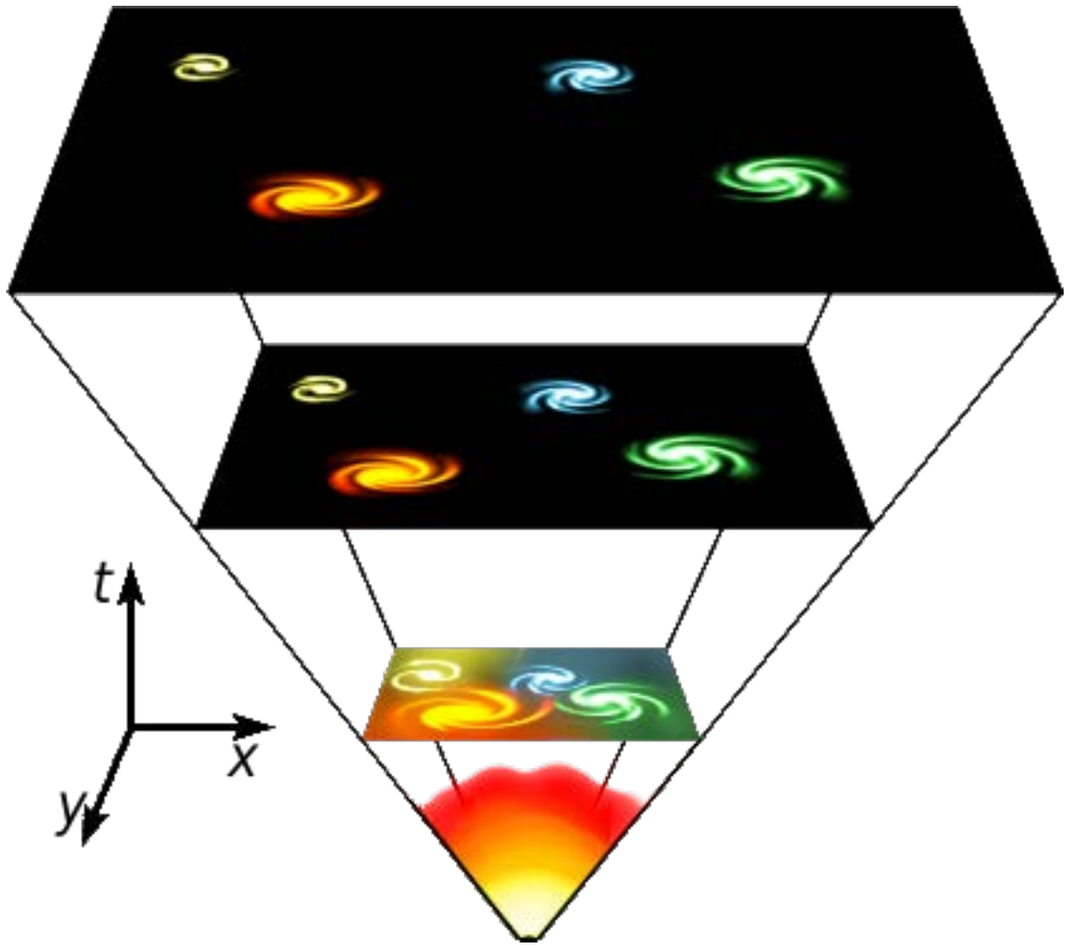


Figure 2.3

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.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies like 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 excellent animation of The Big Bang is here .

One other difference between the universe and a balloon involves the actual size of the galaxies. On balloon, the dots will become larger in size as you inflate it. In the universe, the galaxies stay the same size, just the space between the galaxies increases.

Edwin Hubble RAP (3:06)

Cosmic Microwave Background Radiation (Second major discovery supporting the Big Bang Theory)

The Cosmic Microwave Background Radiation (CMB) is often referred to as the "Echo" of the Big Bang.

On May 20, 1964, American radio astronomers Robert Wilson and Arno Penzias discovered the CMB, the ancient light that began saturating the universe 380,000 years after its creation. And they did so pretty much by accident.

Bell Labs' Holmdale Horn Antenna in New Jersey picked up an odd buzzing sound that came from all parts of the sky at all times. The noise puzzled Wilson and Penzias, who did their best to eliminate all possible sources of interference, even removing some pigeons and their droppings that were nesting in the antenna.

"When we first heard that inexplicable 'hum,' we didn't understand its significance, and we never dreamed it would be connected to the origins of the universe," Penzias said in a statement. "It wasn't until we exhausted every possible explanation for the sound's origin that we realized we had stumbled upon something big."

And it was indeed big. Penzias and Wilson had spotted the CMB, the predicted thermal echo of the universe's explosive birth. The

landmark find put the Big Bang theory on solid ground, suggesting that the cosmos did indeed grow from a tiny seed — a single point — about 13.8 billion years ago.

The two radio astronomers won the 1978 Nobel Prize in physics for their work.

Since their discovery, hundreds of experiments have been conducted to measure the radiation more precisely. Chronologically, 3 famous space satellites known as COBE, WMAP, and Planck have been refining its measurement.

What is it? The CMB, is radiation that fills the universe and can be detected in every direction. Created shortly after the universe came into being in the Big Bang, the CMB represents the earliest radiation (the very first "light") that can be detected. Astronomers have likened the CMB to seeing sunlight penetrating an overcast sky. It is the leftover heat from the Big Bang.

Looking out into deep space, and therefore back into deep time, astronomers see the CMB radiation saturating space beginning at about 378,000 years after the Big Bang. Before the creation of the CMB, the universe was a hot, dense and opaque plasma containing both matter and energy. Photons could not travel freely, so no light escaped from those earlier times. For that reason, the picture (seen below) provided by the satellites is called the "baby" picture of the universe. Though the CMB seemed at first to be very uniform in every direction, the observations have indicated shown slight variations. That's indicated by the picture below in blues, yellows and oranges. Most astronomers use this to explain why our universe is "lumpy," with its matter concentrated in our clusters and galaxies.

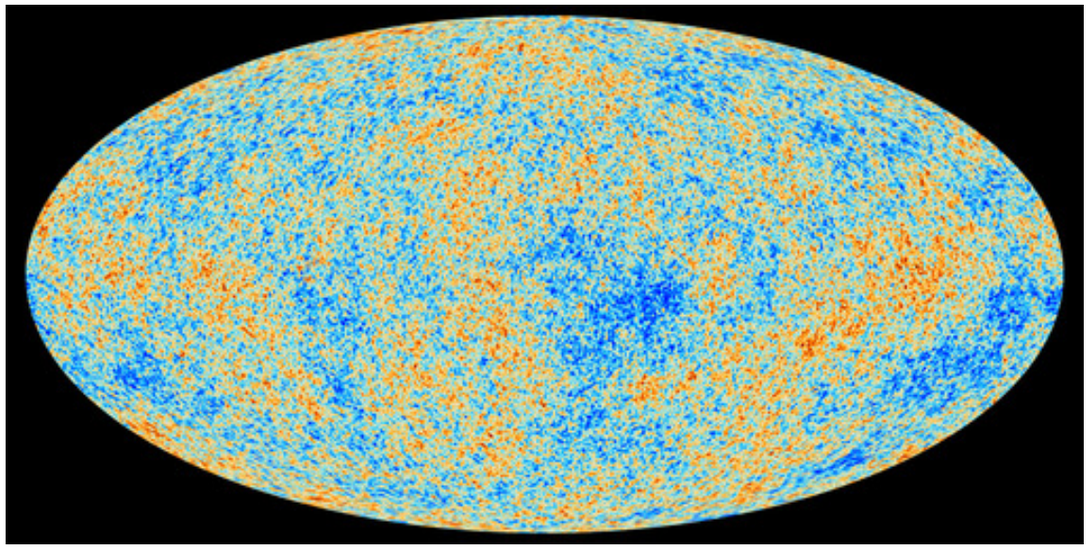


Figure 2.4

Plank satellite's CMB picture

Formation of the Universe

Before Hubble, most astronomers thought that the universe didn’t change. But if the universe is expanding, what does that say about where it was in the past? If the universe is expanding, the next logical thought is that in the past it had to have been smaller.

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 13.8 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.

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** below).



Figure 2.5

Images from very far away show what the universe was like not too long after the Big Bang.

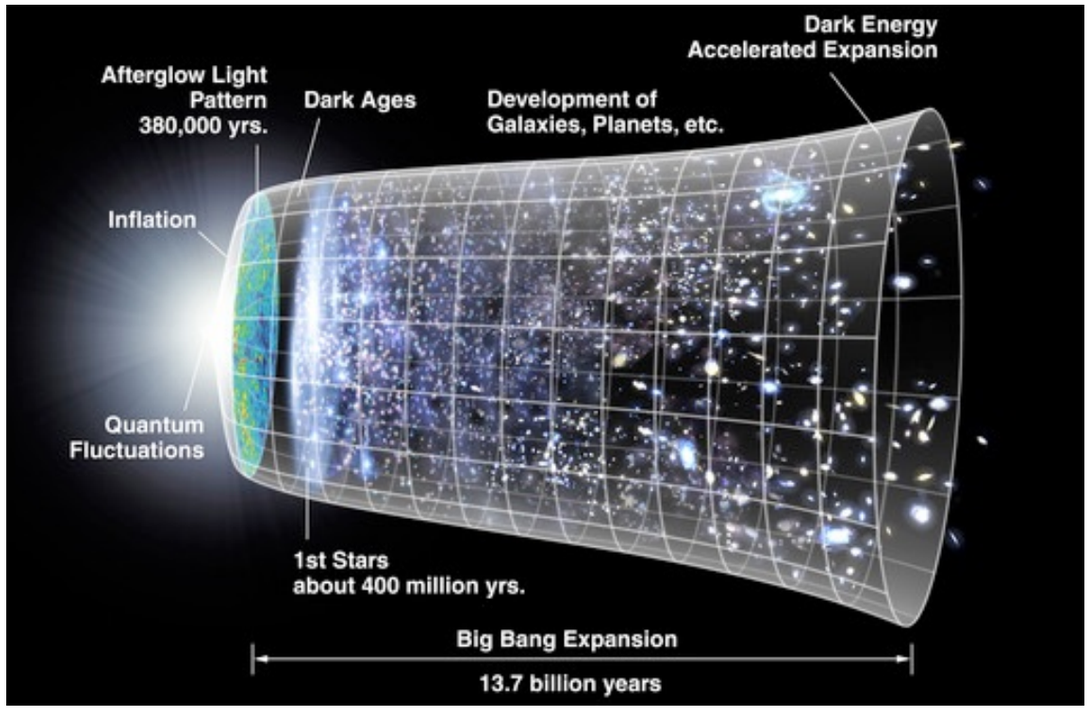


Figure 2.6

The Big Bang Timeline

The diagram above is an excellent representation of the history of our universe. The term inflation refers to the explosively rapid expansion of space-time that occurred a tiny fraction of a second after the Big Bang. In another tiny fraction of a second, inflation slowed to a more leisurely expansion that continues to this day and is accelerating.

History of our Universe Made Easy, Part 1 (9:24)

History of our Universe Made Easy, Part 2 (8:06)

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).



Click on the image above for more content

Dark Matter and Dark Energy

The Big Bang theory is still the best scientific model we have for explaining the formation of the universe and many lines of evidence support it. However, recent discoveries continue to shake up our understanding of the universe. Astronomers and other scientists are now wrestling with some unanswered questions about what the universe is made of and why it is expanding. A lot

of what cosmologists do is create mathematical models and computer simulations to account for these unknown phenomena.

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 85%, 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. This particular discovery was made by astronomer Vera Rubin in the 1970's.



Figure 2.7

Vera Rubin

Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object (**Figure** below). To explain strong gravitational lensing, more matter than is observed must be present.

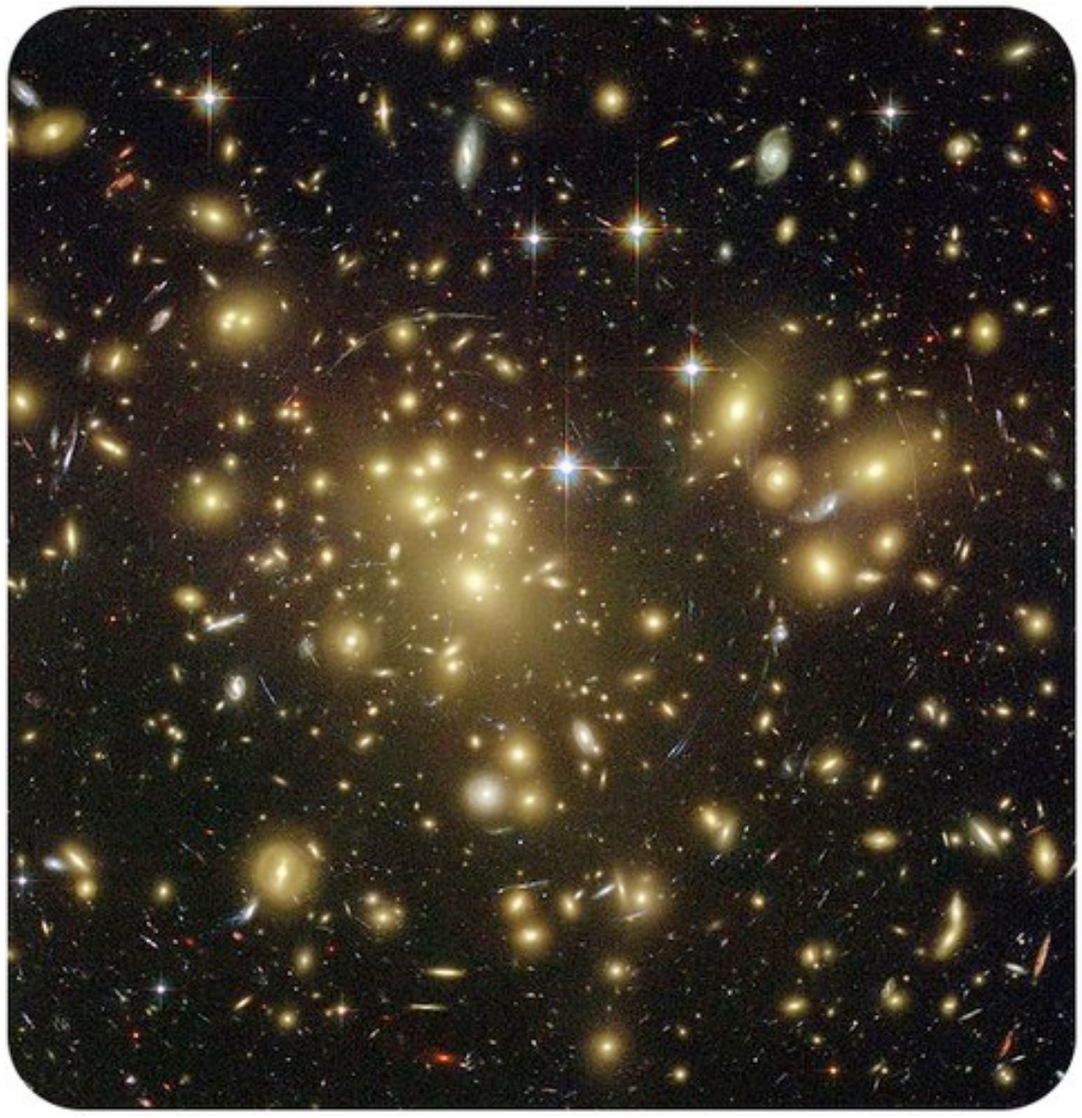


Figure 2.8

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 thought to be much 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.

What is Dark Matter? (animation, 6:11)

What is Dark Matter? A Mystery of the Universe (5:33)

Dark Matter 3D map (3:11)

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** below). Some scientists think that dark energy makes up as much as 68% of the total energy content of the universe.

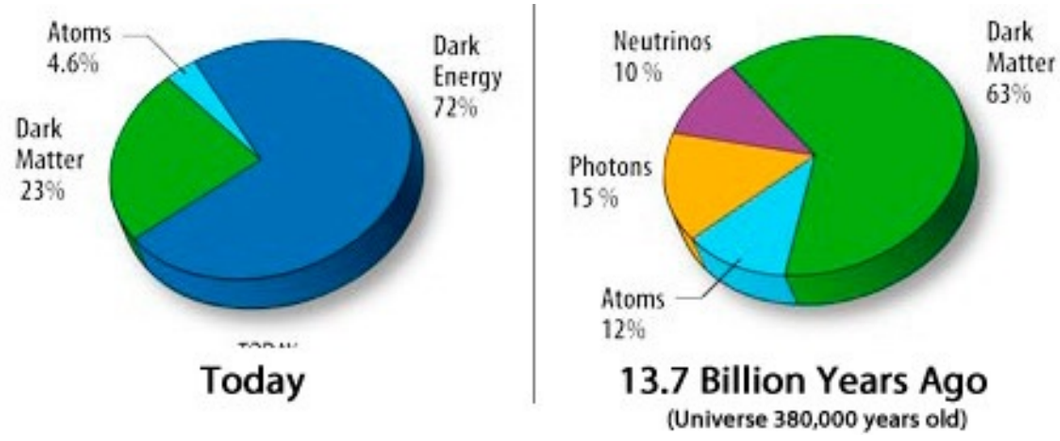


Figure 2.9

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.

What is Dark Energy? (SciShow, 3:46)

Big Mysteries: Dark Energy (FermiLab, 7:42)

Dark Energy (Minute Physics, 1:38)

Dark Matter and Dark Energy (45 min.)

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/ .



Click on the image above for more content

Lesson Summary

- The universe contains all the matter and energy that exists now, that existed in the past, and that will exist in the future. The universe also includes all of space and time.
- Redshift is a shift of element lines toward the red end of the spectrum. Redshift occurs when the source of light is moving away from the observer.
- Light from almost every galaxy is redshifted. The farther away a galaxy is, the more its light is redshifted, and the faster it is moving away from us.
- The redshift of galaxies means that the universe is expanding.

•The universe was squeezed into a very small volume and then exploded in the Big Bang theory about 13.7 billion years ago.
•Recent evidence shows that there is a lot of matter in the universe that we cannot detect directly. This matter is called dark matter.
•The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Review Questions

1. What is redshift, and what causes it to occur? What does redshift indicate?

2. What is Hubble's law?

3. What is the cosmological theory of the formation of the universe called?

4. How old is the universe, according to the Big Bang theory?

5. Describe two different possibilities for the nature of dark matter.

6. What makes scientists believe that dark matter exists?

7. What observation caused astronomers to propose the existence of dark energy?

Further Reading / Supplemental Links

•The science of dark matter: http://cdms.berkeley.edu/Education/DMpages/index.shtml
•More about cosmology: http://stardate.org/resources/btss/cosmology/
•The Big Bang: http://hurricanes.nasa.gov/universe/science/bang.html

Points to Consider

•The expansion of the universe is sometimes modeled using a balloon with dots marked on it, as described earlier in the lesson. In what ways is this a good model, and it what ways does it not correctly represent the expanding universe? Can you think of a different way to model the expansion of the universe?
•The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

Stars

Stars

Lesson Objectives

- Define constellation.
- Describe the flow of energy in a star.
- Classify stars based on their properties.
- Outline the life cycle of a star.
- Use light-years as a unit of distance.

Vocabulary

- absolute magnitude (M)
- alpha particle
- apparent magnitude (m)
- asterism
- binary stars
- black hole
- celestrial object
- Cepheid variable
- constellation
- eclipsing binary
- Hertzsprung-Russell (HR) diagram
- Leavitt, Henrietta
- light year
- luminosity (L)
- main sequence star
- nebula
- neutron star
- nuclear fusion reaction
- parallax
- particle accelerator
- period-luminosity relation
- planetary nebula
- protostar
- pulsar
- red giant
- star
- stellar evolution
- supernova
- white dwarf

Introduction

Introduction to Astronomy (4:45)

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. Every star that you see by eye is a star in our Milky Way Galaxy. About 1/3rd of them are actually **binary stars.** 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 below shows one of the most easily recognized constellations.



Figure 2.10

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".

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 (ly), which is relatively close to Earth, to several thousand light years away.

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy and 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 and temperature 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, four hydrogen protons, in a series of steps, fuse to become an helium nucleus (an alpha particle). Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (**Figure** below). The energy from a nuclear fusion comes from the end result of the reaction turning a small amount of mass into a huge amount of energy as by Albert Einstein's famous equation, $E = mc^2$.



Figure 2.11

A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

The process of nuclear fusion can be followed in this animation: https://www.youtube.com/watch?v=Cb8NX3HiS4U .

An animation for the Proton-Proton chain reaction which occurs in stars < 1.3 x our Sun's mass (symbolized $M_\odot$) : http://astro.unl.edu/classaction/animations/sunsolarenergy/fusion01.html

For more in-depth information about hydrogen fusion in stars, go here: http://bcs.whfreeman.com/universe7e/content/ch18/Look_Deep18-1.pdf .

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity thus stabilizing the star. 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** below).

Figure 2.12

A diagram of a star like the Sun.

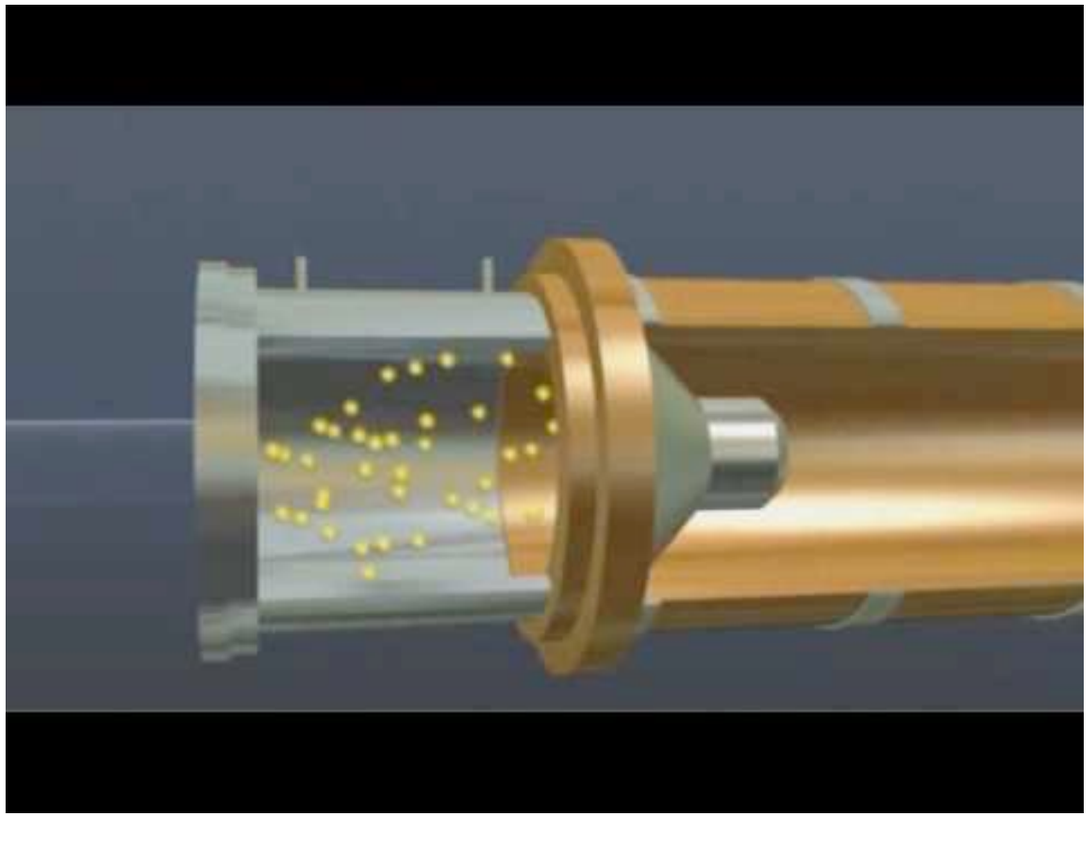
In particle accelerators, subatomic particles are propelled until they have attained almost the same amount of energy as found in the core of a star (**Figure** below). When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium to be produced from the collision of four hydrogen nuclei in the first few minutes of the universe.



Figure 2.13

The SLAC National Accelerator Lab in California can propel particles a straight 2 mi (3.2 km).

The CERN Large Hadron Collider (LHC) 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).



Click on the image above for more content

How Stars Differ

Size

Our Sun is an average, mid-size, middle aged yellow star. It's diameter is 1.392 million km (865,000 miles). You could line up 109 Earths across the face of it. Stars have been found that range in size from 0.1 x our Sun's diameter to 1700 x its diameter. In terms of mass, compared to our Sun's mass (symbolized $M_\odot$), the largest known star is 260 x $M_\odot$. The lifetime of a star is depends solely on its mass. The more massive the star, the shorter its lifetime. Big stars use up their supply of H very quickly. Our Sun will exist for 10 billion years on the Main Sequence (see the

HR diagram below). A star that is 60 x $M_\odot$ will only live 3 million years, while a 0.1 x $M_\odot$ star will live from 6 to 12 trillion years.

Click here for a video that compares sizes of stars.

Brightness

When you go outside and look at a star, you really cannot tell how truely bright it really is. A dim star can appear bright if it is close to our solar system while a really bright star can appear dim if it is very far away. To help understand astronomers use three related phases, **apparent magnitude (m), absolute magnitude (M), and luminosity (L)** .

Apparent magnitude is how bright the star or celestial object appears to an observer on Earth. When the Greeks developed the system, they used a scale of 1 to 6, with m = 1 (first magnitude) being the brightest and m = 6 being barely visible. Today, t he modern system is no longer limited to 6 magnitudes or only to visible light. But we still use the rule that the higher the number, the dimmer the object. So, very bright objects have *negative* magnitudes. For example, Sirius , the brightest star of the celestial sphere , has an apparent magnitude of –1.4. The modern scale includes the Moon and the Sun . The full Moon has a mean apparent magnitude of –12.74 and the Sun has an apparent magnitude of –26.74.

Absolute magnitude is the apparent magnitude a star would have IF it was moved from its actual location to a point 32.6 light-years (ly) away from Earth. This allows the true energy output of astronomical objects to be compared without regard to their variable distances. The absolute magnitude uses the same conventions as the apparent magnitude: brighter objects have smaller magnitudes.

Luminosity is the total amount of energy emitted by a star , galaxy , or other astronomical object per unit time. It is the true indication of the brightness of a star. It depends on **BOTH** the star's temperature and its radius (surface area):

- A hotter star is more luminous than a cooler one of the same radius.
- A bigger star is more luminous than a smaller one of the same temperature.

Absolute magnitude and luminosity are directly related. Luminosity is often indicated as how bright an object is compared to our Sun, which is given a luminosity of 1.

Variable Stars

A **variable star** is a star whose brightness as seen from Earth (its apparent magnitude) fluctuates. This could happen for a variety of reasons. Examples include:.

- **Eclipsing binaries -** double stars where, as seen from Earth's vantage point, the two stars eclipse one another as they orbit. Here is a video of an artist's impression of eclipsing binaries.
- **Pulsating variables -** stars whose radius alternately expands and contracts as part of their natural evolutionary ageing processes. Of these, one of the most important types is the **Cepheid variable.** See the section below entitled "Measuring Star Distances."

Color and Temperature

The many different colors of stars reflect the star's temperature. In Orion (as shown in the **Figure** above) 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.

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** below).

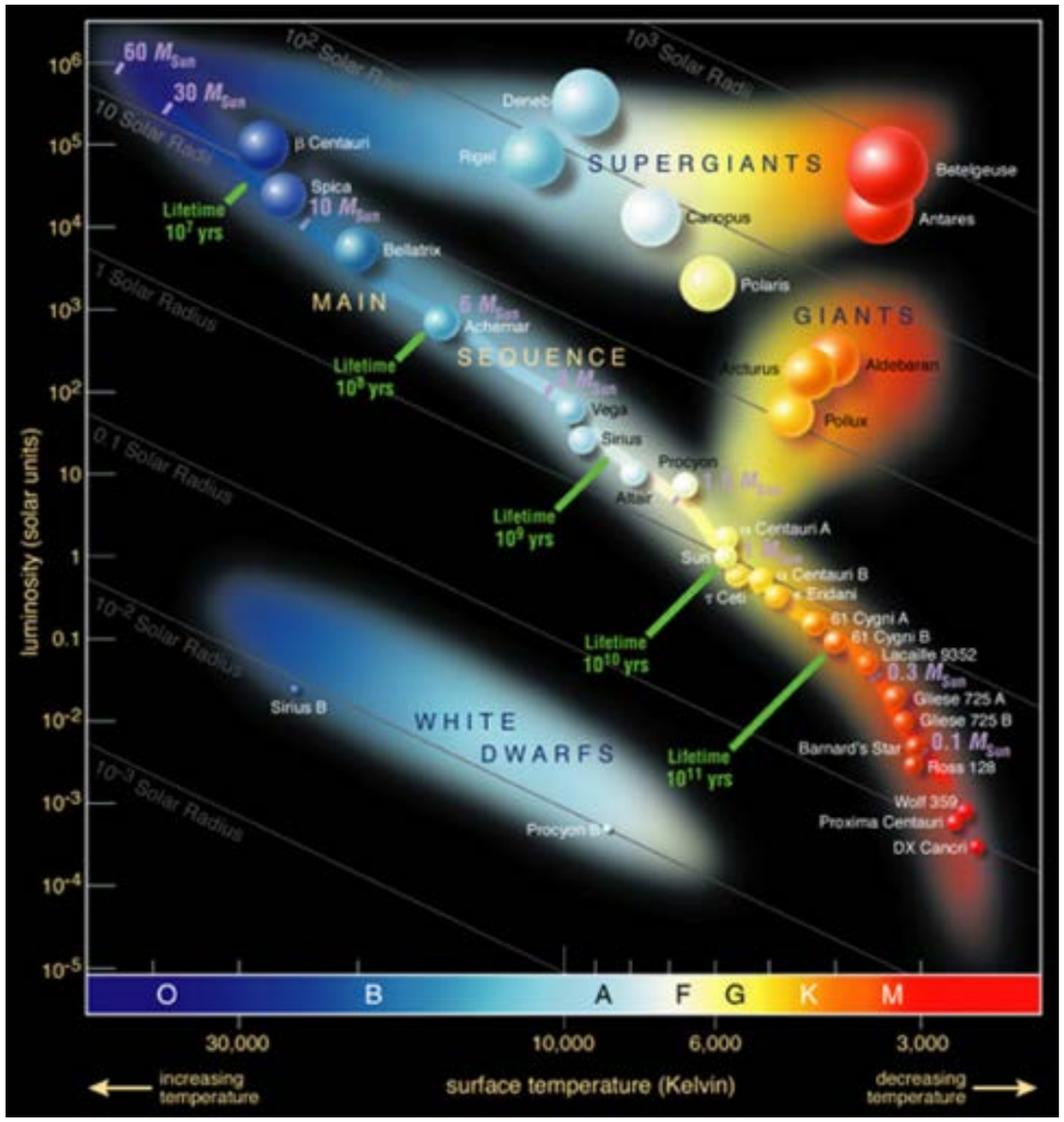


Figure 2.14

A Hertzsprung-Russell (HR) diagram shows the brightness and color of stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in 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** below 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.

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
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. These stars tend toward bluish white. Smaller stars produce less energy. Their surfaces are less hot and so they tend to be yellowish.

Lifetime of Stars

Stars have a life cycle called **stellar evolution** that is expressed similarly to the life cycle of a living creature: they are born, grow, change over time, and eventually 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 the Solar System chapter, stars are born in clouds of gas and dust called nebulas, like the one shown in **Figure** below . As the cloud gets denser and denser in the center, but before it reaches the temperatures and pressures needed to start H fusion, this future star is referred to as a **protostar.**

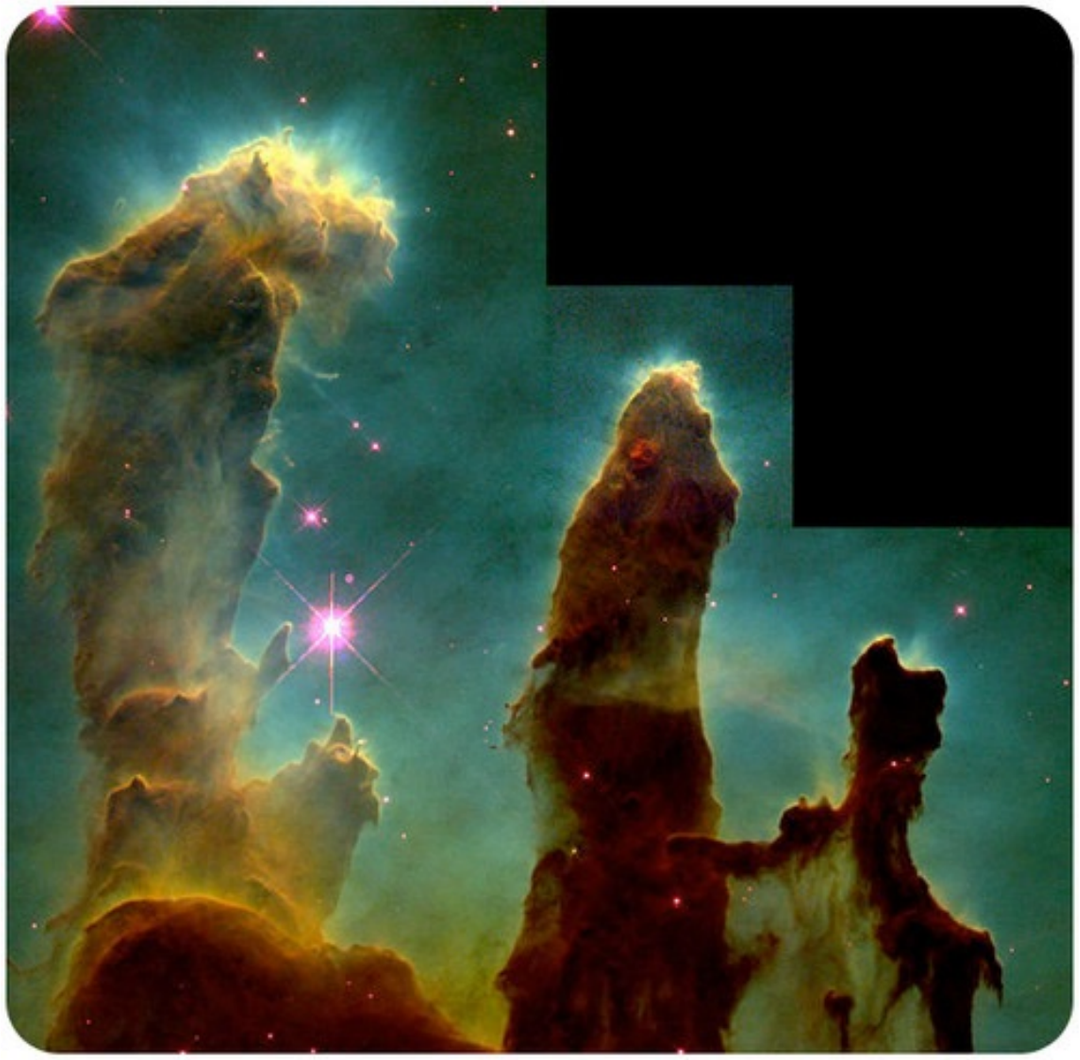


Figure 2.15

The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

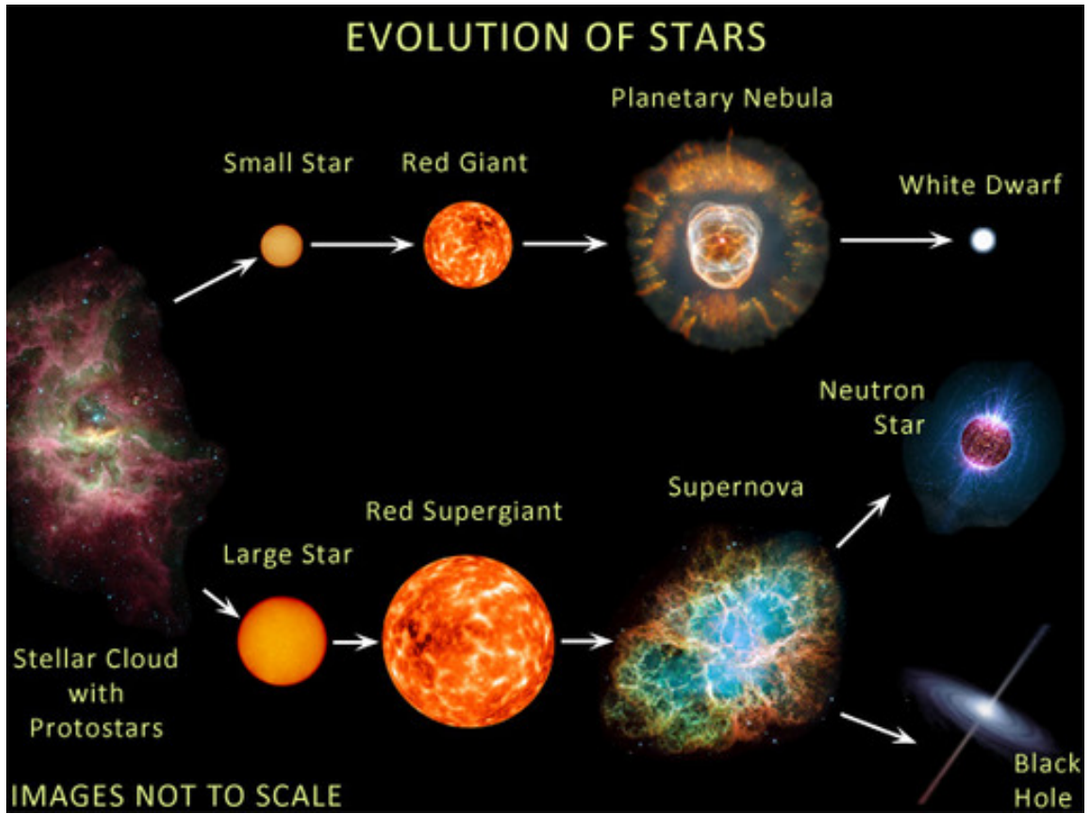


Figure 2.16

The evolution and fate of stars.

For more on star formation, check out http://www.spacetelescope.org/science/formation_of_stars.html or The Lives of Stars .

The Main Sequence

Once fusion begins, the star starts on the HR diagram (figure above) as a **main sequence** star. For most of a star's life, nuclear fusion in the core produces helium from hydrogen. For stars on the main 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. Most often this happens when the star cannot fuse H in its core anymore. 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 4.6 billion years and will continue on the main sequence for about 5 billion more years (**Figure** below). 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 2.17

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/10245-sun-die-earth.html .

Red Giants and White Dwarfs (Fate of stars r oughly 0.3–8 x $M_\odot$)

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 a transitional phase. When the light elements are mostly used up the star can no longer resist gravity and it 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. Toward the end of this stage, the outer layers of the star are expelled by strong stellar winds. These layers form a **planetary nebula,** a kind of nebula consisting of an expanding glowing shell of ionized gas ejected from the red giant. Gravitational collapse then shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (**Figure** below). A white dwarf will cool, and ultimately fade out.

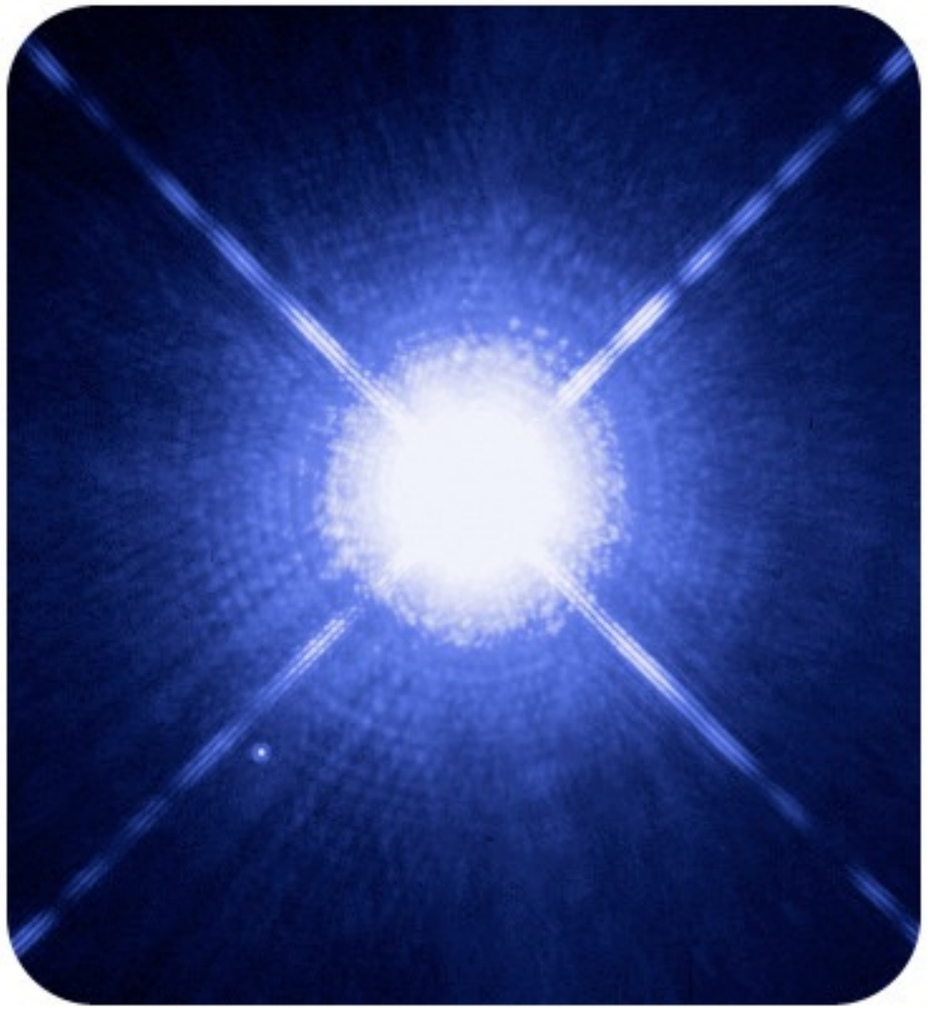


Figure 2.18

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 (Fate of stars > 8 x M ⊙)

A massive 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** below).



Figure 2.19

The red star Betelgeuse in Orion is a red supergiant.

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** below). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. All atoms of any elements whose atomic number is greater than iron ($_{26}$Fe) were formed. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of helium were formed by nuclear fusion in stars.

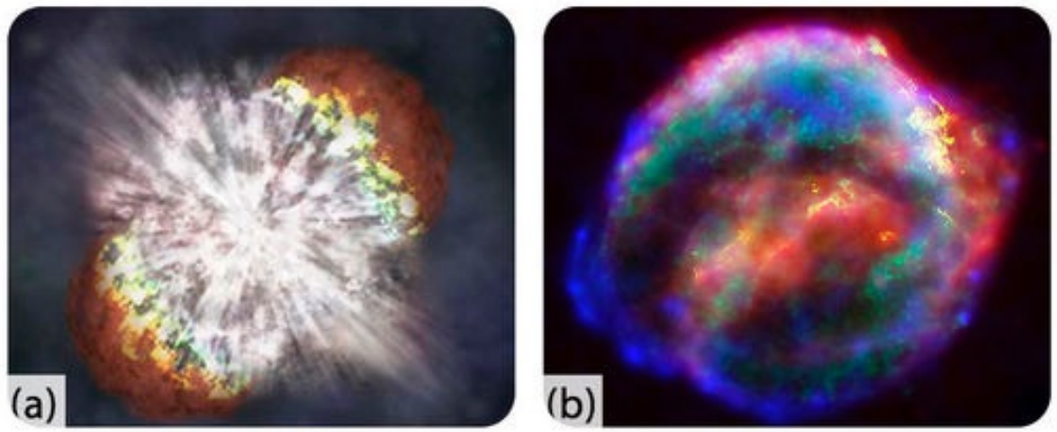
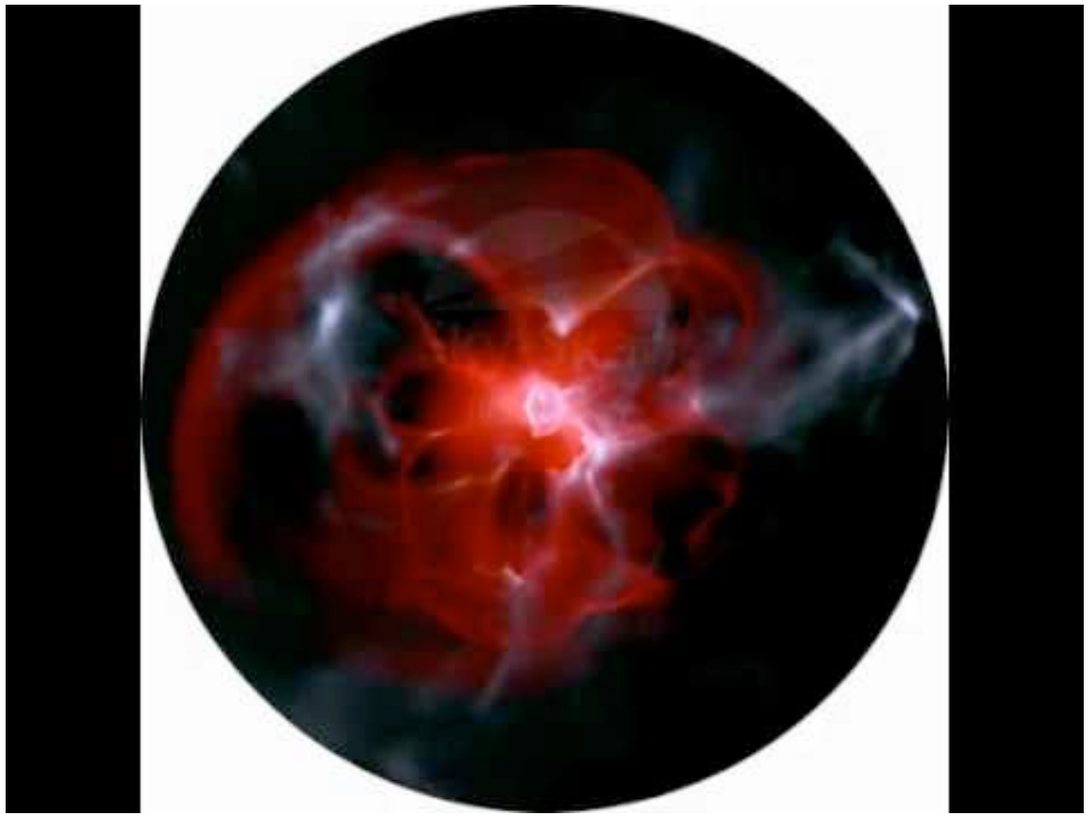


Figure 2.20

(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.

An animation of the Crab Supernova is seen here: http://www.youtube.com/watch?v=eE8QkBlyf5k .

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 (8:30).



Click on the image above for more content

Neutron Stars and Black Holes

After a supernova explosion, the leftover material in the core is extremely dense. If the **core** is less than about three times the mass of the Sun, the star becomes a **neutron star** (**Figure** below). A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge. A special type of neutron star is a pulsar. Learn about neutron stars and pulsars here .

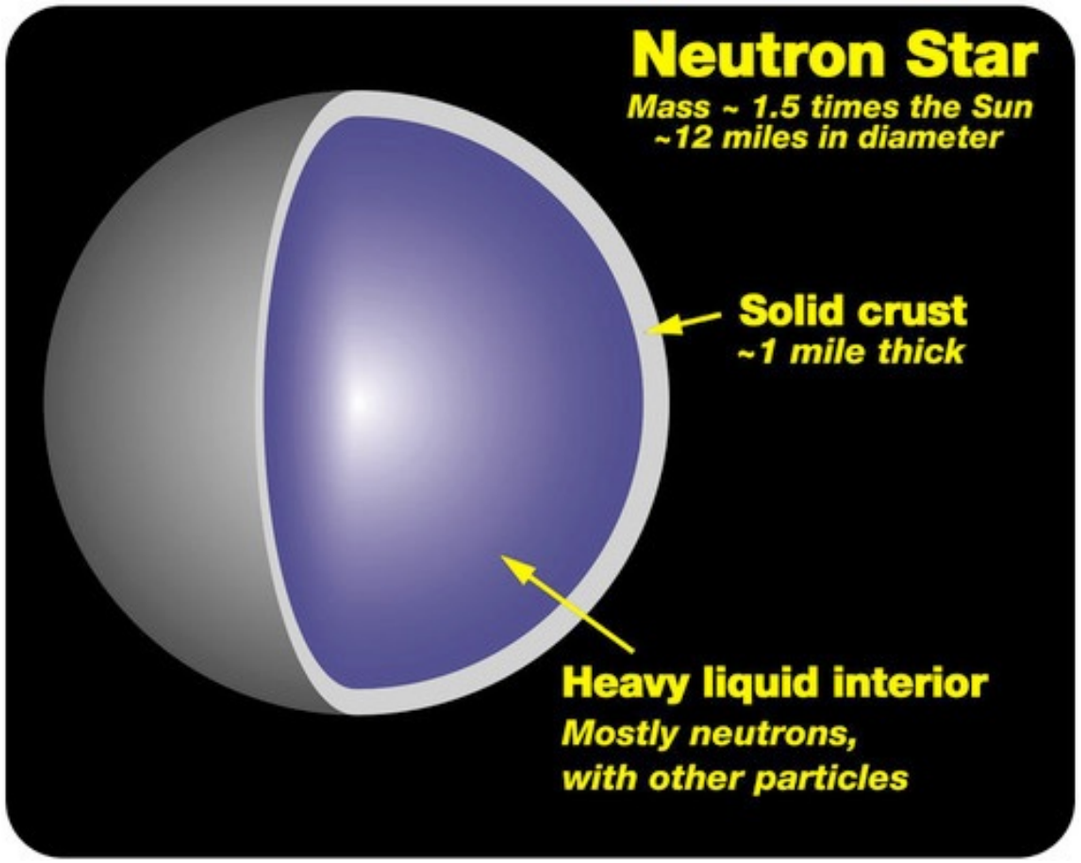


Figure 2.21

After a supernova, the remaining core may end up as a neutron star. A neutron star is more massive than the Sun, but only a few kilometers in diameter.

If the core remaining after a supernova is more than three 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/10033-black-holes-form.html .

A video about black holes is seen on Space.com: http://www.space.com/19520-black-holes-warping-time-space-video.html .

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).



Click on the image above for more content

Another video about neutron stars is available at: http://www.youtube.com/watch?v=VMnLVkV_ovc (4:24).



Click on the image above for more content

Measuring Star Distances

A commonly used unit for measuring distances in space is the light year. A light year is equal to the distance that a beam of light can travel in one year. One light year (ly) = 9.5 x 10^{12} km or 5.9 x 10^{12} miles. The light from our Sun takes 8.3 minutes to travel the 1.5 x 10^{8} km to Earth. Our nearest star, Proxima Centauri, is 4.24 ly away.

How can you measure the distance of an object that is too far away to measure? Now what if you don't know the size of the object or the size or distance of any other objects like it? That would be very difficult, but 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** below 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 .

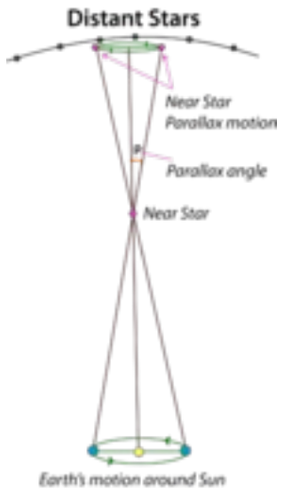


Figure 2.22

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.

Cepheid variables, mentioned above, are also used to determine distances to stars and to galaxies. In 1912 *Henrietta Leavitt* (1868--1921) below (for more info about her) published the results of her study of variable stars in the Large and Small Magellanic Clouds. These are two small satellite galaxies orbiting the Milky Way. Leavitt found a very useful relationship fo **r** Cepheid variables. The fainter Cepheids in the Magellanic Clouds have shorter periods. Because all of the Cepheids in a Magellanic Cloud are at the same distance from us, Leavitt reasoned that the more *luminous* Cepheids pulsated more slowly. This is the **period-luminosity relation** . By using this relation, combined with other measurable information, we can determine intergalatic distances.



Figure 2.23

Henrietta Leavitt

Henrietta Leavitt video

Lesson Summary

- Constellations and asterisms are apparent patterns of stars in the sky.
- Stars in the same constellation are often not close to each other in space.
- A star generates energy by nuclear fusion reactions in its core.
- The brightness of a star is measured in three ways.

•The color of a star is determined by its surface temperature.
•Stars are classified by color and temperature: O (blue), B (bluish white), A (white), F (yellowish white), G (yellow), K (orange), and M (red), from hottest to coolest.
•Stars form from nebulas. Gravity causes stars to collapse until nuclear fusion begins.
•Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
•Typical, Sun-like stars expand into red giants, then fade out as white dwarfs.
•Very large stars expand into red supergiants, explode in supernovas, and end up as neutron stars or black holes.
•Parallax is an apparent shift in an object's position when the position of the observer changes. Astronomers use parallax to measure the distance to relatively nearby stars.

Review Questions

1.What distinguishes a nebula and a star?
2.What kind of reactions provide a star with energy?
3.Stars are extremely massive. Why don't they collapse under the weight of their own gravity?
4.Of what importance are particle accelerators to scientists?
5.Which has a higher surface temperature: a blue star or a red star?
6.List the seven main classes of stars, from hottest to coolest.
7.What is the main characteristic of a main sequence star?
8.What is the difference between the 4 groups on a HR diagram?
9.What kind of star will the Sun be after it leaves the main sequence?
10.Suppose a large star explodes in a supernova, leaving a core that is 10 times the mass of the Sun. What would happen to the core of the star?
11.Since black holes are black, how do astronomers know that they exist?
12.What is the difference between a neutron star and a pulsar?
13.What is a light year?
14.Why don't astronomers use parallax to measure the distance to stars that are very far away?

Further Reading / Supplemental Links

•Myths and history of constellations: http://www.ianridpath.com/startales/contents.htm
•NASA, parts of a star: http://imagine.gsfc.nasa.gov/docs/science/know_l1/stars.html

Points to Consider

•Although stars may appear to be close together in constellations, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
•Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

Section 3

Galaxies

Galaxies

Lesson Objectives

- Distinguish between star systems and star clusters.
- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.
- Learn about larger structures in our universe.

Vocabulary

- Andromeda Galaxy
- barred spiral galaxy
- binary star
- central bulge
- dwarf galaxy
- elliptical galaxy
- galactic cluster
- galactic disk
- galactic group
- galactic halo
- galaxy
- globular cluster
- interacting galaxies
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster
- star system
- supercluster
- voids

Introduction

Where do you live? Sure you live in a house or apartment, on a street, in a town or city, in a state, and in a country. You may not think to mention that you live on planet Earth in the solar system (as if there is no other), which is in the Milky Way Galaxy. Our galaxy is just one of many billions of galaxies in the universe. These galaxies are incomprehensible distances from each other and from Earth.

Star Systems and Star Clusters

Although constellations have stars that usually only appear to be close together, stars may be found in the same portion of space. Stars that are grouped closely together are called **star systems** . Larger groups of hundreds or thousands of stars are called **star clusters** .

Star Systems

Although the star humans know best is a single star, it is estimated that approximately 1/3 of the star systems in our Milky Way galaxy are binary or multiple systems. A system of two stars orbiting each other is a **binary star** . A system with more than two stars orbiting each other is a multiple star system. The stars in a binary or multiple star system are often so close together that they

appear as one and only through a telescope can the pair be distinguished.

An animation of a solar system like ours but with two suns was created by NASA: http://www.spitzer.caltech.edu/video-audio/852-ssc2007-05v1-Two-Suns-Raise-Family-of-Planetary-Bodies-

Star Clusters

Star clusters are divided into two main types, **open clusters** and **globular clusters** . Open clusters are groups of up to a few thousand stars that are loosely held together by gravity. The Pleiades, shown in **Figure** below , is an open cluster that is also called the Seven Sisters.



Figure 2.24

In the Pleiades, seven stars can be seen without a telescope, but the cluster has close to a thousand stars.

Open clusters tend to be blue in color and often contain glowing gas and dust. Why do you think that open clusters have these features? Open clusters are made of young stars that formed from the same nebula. The stars may eventually be pulled apart by gravitational attraction to other objects. Open clusters are found in a galaxy's disk.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. **Figure** below shows an example of a globular cluster. Globular clusters have a definite, spherical shape and contain mostly reddish stars. The stars are closer together, closer to the center of the cluster. Globular clusters don't have much dust in them — the dust has already formed into stars. The stars are much older than the stars in open clusters. Globular clusters are found in the halo of a galaxy where they orbit the galatic core as a satellite. The Milky Way galaxy has around 160 globular clusters, while the larger Andromeda galaxy may have as many as 500.

Check out http://messier.seds.org/cluster and http://hubblesite.org/newscenter/archive/releases/star-cluster/ for more information about star clusters.



Figure 2.25

M80 is a large globular cluster containing hundreds of thousands of stars. Note that the cluster is spherical and contains mostly red stars.

Types of 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** below — looks like only a dim, fuzzy spot.. But that fuzzy spot contains one trillion stars -- 1,000,000,000,000 stars!

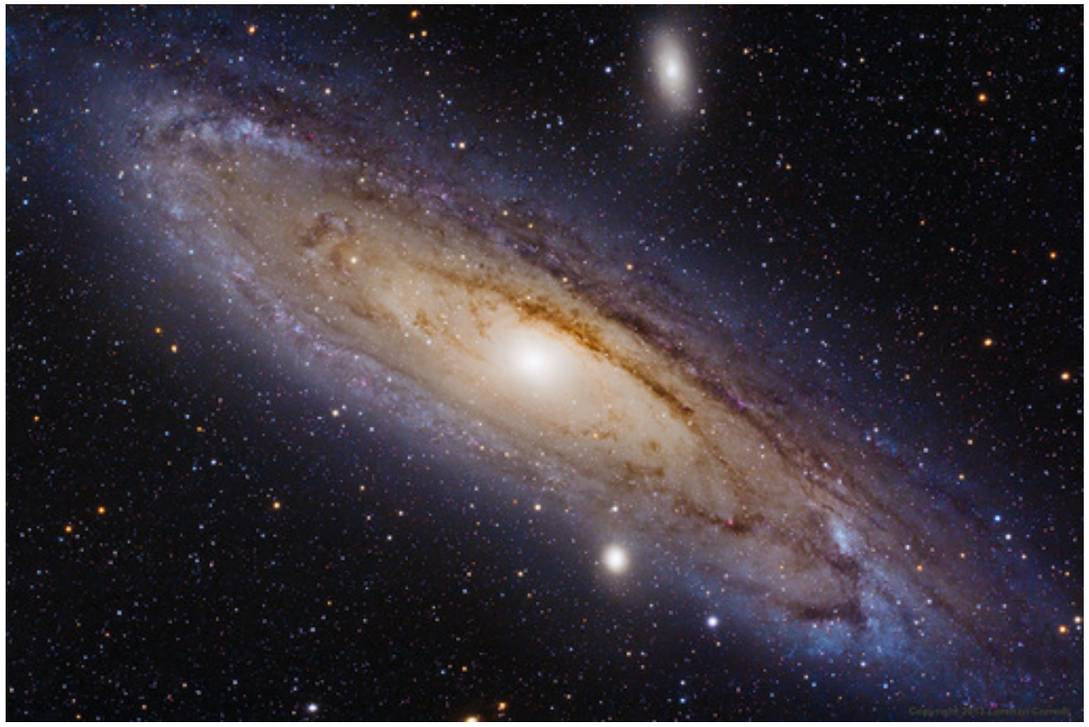


Figure 2.26

The Andromeda Galaxy is a large spiral galaxy 2.5 million ly away from the Milky Way.

The Andromeda Galaxy is the ONLY galaxy that can be seen by naked eye in the Northern Hemisphere. If you happen to live in the Southern Hemisphere, two other galaxies can be seen. Both are closer to the Milkly Way than the Andromeda, but are much smaller. Their names are the Large Magellanic Clound (LMC) and

the Small Magellanic Cloud (SMC). Both of these are examples of irregular galaxies.

Most galaxies are divided into three major types according to shape: **spiral galaxies** , **elliptical galaxies** , and **irregular galaxies** .

Spiral Galaxies

Both the Andromeda and the Milky Way are 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** below . Several arms spiral outward in the Pinwheel Galaxy (seen in **Figure** below) and are appropriately called **spiral arms** . Spiral galaxies have lots of gas and dust and lots of young stars.

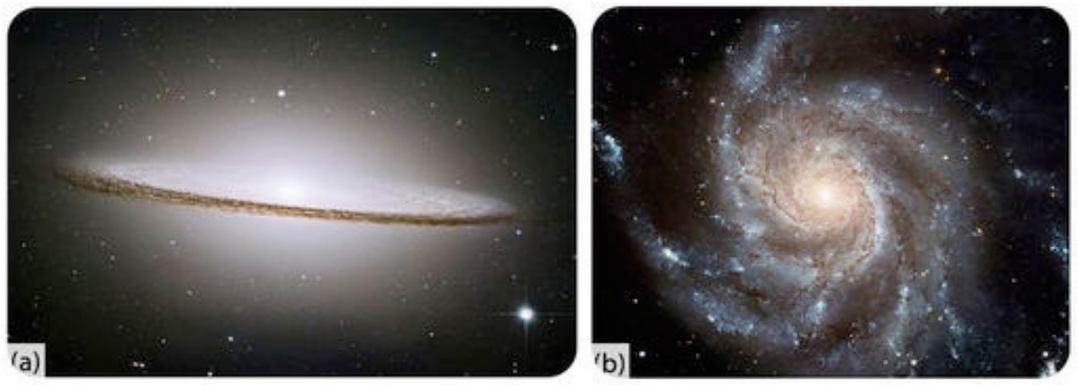


Figure 2.27

(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.

Components of a Spiral Galaxy

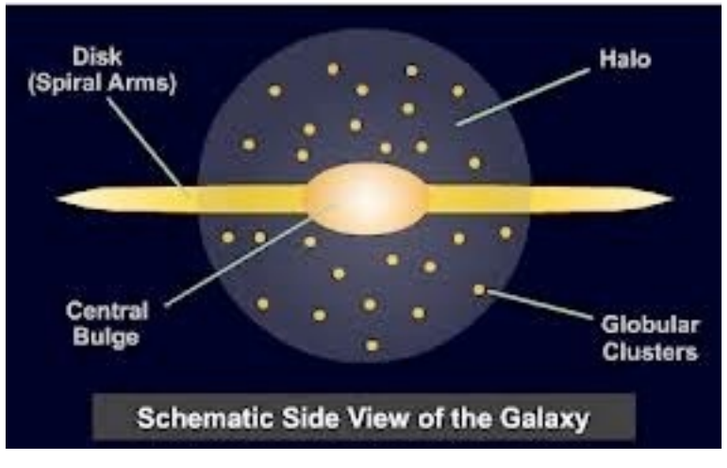


Figure 2.28

Major components of a spiral galaxy

The very dense **central bulge** contains older stars and very likely a massive black hole at its center. The **halo** is a spherical region surrounding the Bulge which contains the Globula Clusters. The oldest stars of the galaxy are found in these clusters. The **disk** is a flattened plane which contains the spiral arms, many young stars, gas, dust and open clusters.

A **barred spiral galaxy** (see below) is a spiral galaxy with a central bar-shaped structure composed of stars . Bars are found in approximately two-thirds of all spiral galaxies. Bars are thought to be a temporary phenomenon in the life of spiral galaxies, the bar structure decaying over time, transforming the galaxy from a barred spiral to a "regular" spiral pattern. Recent evidence has show that the Milky Way is a barred spiral.



Figure 2.29

NGC 1300 is a barred spiral galaxy.

Elliptical Galaxies

Figure below shows a typical egg-shaped **elliptical galaxy** . The smallest elliptical galaxies are as small as some 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. Elliptical galaxies are the most abundant type of galaxies found in the universe. Because elliptical galaxies contain older stars and less gas, scientists think that they are nearing the end of the evolution line for galaxies.



Figure 2.30

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?

Most elliptical galaxies contain very little gas and dust because the gas and dust has already formed into stars. However, some elliptical galaxies, such as the one shown in **Figure** below ,

contain lots of dust. Why might some elliptical galaxies contain dust?



Figure 2.31

Astronomers believe that these dusty elliptical galaxies form when two galaxies of similar size collide.

The universe is a violent place, and collisions between galaxies are frequent — indeed, the Milky Way is due to crash into the Andromeda Galaxy in about 4 billion years. When two spirals collide, they lose their familiar shape, morphing into the less-structured elliptical galaxies.

A supermassive black hole is thought to lie at the center of these ancient galaxies. These gluttonous giants consume gas and dust, and may play a role in the slower growth of elliptical galaxies.

Born from collision, elliptical galaxies are more commonly found around clusters and groups of galaxies. They are less frequently spotted in the early universe, which supports the idea that they evolved from the collisions that came later in the life of a galaxy.

Irregular Galaxies

Is the galaxy in the Figure below a spiral galaxy or an elliptical galaxy? It is neither one! Galaxies that are not clearly elliptical galaxies or spiral galaxies are irregular galaxies. They make up 3 percent of the galaxies in the universe. They are neither round nor boast spiral arms, and their shapes lack specific definition. How might an irregular galaxy form? The gravity of other galaxies has often affected them, stretching them out or warping them. Collisions or close calls with other galaxies can also deform their shapes. As mentioned above, the LMC and the SMC seen in the Southern Hemisphere are examples of irregular galaxies, although recent research has questioned LMC as an irregular.



Figure 2.32

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 Andromeda galaxy. In the figure, you can see two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere below and slightly to the right of the center, and the other is a long ellipse toward the top of the picture and to the right of center. Dwarf galaxies are often found near larger galaxies. The Milky Way has between 14 and 26 dwarf galaxies near it. They sometimes collide with and merge into their larger neighbors.

Interacting Galaxies

Speaking of colliding and merging galaxies, it turns out that this happens fairly often throughout our universe **. Interacting galaxies** (***colliding galaxies***) are galaxies whose gravitational fields result in a disturbance of one another. An example of a minor interaction is a satellite galaxy 's disturbing the primary galaxy's spiral arms. An example of a major interaction is a galactic collision. As mentioned above, the Andromeda galaxy and the Milky Way will collide in about 4 billion years. Don't worry however, since the space between individual star systems is so huge, this will have very little effect on our own solar system, unless.... Actually our galaxy is interacting with the satellite Sagittarius dwarf galaxy right now. See this article .

Here is a Hubble Telescope picture album of interacting galaxies. Some of these pictures were used to create this video . A computer simulation of two spiral galaxies interacting is shown. At various

points during the simulation, it is paused, and an actual picture of two galaxies is shown at that stage of the interaction, then the animation continues.

An updated video with current events as of July 2014 can be seen here .

The Milky Way Galaxy

On a dark, clear night, you will see a milky band of light stretching across the sky, as in Figure below or this picture album . This band is the disk of a 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. The oldest known star in the Galaxy is at least 13.6 billion years old and thus must have formed shortly after the Big Bang .

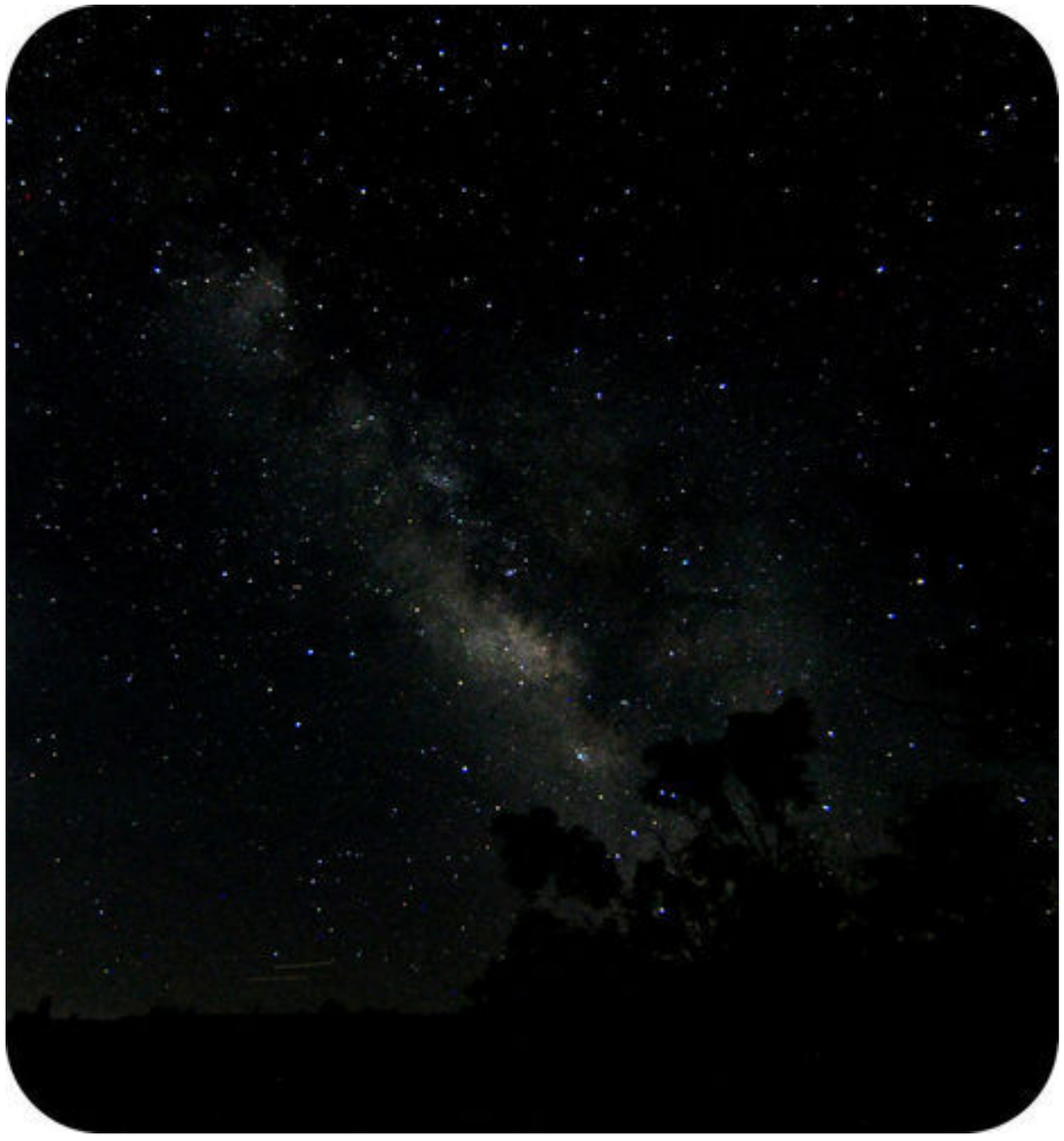


Figure 2.33

The Milky Way Galaxy looks different than other galaxies because we are looking along the main disk from within the galaxy.

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 200 billion to 400 billion stars (**Figure** below).

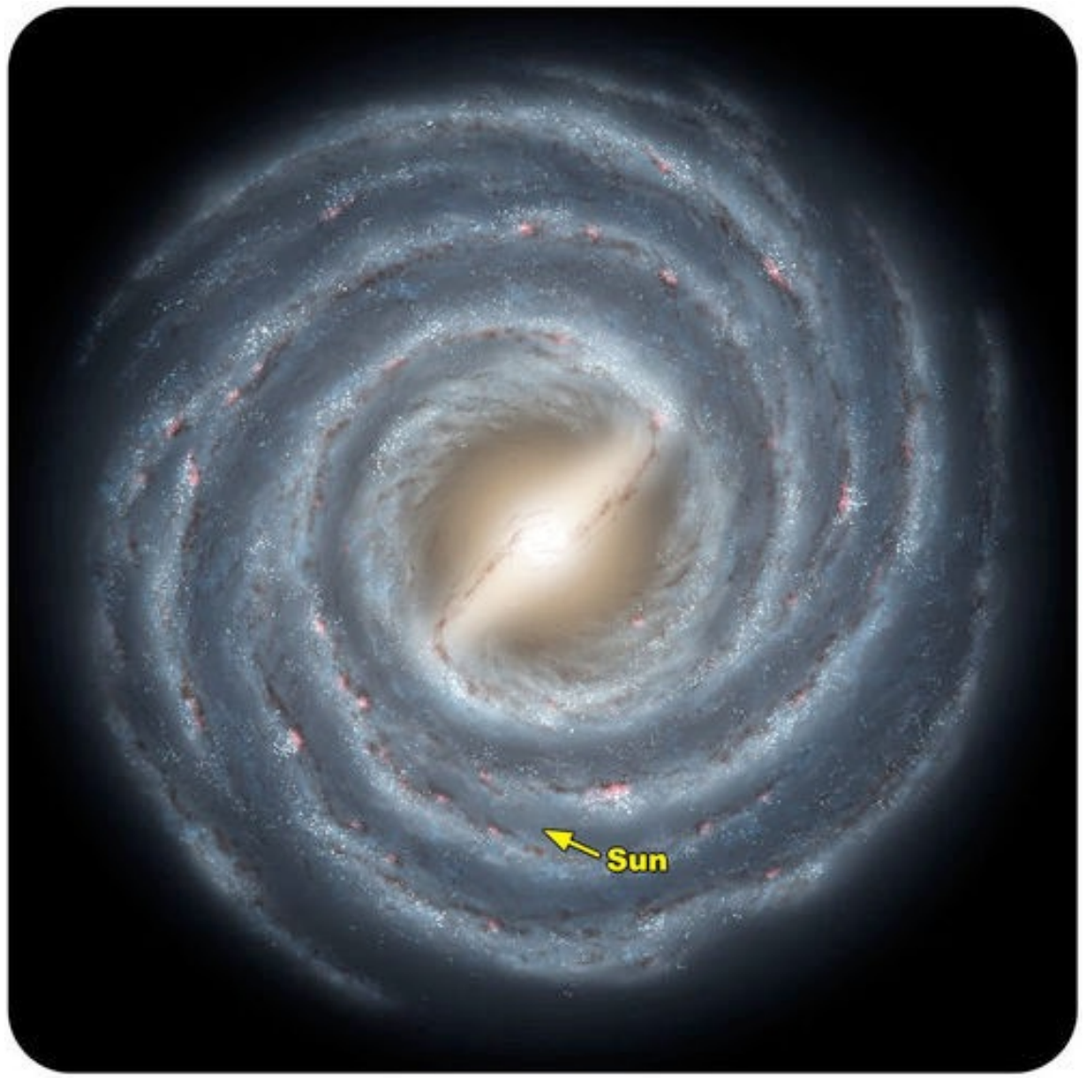


Figure 2.34

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, a halo and spiral arms. The disk is about 100,000 light-years across and 1,000 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** below).

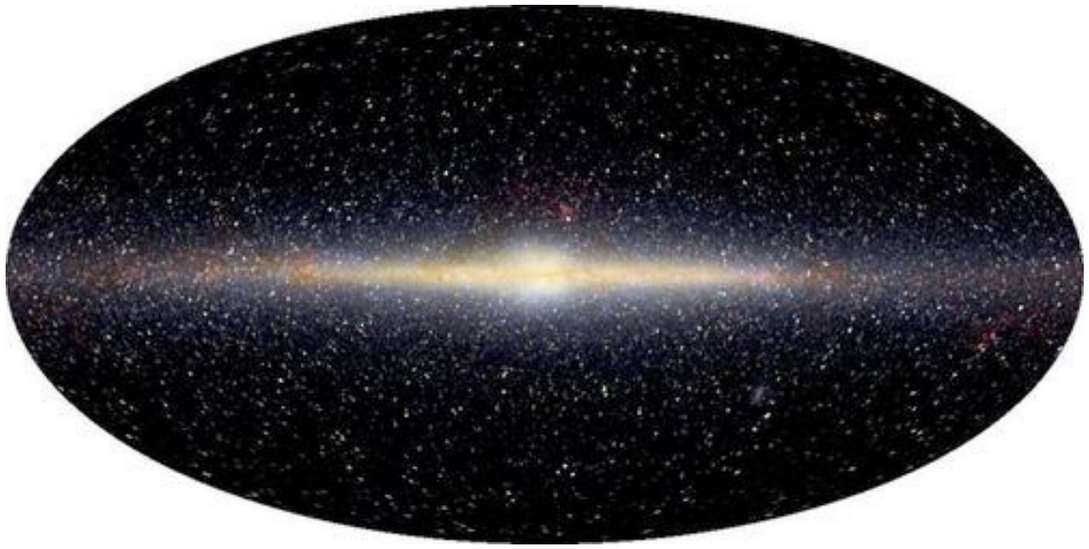


Figure 2.35

An infrared image of the Milky Way shows the long thin line of stars and the central bulge typical of spiral galaxies.

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 some 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.

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!

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 27,000 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.

A good video summary of this chapter, with an emphais on our Milky Way Galaxy can be found here .

This video describes the solar system in which we live. **(2a)** : http://www.youtube.com/watch?v=0Rt7FevNiRc (5:10).



Click on the image above for more content

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 (5:59).



Click on the image above for more content

Beyond Galaxies

But what about the very large? What is the large-scale structure of the universe? Let's start by looking at galaxy groupings and move on to even larger structures.

Although there are some galaxies that are found to stray away by their lonesome, most of them are actually bundled into groups and clusters. **Groups** are smaller, usually made up of less than 50 galaxies and can have diameters up to 6 million light-years. However, this definition should be used as a guide only, as larger and more massive galaxy systems are sometimes classified as galaxy groups. Gravity holds these galaxies together.

In fact, our Milky Way is a member of a group called the **Local Group** which comprises over 54 galaxies, including many dwarf galaxies. The Milky Way galaxy is the second largest member of the group with the Andromeda Galaxy being the largest.

Generally speaking, galaxy **clusters** are larger than groups, although there is no sharp dividing line between the two. One very peculiar property of clusters is that the velocities of their galaxies are supposed to be too high for gravity alone to keep them bunched together … and yet they are. The idea that dark matter exists starts at this scale of structure. Dark matter is believed to provide the gravitational force that keeps them all bunched up. There will be more about dark matter in the next section.

A great number of groups, clusters and individual galaxies can come together to form the next larger structure – **superclusters** . Superclusters are among the largest structures ever to be discovered in the universe. These superclusters of galaxies are distributed, not uniformly across space, but in filiments, sheets, and walls, interspersed with large, nearly empty **voids** between them. The material in our universe is not evenly spread out, but in a true sense "lumpy."

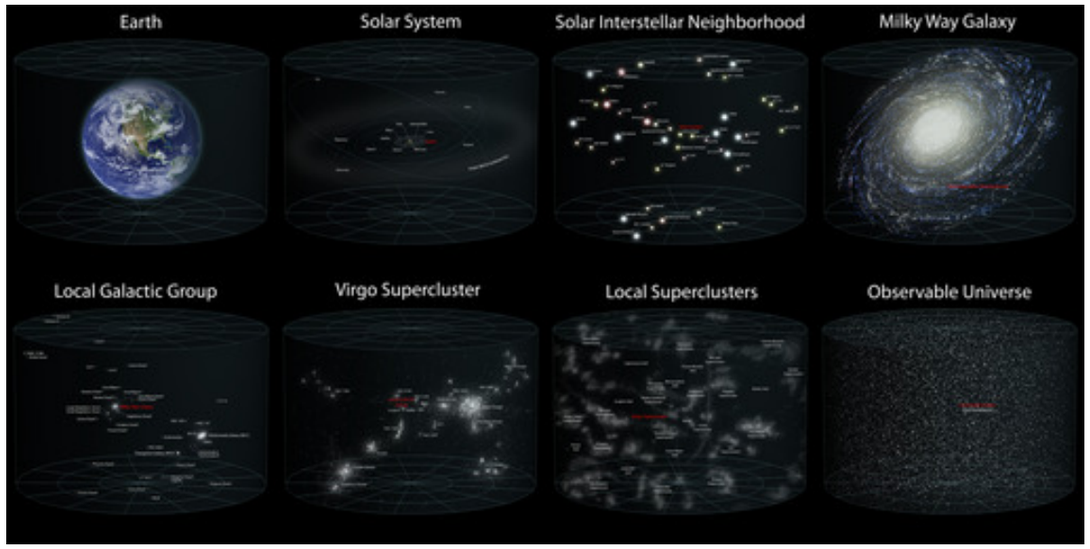


Figure 2.36

Earth's location in the Universe

Read more: http://www.universetoday.com/37360/structure-of-the-universe/#ixzz37AYWR1bP

Lesson Summary

•Many stars are in systems of two or more stars.
•Open clusters are groups of young stars loosely held together by gravity.
•Globular clusters are spherical groups of old stars held tightly together by gravity.
•Galaxies are collections of millions to many billions of stars.
•Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
•Typical elliptical galaxies are egg-shaped, reddish, and contain mostly old stars.
•Galaxies that are not elliptical or spiral galaxies are called irregular galaxies. These galaxies were probably deformed by other galaxies.
•Small galaxies with up to a few billion stars are called dwarf galaxies and they come in the same variety of types that regular galaxies do.
•Galaxies frequently interact, especially a main galaxy and its satellite dwarf galaxies.
•The Milky Way Galaxy is a typical spiral galaxy. Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk.
•Numerous galaxies come together to form larger structures and open spaces in our universe.

Review Questions

1. What is a binary star?
2. Compare globular clusters with open clusters.
3. Name the three main types of galaxies.
4. How is a dwarf galaxy different than a regular galaxy?
5. List the main features of a spiral galaxy.
6. What will happened when the Andromeda and Milky Way collide?
7. Suppose you see a round galaxy that is reddish in color and contains very little dust. What kind of galaxy is it?
8. What galaxy do we live in, and what kind of galaxy is it?
9. What is the evidence that the galaxy we live in is this type of galaxy?
10. Describe the location of our solar system in our galaxy.
11. What is the difference between a galaxy group and a galaxy cluster?
12. What is meant by our universe being "lumpy?"

Further Reading / Supplemental Links

- Variety of astronomy news: http://www.space.com
- More about galaxies: http://stardate.org/resources/btss/galaxies/
- Hundreds of images from the Hubble Space Telescope: http://hubblesite.org/gallery/album/

Points to Consider

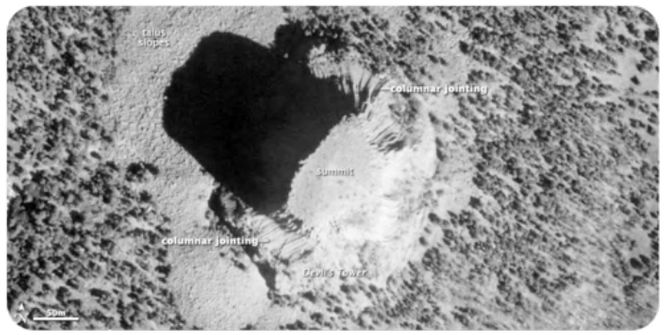
- Objects in the universe tend to be grouped together. What forces or factors do you think cause objects to form and stay in groups?
- Some people used to call galaxies "island universes." Are they really universes?
- Can you think of anything, either an object or a group of objects, that is bigger than a galaxy?

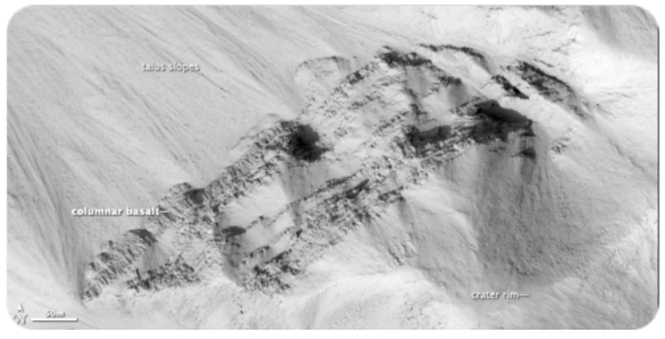
References

1.(a) Courtesy of NASA; (b) Courtesy of NASA, J. English (U. Manitoba), S. Hunsberger, S. Zonak, J. Charlton, S. Gallagher (PSU), and L. Frattare (STScI). (a) http://quest.arc.nasa.gov/hst/about/edwin.html; (b) http://hubblesite.org/newscenter/archive/releases/2002/22/image/a/ . Public Domain
2.Jodi So. CK-12 Foundation . CC BY-NC 3.0
3.User:Gnixon/Wikipedia. http://commons.wikimedia.org/wiki/File:Universe_expansion2.png . Public Domain
4.Courtesy of NASA/ESA/S. Beckwith(STScI) and the HUDF Team. http://www.nasa.gov/vision/universe/starsgalaxies/hubble_UDF.html . Public Domain
5.Courtesy of NASA, N. Benitez (JHU), T. Broadhurst (Racah Institute of Physics/The Hebrew University), H. Ford (JHU), M. Clampin (STScI),G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA. http://commons.wikimedia.org/wiki/File:Gravitationell-lins-4.jpg . Public Domain
6.Courtesy of the NASA/WMAP Science Team. http://commons.wikimedia.org/wiki/File:080998_Universe_Content_240.jpg . Public Domain
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11.. Hertzsprung-Russell (HR) diagram.
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27.Courtesy of the COBE Project, DIRBE, NASA. http://map.gsfc.nasa.gov/universe/rel_milkyway.html . Public Domain

Ch. 3: The Solar System





How do planetary geologists learn about the geology of other planets? Since much of the available information is from spacecraft flying high above the planet, these scientists compare images taken of the planet with images taken on Earth. Look at the images above and see if you can find the similarities and differences. Which is from Earth and which from another planet?

It's easy to figure out that the top image is Earth since there are plants. It is Devil's Tower in Wyoming and the bottom image is Marte Vallis on Mars. The features that are common to the images are columnar basalts showing columnar jointing and talus slopes. Columnar basalts form from basalt lavas that flow in a thick layer along a cool surface. The vertical joints speed cooling. Weathering causes the columns to break and form talus slopes.

On Mars the columnar basalts are exposed on the rim of a 160 km diameter crater. Evidence of the lava flows covers more than 200 square km (77 square miles), similar to terrestrial flood basalts. A meteorite impact appears to have created a crater to expose the columnar basalts.

Devil's Tower is a magma that cooled below the surface in sedimentary rock layers and formed columnar joints. The sedimentary rocks have since been eroded, exposing the tower. At the base are slopes of broken columns creating talus slopes.

Mars image courtesy High Resolution Imaging Science Experiment, Arizona State University. Devil's Tower image courtesy Wyoming Geographic Information Advisory Council. earthobservatory.nasa.gov/IOTD/view.php?id=38904. Public Domain.

Introduction to the Solar Sys-

Introduction to the Solar System

Lesson Objectives

- Describe historical views of the solar system.
- Name the planets, and describe their motion around the sun.
- Explain how the solar system formed.

Vocabulary

- geocentric model
- heliocentric model
- moon
- nebula
- nebular hypothesis
- solar system

Changing Views of the Solar System

Humans' view of the **solar system** has evolved as technology and scientific knowledge have increased. The ancient Greeks identified five of the planets and for many centuries they were the only planets known. Since then, scientists have discovered two more planets, many other solar-system objects and even planets found outside our solar system.

The Geocentric Universe

The ancient Greeks believed that Earth was at the center of the universe, as shown in **Figure** below . This view is called the **geocentric model** of the universe. Geocentric means "Earth-centered." 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.



Figure 3.1

Model of a geocentric universe. This diagram of the universe from the Middle Ages shows Earth at the center, with the Moon, the Sun, and the planets orbiting Earth.

The geocentric model worked well, by explaining 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** below). 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.

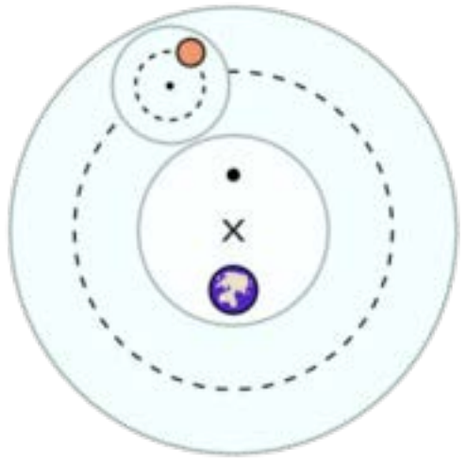


Figure 3.2

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 is seen here:

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

The Heliocentric Universe

Ptolemy's geocentric model worked but it was not only complicated, it 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 of the universe (**Figure** below). Copernicus' model explained the motion of the planets as well as Ptolemy's model did, but it did not require complicated additions like epicycles and deferents.

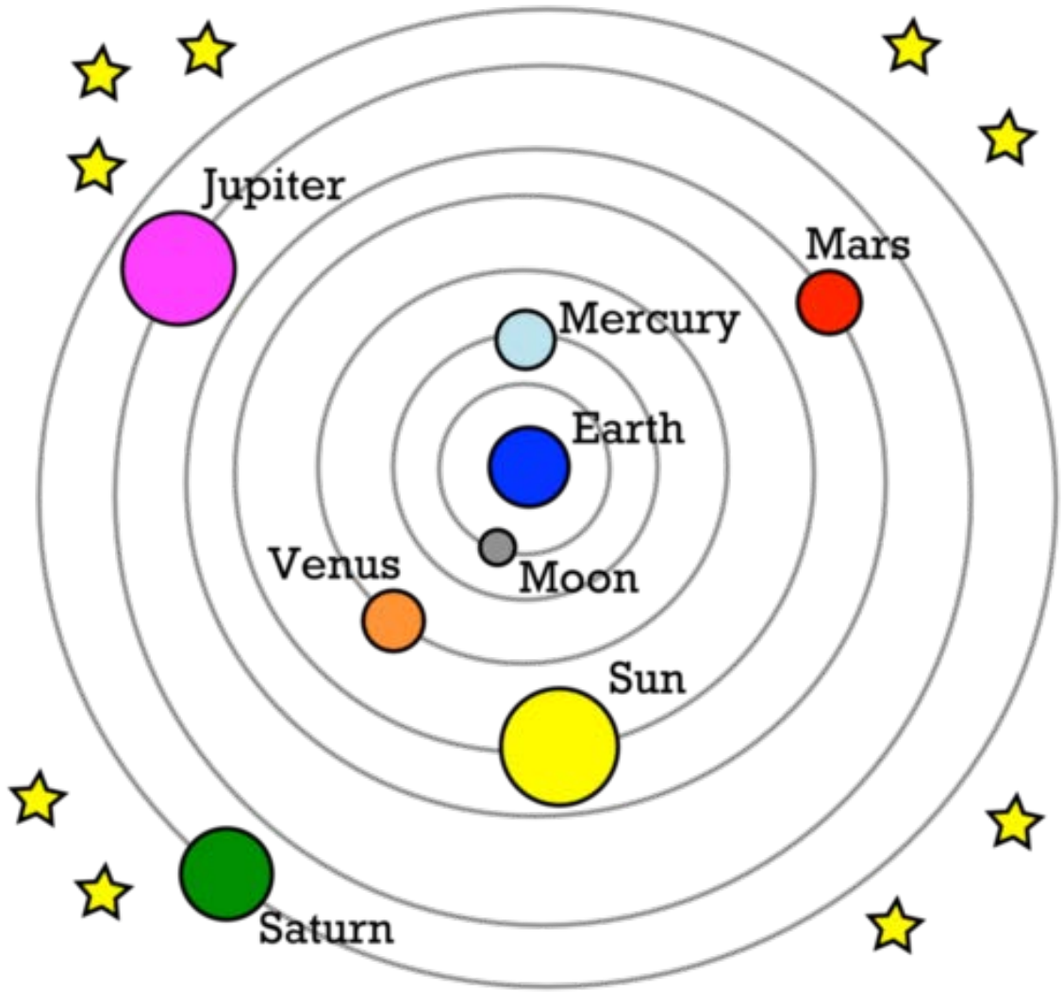


Figure 3.3

Unlike the geocentric model, the heliocentric model had the Sun at the center and did not require epicycles.

Although Copernicus' model worked more simply than Ptolemy's, it still did not perfectly describe the motion of the planets because, like Ptolemy, Copernicus thought planets moved in perfect circles. Not long after Copernicus, Johannes Kepler refined the heliocentric model so that the planets moved around the Sun in

ellipses (ovals), not circles (**Figure** below). Kepler's model matched observations perfectly.

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

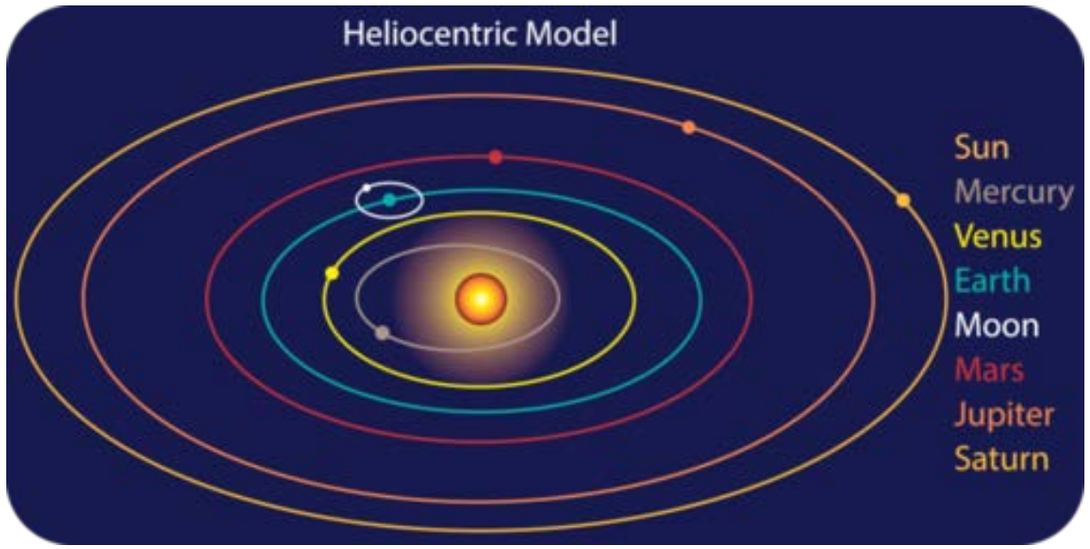


Figure 3.4

Kepler's model showed the planets moving around the sun in ellipses. The elliptical orbits are exaggerated in this image.

Because people were so used to thinking of Earth at the center of the universe, the heliocentric model was not widely accepted at first. However, 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 is 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** below), which provides direct evidence that Venus orbits the Sun.

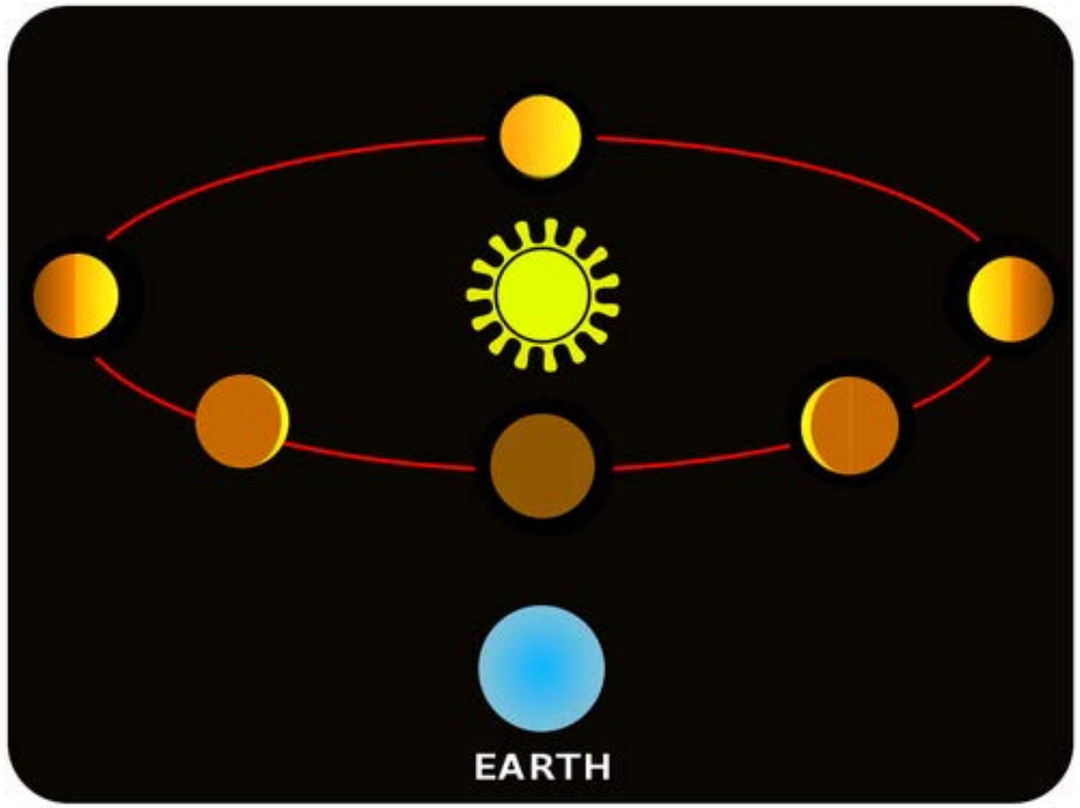


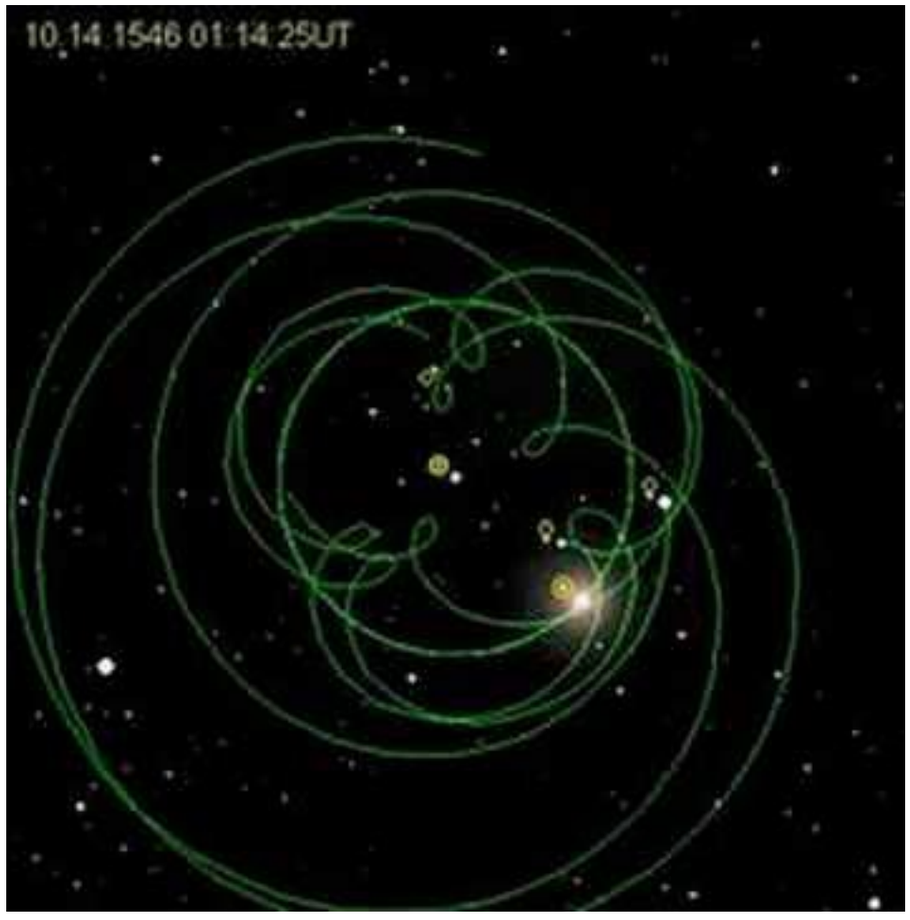
Figure 3.5

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 for his ideas. The shift from an Earth-centered view to a Sun-centered view of the universe is referred to as the Copernican Revolution.

Watch this animation of the Ptolemaic and Copernican models of the solar system. Ptolemy made the best model he could with the

assumption that Earth was the center of the universe, but by letting that assumption go, Copernicus came up with a much simpler model. Before people would accept that Copernicus was right, they needed to accept that the Sun was the center of the solar system **(1n - I&E Stand.)** : http://www.youtube.com/watch?v=VyQ8Tb85HrU (0:47).



Click on the image above for more content

The Modern Solar System

Today, we know that our solar system is just one tiny part of the universe as a whole. Neither Earth nor the Sun are at the center of the universe. However, the heliocentric model accurately describes the solar system. In our modern view of the solar system, the Sun is at the center, with the planets moving in elliptical orbits around the Sun. The planets do not emit their own light, but instead reflect light from the Sun.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun (called "extrasolar planets" or simply "exoplanets") (**Figure** below).

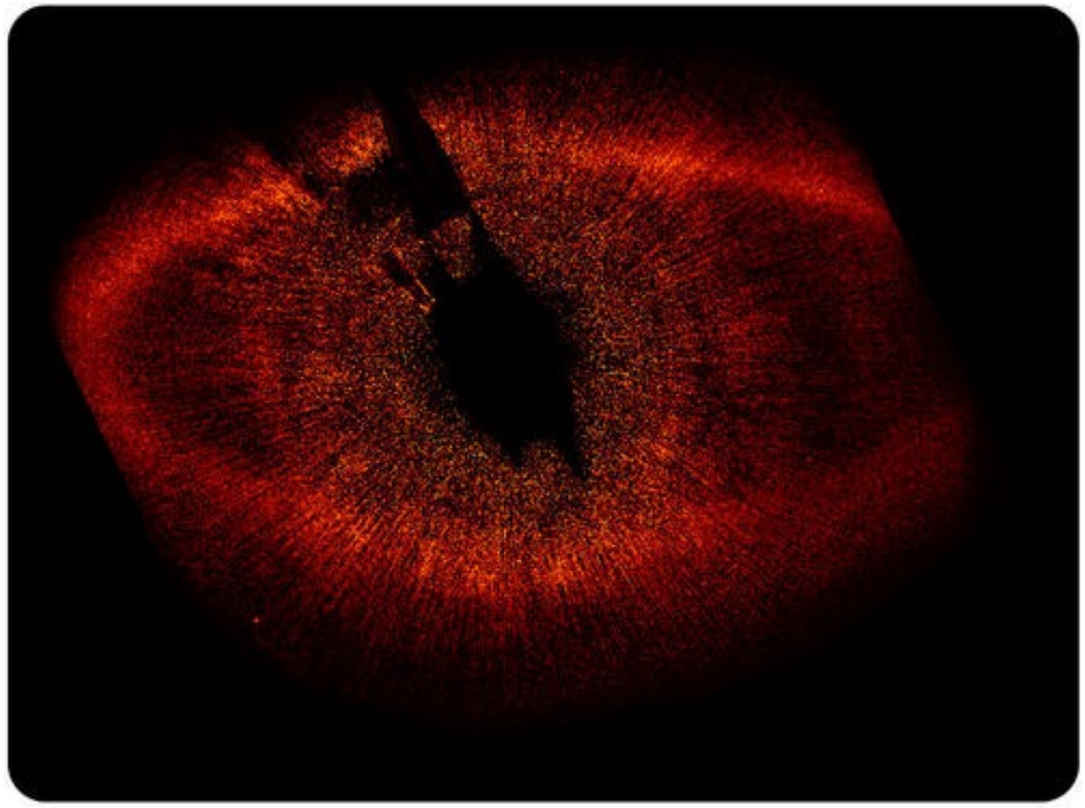


Figure 3.6

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.

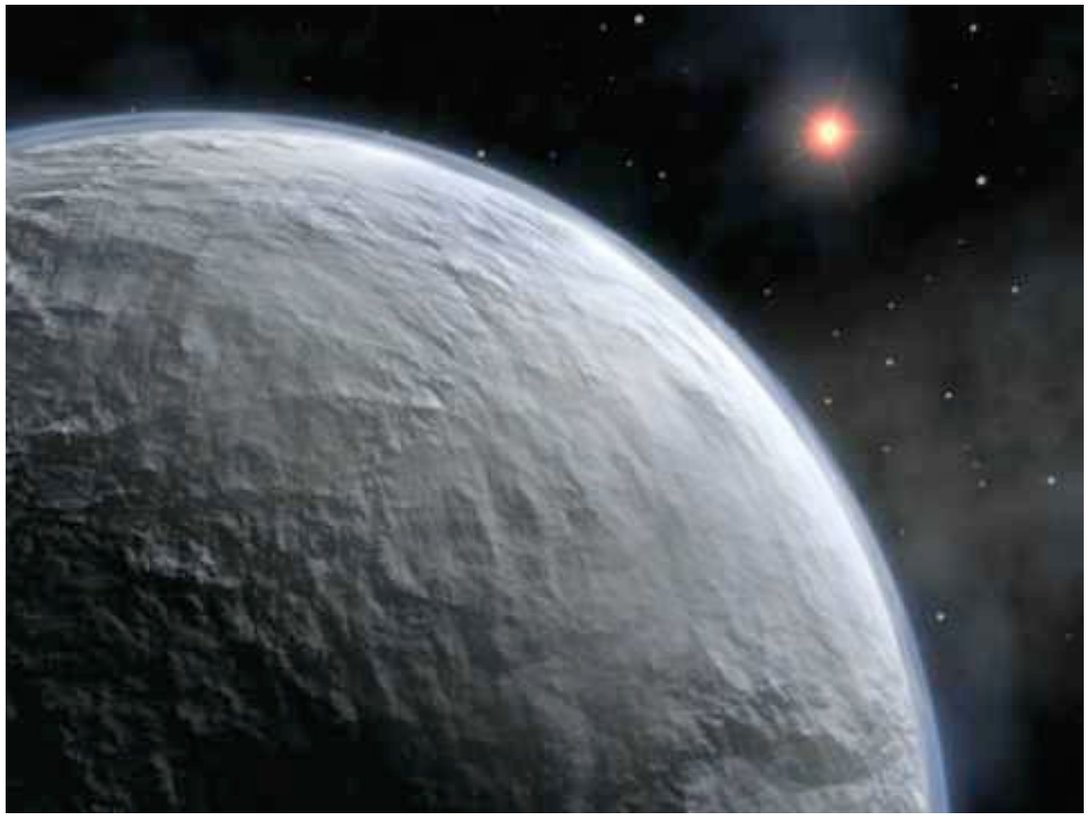
Some extrasolar planets have been directly imaged, but most have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet or, sometimes, another star orbiting the star.

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 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 3,600 extrasolar planets have been identified 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).



Click on the image above for more content

An introduction to extrasolar planets from NASA is available at **(1g)** : http://www.youtube.com/watch?v=oeeZCHDNTvQ (3:14).



Click on the image above for more content

KQED: The Planet Hunters

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. Learn more at: http://science.kqed.org/quest/video/the-planet-hunters/ and http://science.kqed.org/quest/audio/exoplanets/ .



Click on the image above for more content



Click on the image above for more content

Planets and Their Motions

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), four dwarf

planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

(**Figure** below) shows the Sun and the major objects that orbit the Sun. There are eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune) and the five known dwarf planets and the five known dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris).

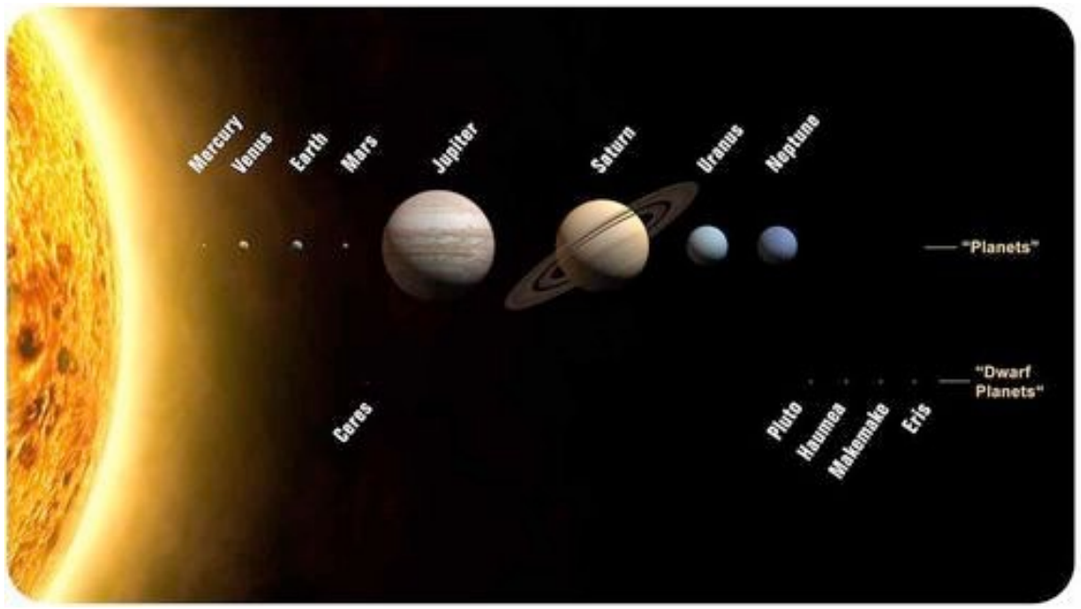


Figure 3.7

Relative sizes of the Sun, planets and dwarf planets. The relative sizes are correct and their position relative to each other is correct, but the relative distances are not correct.

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 below gives data on the sizes of the Sun and planets relative to Earth.

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

The Size and Shape of Orbits

Figure below 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 (**Figure** below).

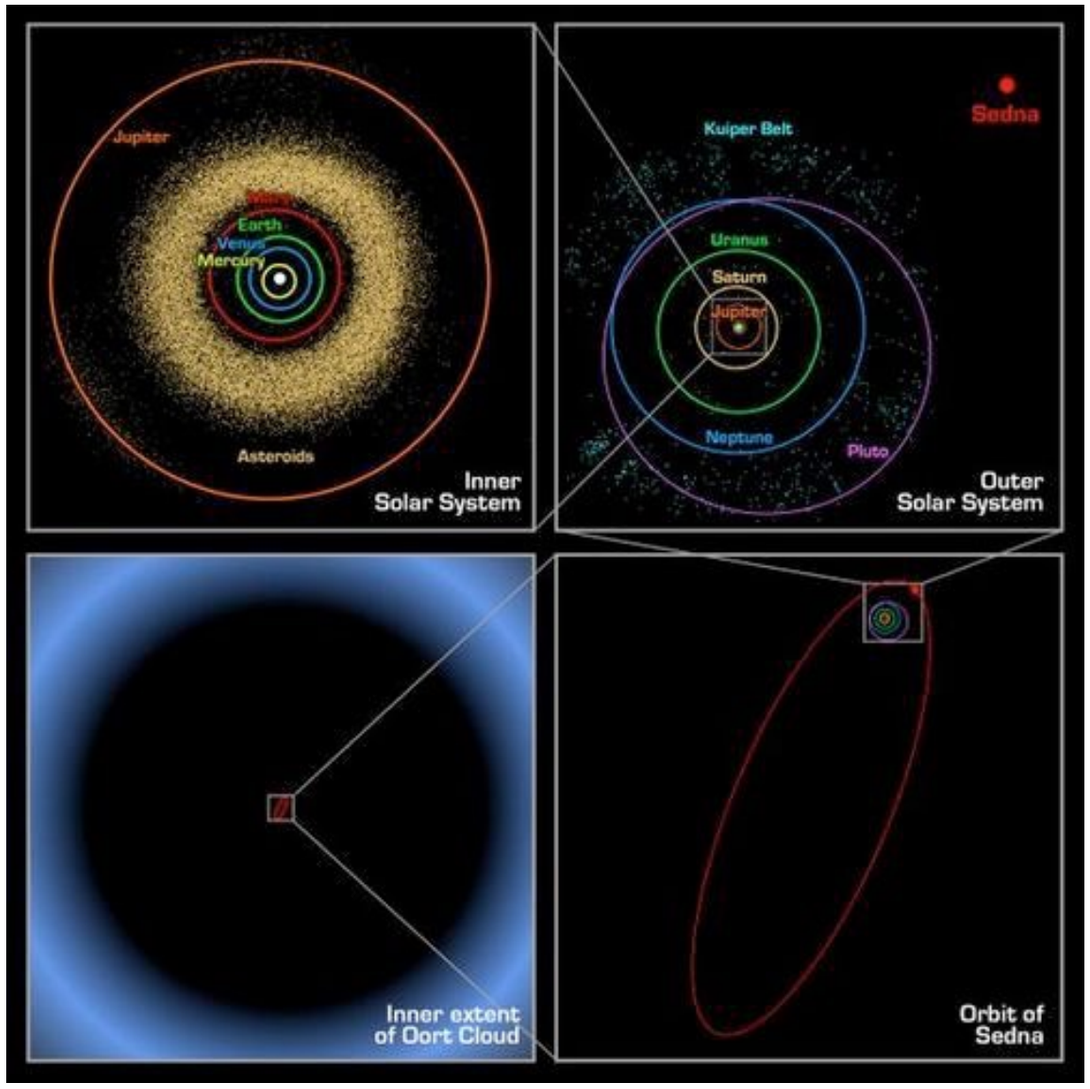


Figure 3.8

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.

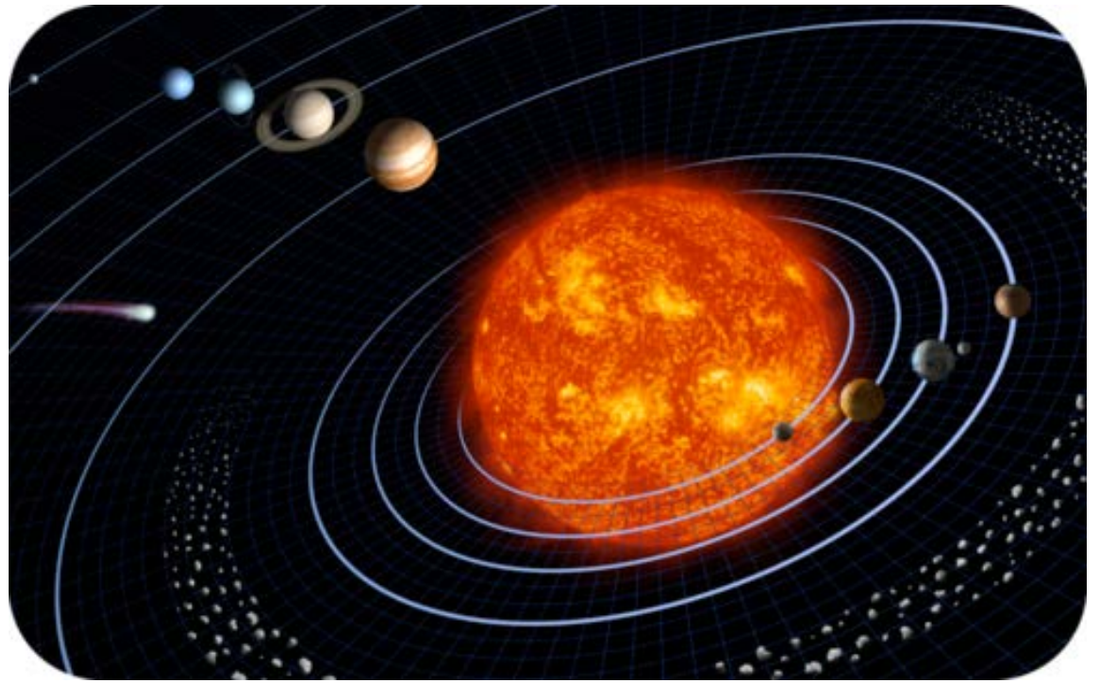


Figure 3.9

The planets orbit the Sun in regular paths.

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.

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 mi. **Table** below 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.

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

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?v=-6szEDHMxP4 (4:44).



Click on the image above for more content

The Role of Gravity

Isaac Newton was one of the first scientists to explore gravity. He understood that the Moon circles the Earth because a force is pulling the Moon toward Earth's center. Without that force, the Moon would continue moving in a straight line off into space. Newton also came to understand that the same force that keeps the Moon in its orbit is the same force that causes objects on Earth to fall to the ground.

Newton defined the Universal Law of Gravitation, which states that a force of attraction, called gravity, exists between all objects in the universe (**Figure** below). 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 the objects, the smaller the force of attraction.

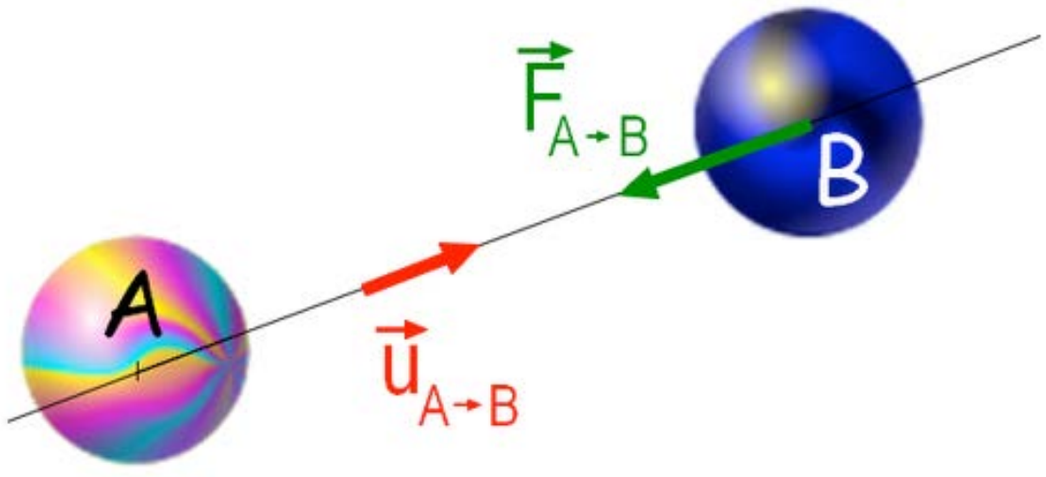


Figure 3.10

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.

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.

Formation of the Solar System

There are two additional key features of the solar system:

1. All the planets lie in nearly the same plane, or flat disk like region.

2. All the planets orbit in the same direction around the Sun.

These two features are clues to how the solar system formed.

A Giant Nebula

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, as shown in **Figure** below . The disk contained hydrogen and helium, along with heavier elements and even simple organic molecules.

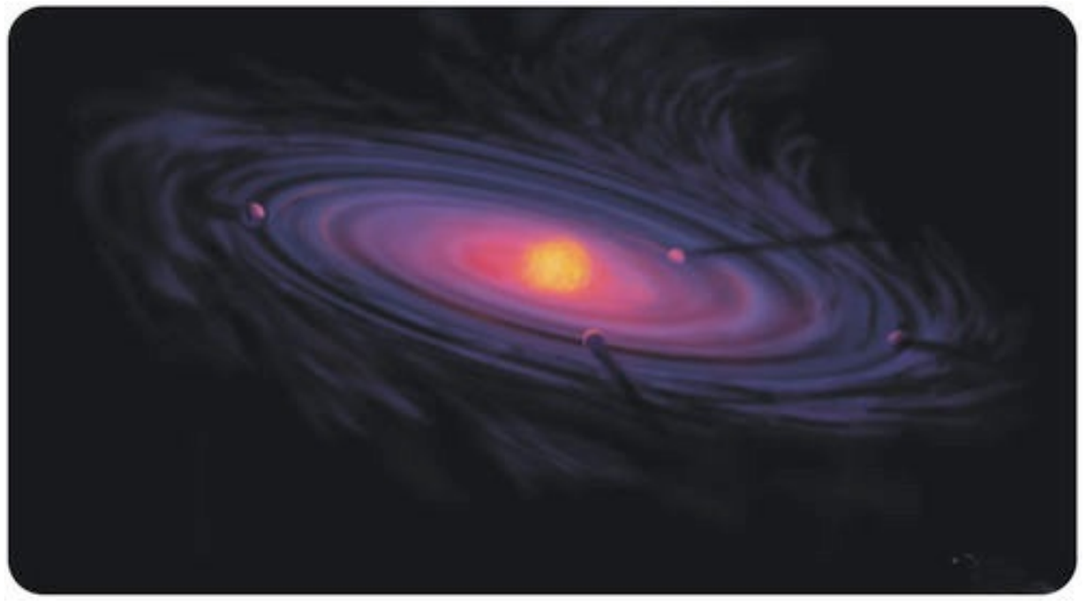


Figure 3.11

An artist's painting of a protoplanetary disk.

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.

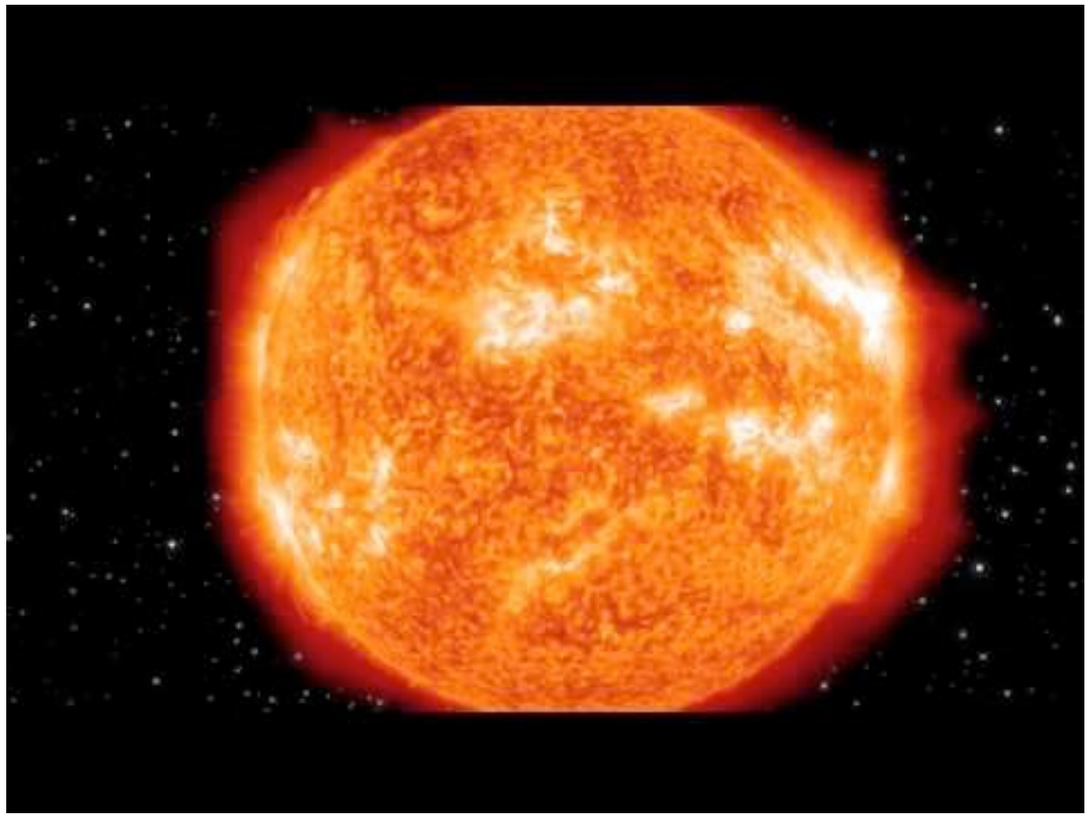
Meanwhile, the outer parts of the disk were cooling off. Matter condensed from the cloud and small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps, called planetesimals, attracted smaller clumps with their gravity. Gravity at the center of the disk attracted heavier particles, 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 (8:34).



Click on the image above for more content

[Formation of the Solar System (4:27)]

Lesson Summary

•The solar system is the Sun and all the objects that are bound to the Sun by gravity.
•The solar system has eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Ceres, Makemake, Pluto and Eris are dwarf planets.
•The ancient Greeks and people for centuries afterwards believed in a geocentric model of the universe, with Earth at the center and everything else orbiting our planet.
•Copernicus, Kepler, and Galileo promoted a heliocentric model of the universe, with the Sun at the center and Earth and the other planets orbiting the Sun.
•Gravity holds planets in elliptical orbits around the Sun.
•The nebular hypothesis describes how the solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.

Review Questions

1. What does geocentric mean?

2. Describe the geocentric model and heliocentric model of the universe.

3. How was Kepler's version of the heliocentric model different from Copernicus'?

4. Name the eight planets in order from the Sun outward. Which are the inner planets and which are the outer planets?

5. Compare and contrast the inner planets and the outer planets.

6. What object used to be considered a planet, but is now considered a dwarf planet? What are the other dwarf planets?

7. What keeps planets and moons in their orbits?

8. How old is the solar system? How old is Earth?

9. Use the nebular hypothesis to explain why the planets all orbit the Sun in the same direction.

Further Reading / Supplemental Links

•More information about the solar system from NASA: http://sse.jpl.nasa.gov/planets/index.cfm
•Lots of information about the solar system from the BBC: BBC Explore the solar system http://www.bbc.co.uk/solarsystem/
•Information about solar system objects: http://www.solarviews.com/eng/homepage.htm
•A multimedia tour of the solar system: http://www.nineplanets.org/
•Windows to the Universe: http://www.windows.ucar.edu/tour/link=/our_solar_system/formation.html
•Space news: http://www.space.com/

Points to Consider

•Would you expect all the planets in the solar system to be made of similar materials? Why or why not?
•The planets are often divided into two groups: the inner planets and the outer planets. Which planets do you think are in each of these two groups? What do members of each group have in common?

Inner Planets

Lesson Objectives

- Describe key features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

Vocabulary

- day
- inner planets
- terrestrial planets
- year

Introduction

Website for our Solar System

Solar System animation

What evidence do planetary geologists have to go on to determine the geology of the inner planets? On Earth, scientists can collect and analyze the chemistry of samples, do radiometric dating to determine their ages, and look at satellite images to see large-scale features. Rovers have landed on Mars and sent back enormous amounts of information but much of the rest of what is known about the inner planets is from satellite images.

The Inner Planets

The **inner planets** , or **terrestrial planets** , are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. **Figure** below shows the relative sizes of these four inner planets.

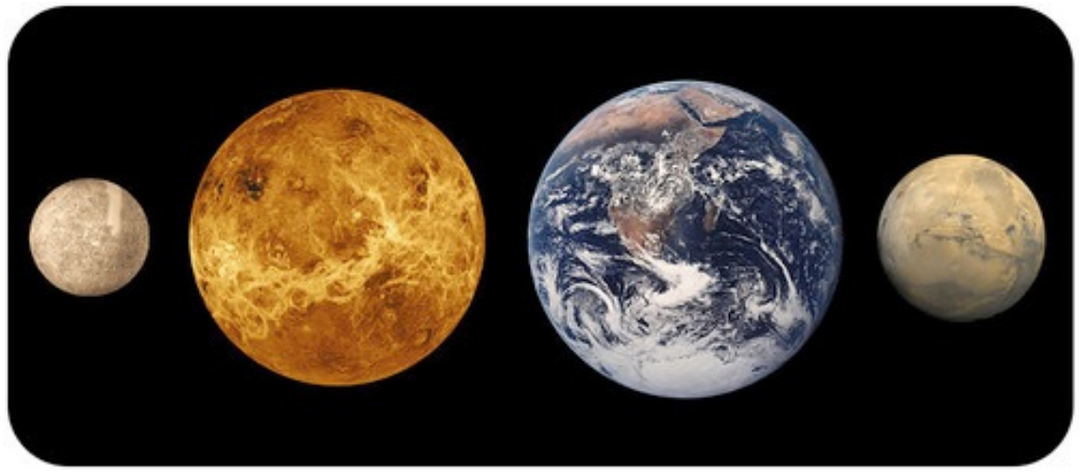


Figure 3.12

This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

Unlike the outer planets, which have many of 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.

Earth

Although Earth is the third planet out from the Sun this lesson will start here. We know a lot more about Earth, so what we know can be used for comparison with the other planets.



Figure 3.13

What are Earth's most distinctive features? This famous image of Earth was taken during the Apollo 17 mission to the moon. Can you find a hurricane? A storm spinning in the opposite direction from the hurricane?

Earth's Surface and Life

As you can see in (**Figure** above), Earth has vast oceans of liquid water, large masses of exposed land, and a dynamic atmosphere with clouds of water vapor. Earth also has ice covering its polar regions. Earth's average surface temperature is 14°C (57°F). Water is a liquid at this temperature, but the planet also has water in its other two states, solid and gas. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

As yet Earth is the only planet known to have life. The presence of liquid water, the ability of the atmosphere to filter out harmful radiation, and many other features make the planet uniquely suited to harbor life. Life and Earth now affect each other; for example, the evolution of plants allowed oxygen to enter the atmosphere in large enough quantities for animals to evolve. Although life has not been found elsewhere in the solar system, other planets or satellites may harbor primitive life forms. Life may also be found elsewhere in the universe.

Structure and Plate Tectonics

The heat that remained from the planet's accretion, gravitational compression, and radioactive decay allowed the Earth to melt, probably more than once. As it subsequently cooled, gravity pulled metal into the center to create the core. Heavier rocks formed the mantle and lighter rocks formed the crust.

Earth's crust is divided into tectonic plates, which move around on the surface because of the convecting mantle below. Movement of the plates causes other geological activity, such as earthquakes, volcanoes, and the formation of mountains. The locations of these features are mostly related to current or former plate boundaries. Earth is the only planet known to have plate tectonics.

Earth's Motions and Satellites

Earth rotates on its axis once per **day** , by definition. Earth orbits the Sun once every 365.24 days, which is defined as a **year** . Earth has one large moon, which orbits Earth once every 29.5 days, a period known as a month.

Earth's moon is the only large moon orbiting a terrestrial planet in the solar system. The Moon is covered with craters; it also has large plains of lava. The huge number of craters suggests that

Moon's surface is ancient. There is evidence that the Moon formed when a large object — perhaps as large as the planet Mars — struck Earth in the distant past (**Figure** below).

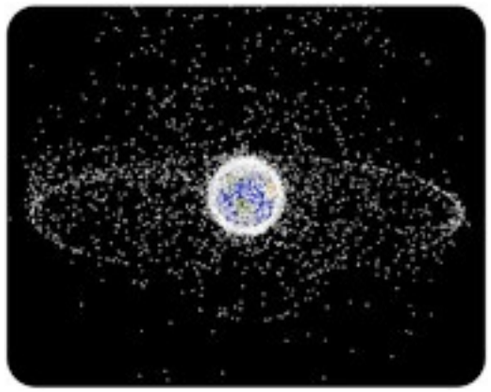


Figure 3.14

Besides its Moon, Earth is orbited by a great deal of space debris, the remains of satellites, and rocket stages.

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** below , 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 3.15

(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** below 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.

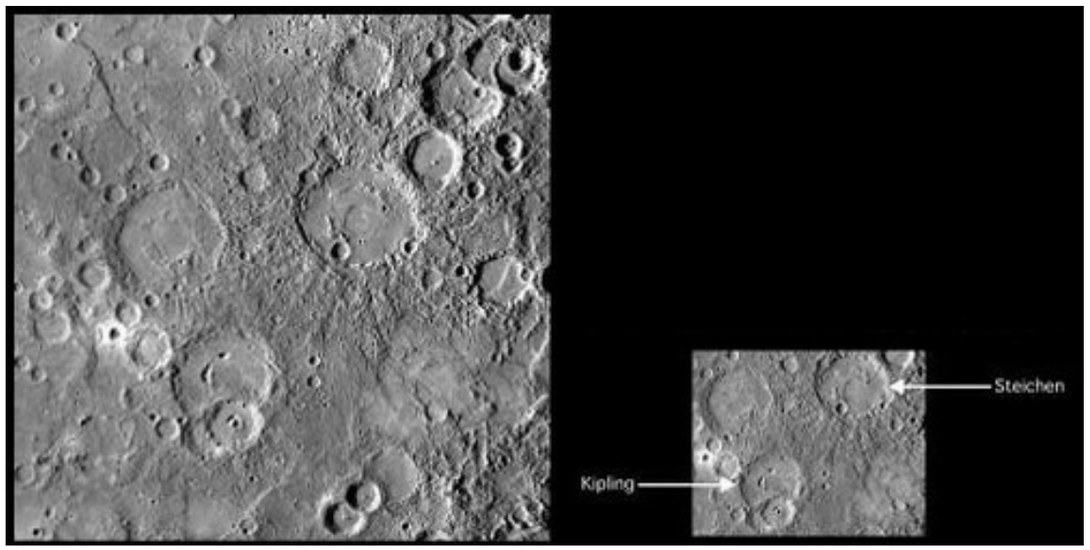


Figure 3.16

Mercury is covered with craters, like Earth's moon. MESSENGER has taken extremely detailed pictures of the planet's surface.

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 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°C (801°F). On the dark side, or in the shadows inside craters, the surface can be as cold as -183°C (-297°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 below 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.

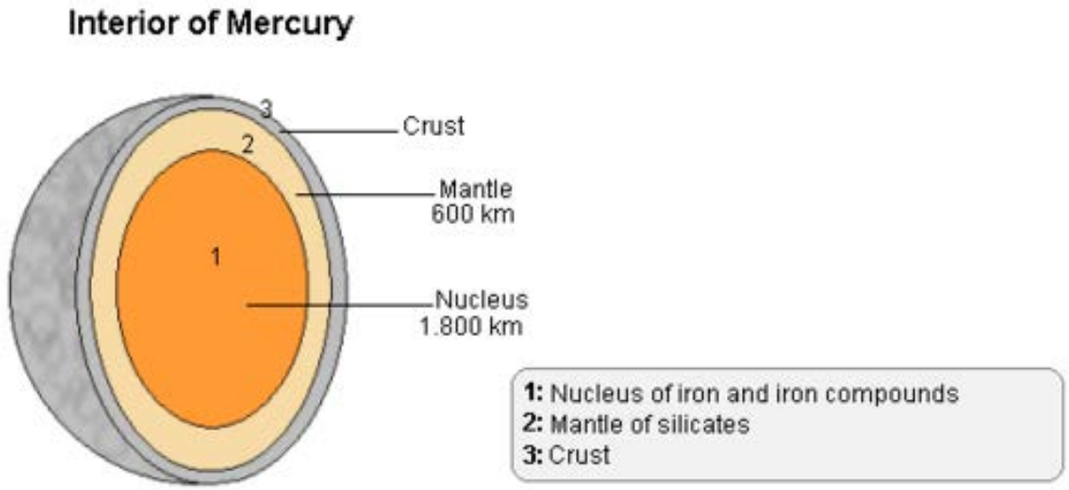


Figure 3.17

Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. 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** below). 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 .

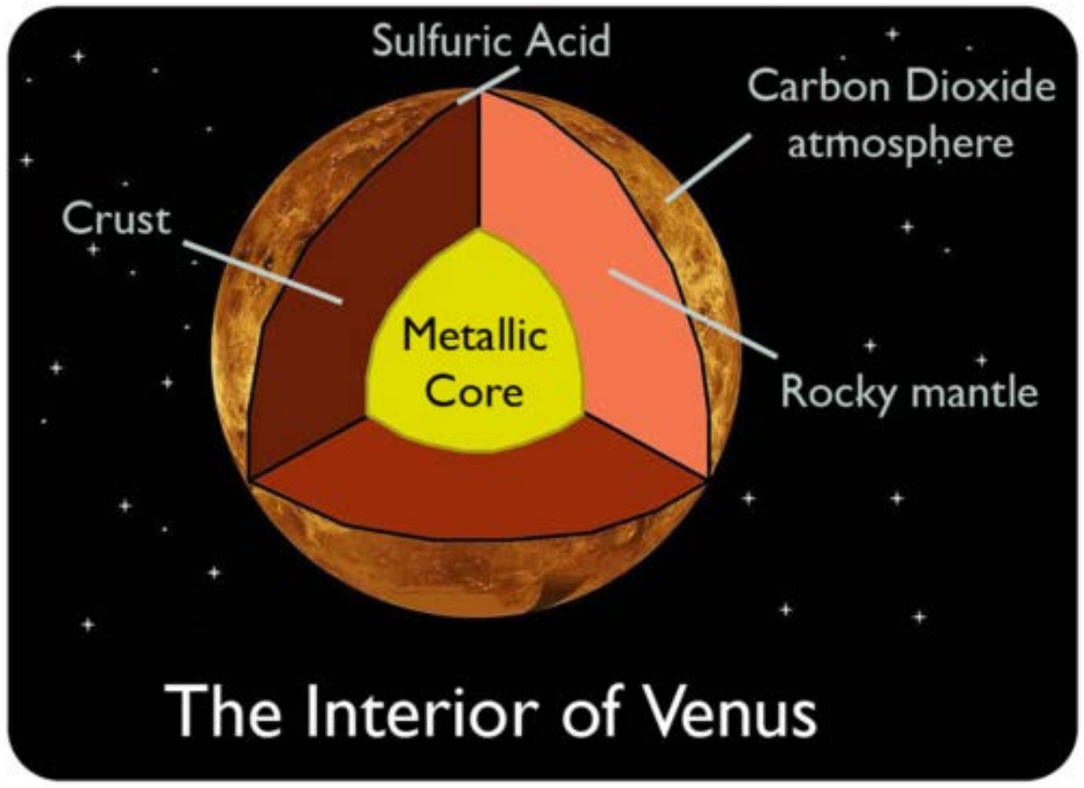


Figure 3.18

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 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** below).

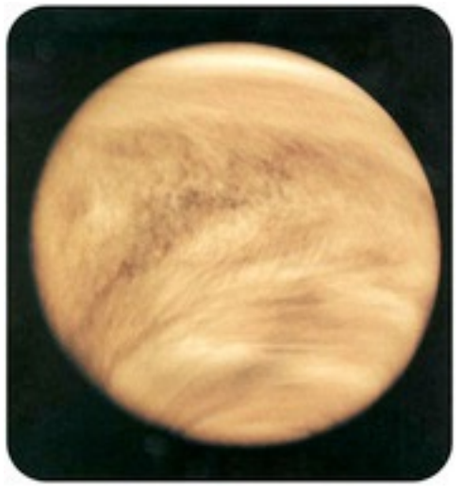
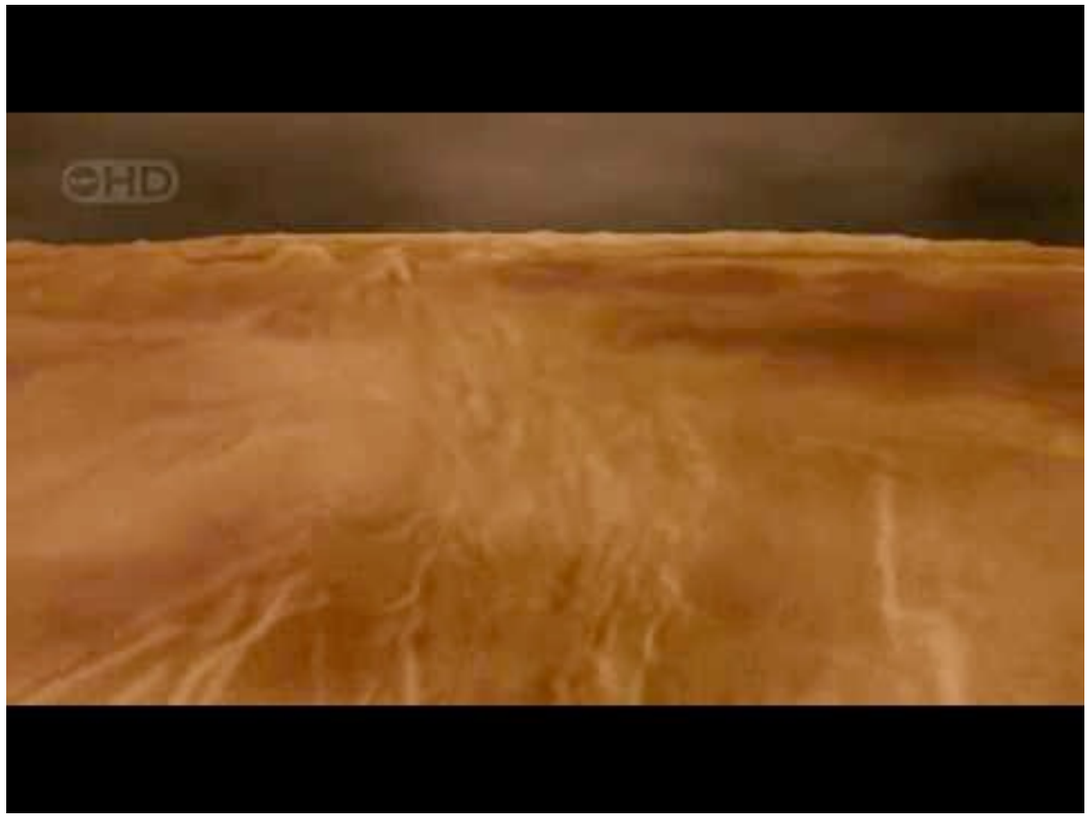


Figure 3.19

This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus.

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 — and they also contain corrosive sulfuric acid. Because carbon dioxide is 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°C (860°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).



Click on the image above 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** below shows a topographical map of Venus produced by the Magellan probe using radar.

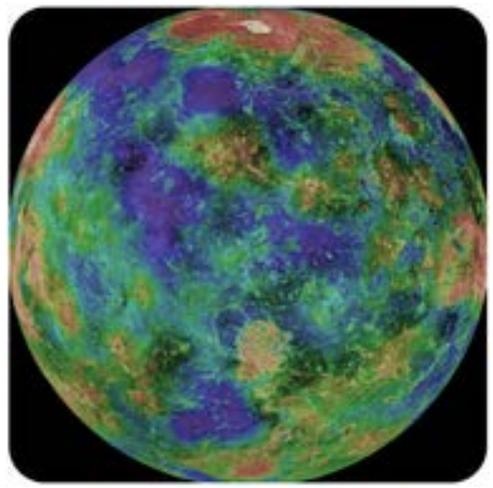


Figure 3.20

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?

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** below). 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?

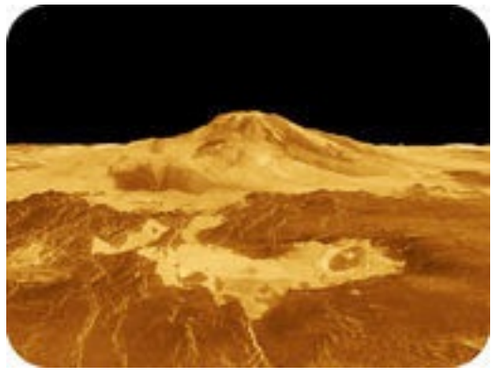


Figure 3.21

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 that has no escape until finally it destroys the crust and results in volcanoes.

Mars

Mars is the fourth planet from the Sun, and the first planet beyond Earth's orbit (**Figure** below). 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 3.22

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. But 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** below).

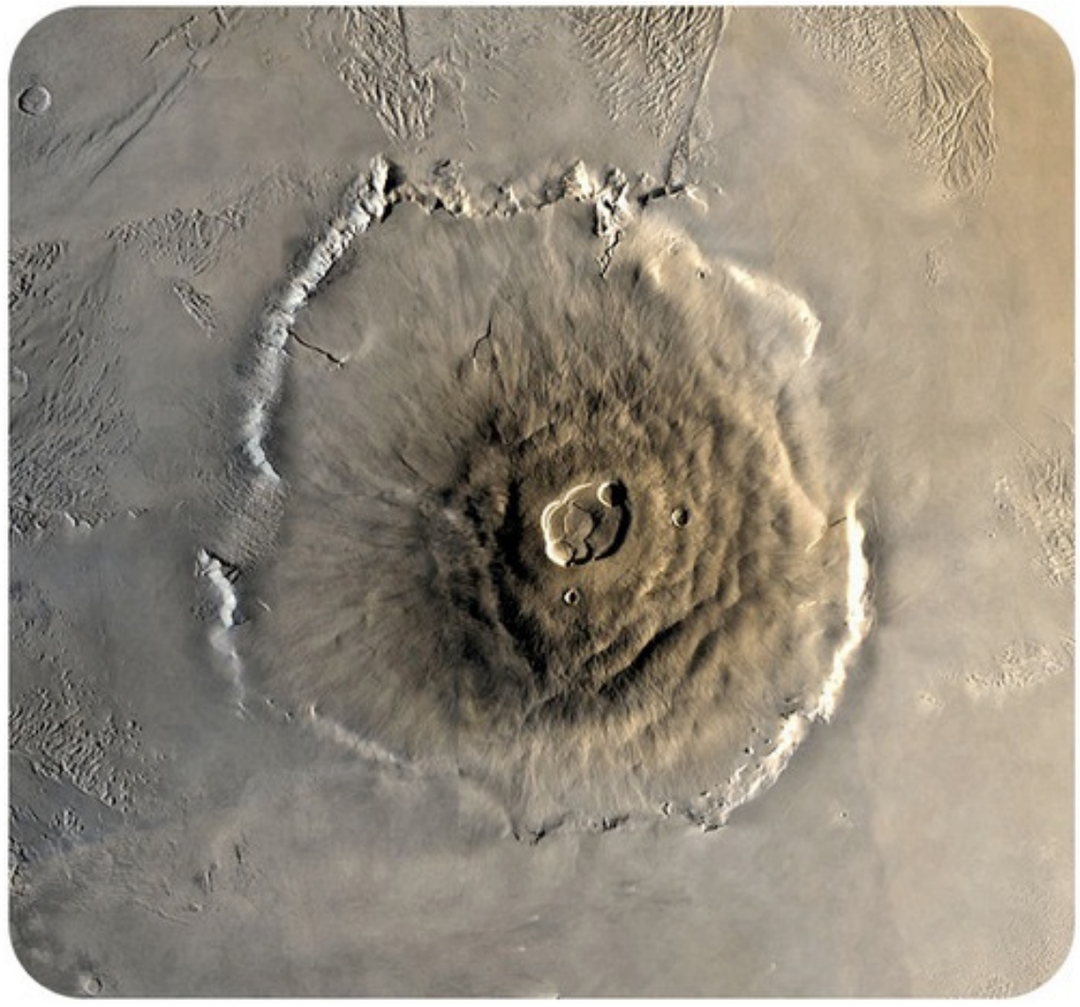


Figure 3.23

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.

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** below).



Figure 3.24

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.

Mars has more impact craters than Earth, though fewer than the Moon. A video comparing geologic features on Mars and Earth is seen here: Mars tectonics video 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** below). Scientists also think that there is a lot of water ice present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

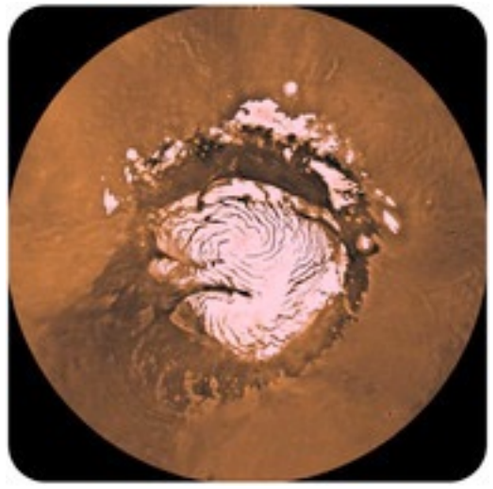


Figure 3.25

The north polar ice cap on Mars.

Scientists think that water once flowed over the Martian surface because there are surface features that look like water-eroded canyons (**Figure** below). 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.



Figure 3.26

The Mars rover collected rounded clumps of crystals that, on Earth, are known to form in water.

A video of the top five Phoenix Lander sites on Mars is seen here: http://news.discovery.com/videos/space-top-5-mars-phoenix-lander-images.html .

Two Martian Moons

Mars has two very small moons that are irregular rocky bodies (**Figure** below). 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.

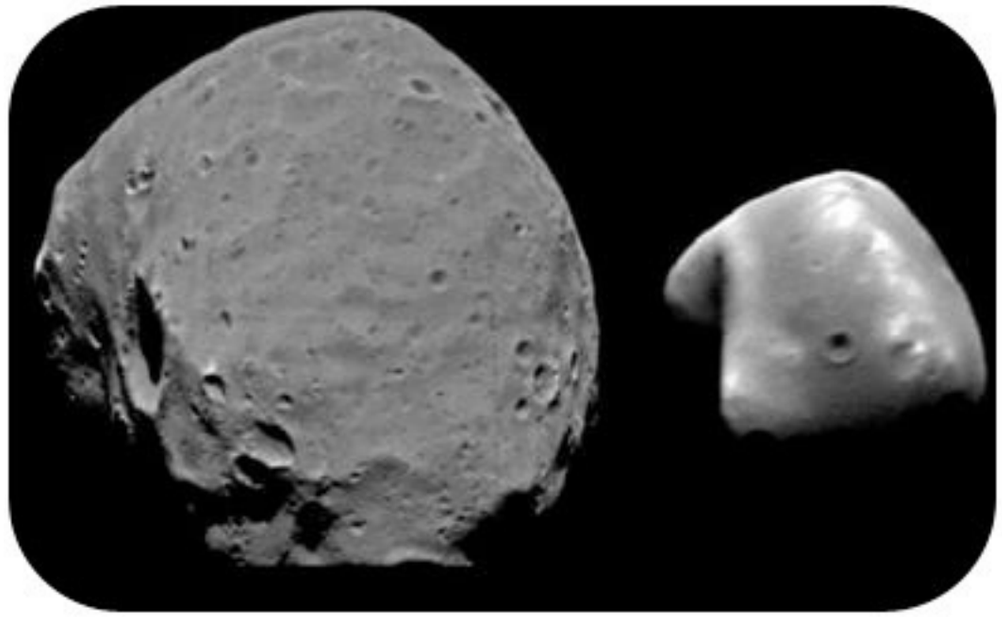


Figure 3.27

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://commons.wikimedia.org/wiki/File:Orbits_of_Phobos_and_Deimos.gif .

KQED: Searching for Life on Mars

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

is scouring the red planet for clues; it landed in August 2012. Learn more at: http://science.kqed.org/quest/video/searching-for-life-on-mars/ .



Click on the image above for more content

Lesson Summary

•The four inner planets, or terrestrial planets, have solid, rocky surfaces.
•Earth, the third planet from the Sun, is the only planet with large amounts of liquid water, and the only planet known to support life. Earth has a large round moon.
•Mercury is the smallest planet and is the closest to the Sun. With its extremely thin atmosphere, Mercury has a large temperature range. Like the Moon, it is covered with craters.
•Venus is the second planet from the Sun and the closest planet to Earth, in distance and in size. With its thick, corrosive atmosphere, the surface temperature is extremely high.
•Venus has mountainous areas, as well as volcanoes surrounded by plains of lava.
•Mars is the fourth planet from the Sun. Mars is reddish in color and has the largest mountain and the largest canyon in the solar system. It has two small moons.
•Water ice is found in the polar ice caps and under the surface of Mars.

Review Questions

1. Name the inner planets from the Sun outward. Then name them from smallest to largest.

2. Why do the temperatures on some planets vary widely? Why are some temperatures much less variable?

3. Why does Venus have higher temperatures than Mercury?

4. How are maps of Venus made?

5. Name two major ways in which Earth is unlike any other planet.

6. Why is Mars red?

7. Suppose you are planning a mission to Mars. Identify two places where you might be able to get water on the planet. Why is this important?

Further Reading / Supplemental Links

•The Jet Propulsion Lab home page has all the current and past missions with media and activities and great images: http://www.jpl.nasa.gov/ .
•NASA Solar System Explorer, Mercury: http://solarsystem.nasa.gov/planetselector.cfm?Object=Mercury ; http://solarsystem.jpl.nasa.gov/planets/profile.cfm?Object=Mercury&Display=Kids
•Google maps has Mars! http://www.google.com/mars/
•Home page of the Mars Exploration Rover Mission: http://marsrovers.jpl.nasa.gov/home/index.html
•A short video about Mercury: http://www.youtube.com/watch?v=U8-DTJpygyk
•A short video about Venus: http://www.youtube.com/watch?v=HqFVxWfVtoo
•A short video about Mars: http://www.youtube.com/watch?v=M-KfYEQUg2s

Points to Consider

•The first humans may reach Mars sometime in the next few decades. What conditions will they face? Why do you think we are going to Mars instead of Mercury or Venus?
•Why are the four inner planets called terrestrial planets? What might a planet be like if it weren't a terrestrial planet?

Outer Planets

Lesson Objectives

- Describe key features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Vocabulary

- Galilean moons
- gas giants
- Great Red Spot
- outer planets
- planetary rings

Introduction

Solar System webpage

Solar system interactive tour

The four outer planets are farther from the Sun as well as farther from Earth. They are much more difficult to learn about since they are very different from our home planet.

The Outer Planets

The four planets farthest from the Sun are the **outer planets** . **Figure** below 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** .

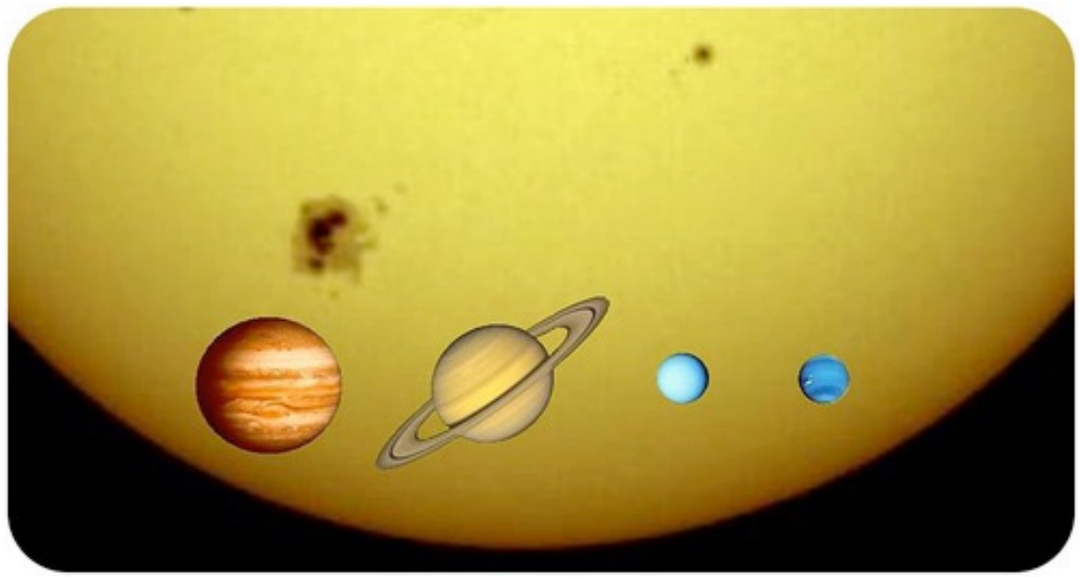


Figure 3.28

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.

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.

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.

Jupiter

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** below). 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.



Figure 3.29

This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details.

Jupiter is named for the king of the gods in Roman mythology. The planet 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.

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** below).

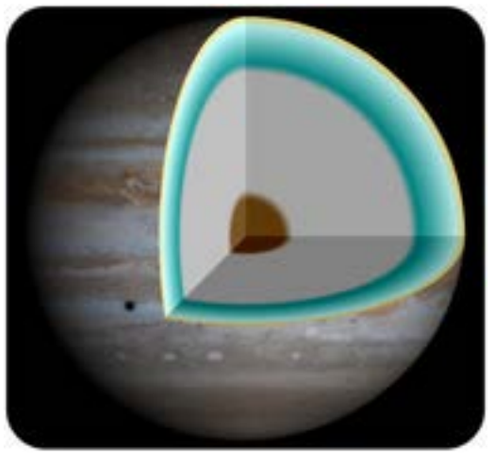


Figure 3.30

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.

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** below) 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 3.31

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** below). 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!



Figure 3.32

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.

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** below). 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.



Figure 3.33

An enhanced color image of a portion of Europa's icy surface. The surface ice may have motions similar to plate tectonics on Earth.

In 1979, two spacecrafts — Voyager 1 and Voyager 2 — visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is difficult to observe from Earth.

Saturn

Saturn, shown in **Figure** below , 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.

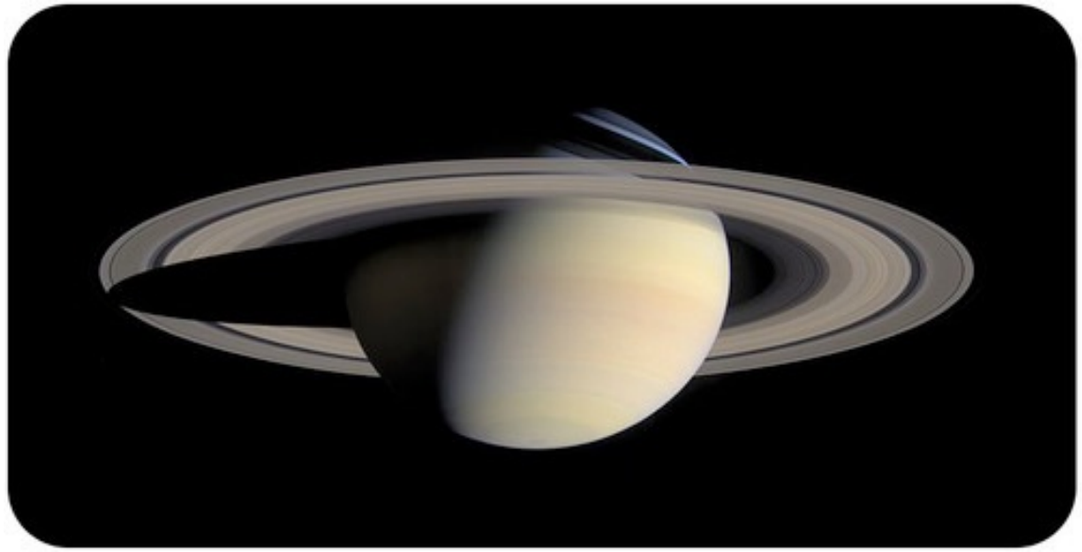


Figure 3.34

This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2008

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 phenomena 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.

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 Lots 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** below).

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.



Figure 3.35

A color-exaggerated mosaic of Saturn and its rings taken by Cassini as Saturn eclipses the Sun.

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** below). There are several gaps in the rings that scientists think have originated because (1) the material was cleared out by the gravitational pull within the rings or (2) by the gravitational forces of Saturn and of moons outside the rings.

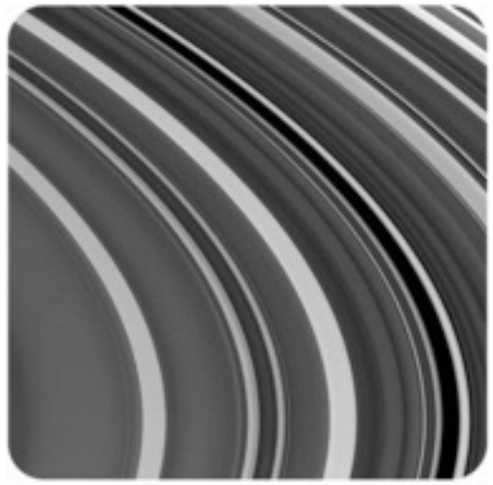


Figure 3.36

A close-up of Saturn's outer C ring showing areas with higher particle concentration and gaps.

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.

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** below).

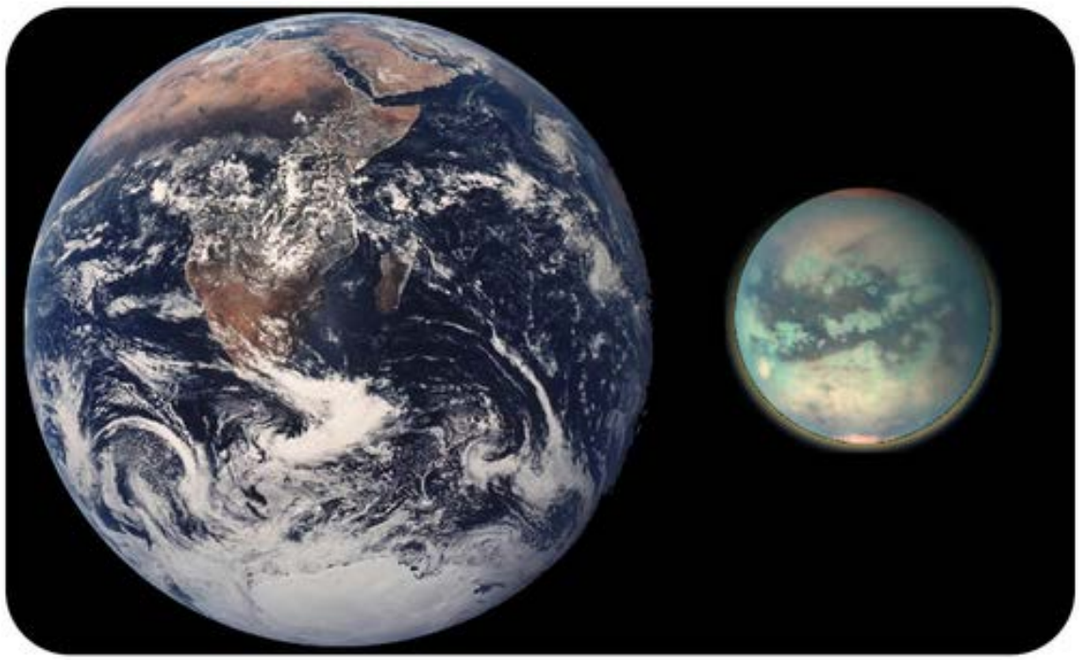


Figure 3.37

This composite image compares Saturn's largest moon, Titan (right) to Earth (left).

Uranus

Uranus (YOOR-uh-nuhs) is named for the Greek god of the sky (**Figure** below). From Earth, Uranus is so faint that it was unnoticed by ancient observers. William Herschel first discovered the planet in 1781.



Figure 3.38

Uranus is an icy blue-green ball.

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** below). 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.

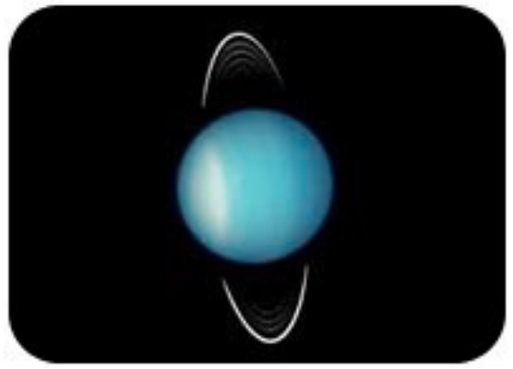


Figure 3.39

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** below .



Figure 3.40

These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus.

Neptune

Neptune, shown in **Figure** below , 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.

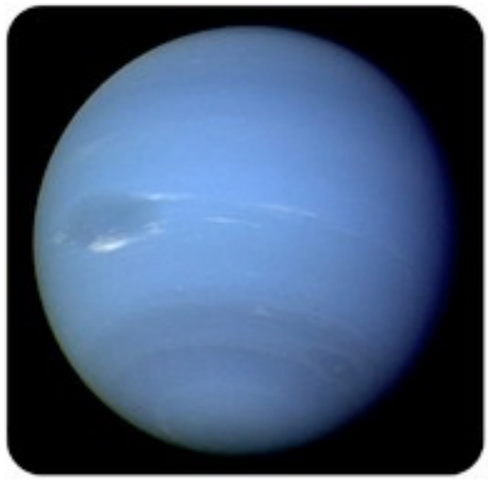


Figure 3.41

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** below). 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.

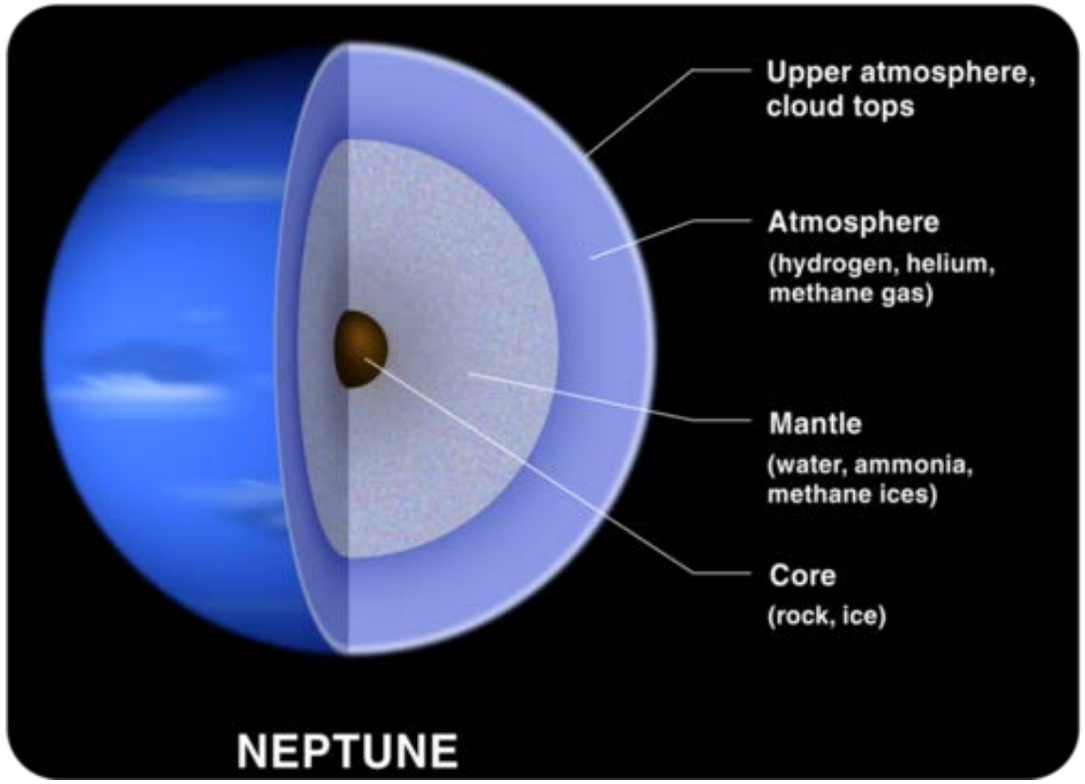


Figure 3.42

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.

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 that 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 is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about -218 ◦C (-360 ◦F).

Neptune's Rings and Moons

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** below , 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.

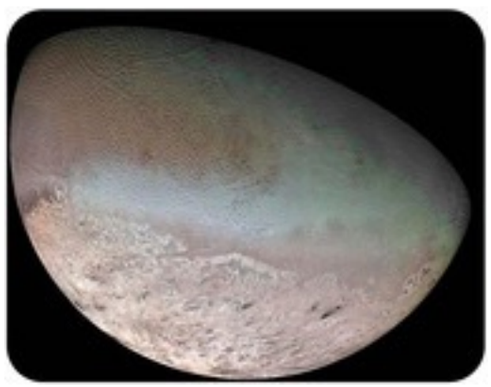


Figure 3.43

This image 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

Lesson Summary

- The four outer planets are all gas giants made primarily of hydrogen and helium. They have thick gaseous outer layers and liquid interiors.
- The outer planets have numerous moons, as well as planetary rings.
- Jupiter, by far the largest planet in the solar system, has bands of different colored clouds, and a long-lasting storm called the Great Red Spot.
- Jupiter has more than 60 moons including the four largest, the Galilean moons.
- Europa has an ocean of liquid water under a layer of ice where life may have formed.
- Saturn is smaller than Jupiter but has a large system of beautiful rings.
- Titan's atmosphere is similar to early Earth's and the moon could harbor primitive life.
- Uranus and Neptune were discovered relatively recently since they are so far away.
- Uranus is tilted on its side, probably because of a past collision with a large object.
- Neptune is very cold and has strong winds. Its dark spots are storms in Neptune's atmosphere.

Review Questions

1. Name the outer planets a) in order from the Sun outward, b) from largest to smallest by mass, and c) from largest to smallest by size.

2. Why are the outer planets called gas giants?

3. How do the Great Red Spot and Great Dark Spot differ?

4. Name the Galilean moons, and explain why they have that name.

5. Why might Europa be a likely place to find extraterrestrial life?

6. What causes gaps in Saturn's rings?

7. Why are scientists interested in the atmosphere of Saturn's moon Titan?

8. What liquid is found on the surface of Titan?

9. Why is Uranus blue-green in color?

10. What is the name of Neptune's largest moon?

Further Reading / Supplemental Links

- Cool jobs! Planetary meteorologist: http://news.discovery.com/videos/discovery-news-2009-planetary-meteorologist.html
- About the Cassini Mission to Saturn: http://saturn.jpl.nasa.gov/
- NASA's world book, Jupiter: http://www.nasa.gov/worldbook/jupiter_worldbook.html
- NASA's planet selector: http://solarsystem.nasa.gov/planetselector.cfm
- Short videos of the planet Jupiter: http://www.youtube.com/watch?v=5iVw72sX3Bg;
- Video of Saturn: http://www.youtube.com/watch?v=iLXeUVCNoX8
- From the BBC Documentary, The Planets, Neptune: http://www.youtube.com/watch?v=29wfzotaBIg

Points to Consider

- The inner planets are small and rocky, while the outer planets are large and gaseous. Why might the planets have formed into these two groups?
- We have discussed the Sun, the planets, and the moons of the planets. What other objects can you think of that can be found in our solar system?

Other Objects in the Solar

Other Objects in the Solar System

Lesson Objectives

- Locate and describe the asteroid belt.
- Explain where comets come from and what causes their tails.
- Differentiate between meteors, meteoroids, and meteorites.

Vocabulary

- asteroid
- asteroid belt
- comet
- dwarf planet
- Kuiper belt
- meteor
- meteor shower
- meteoroid

Introduction

Solar System website

When the solar system formed, most of the matter ended up in the Sun. Material spinning in a disk around the Sun clumped together into larger and larger pieces to form the eight planets. But some of the smaller pieces of matter never joined one of these larger bodies and are still out there in space.

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** below). Collisions with other bodies may break up the asteroid or create craters on its surface.



Figure 3.44

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).

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 history.

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** below . Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's moon.

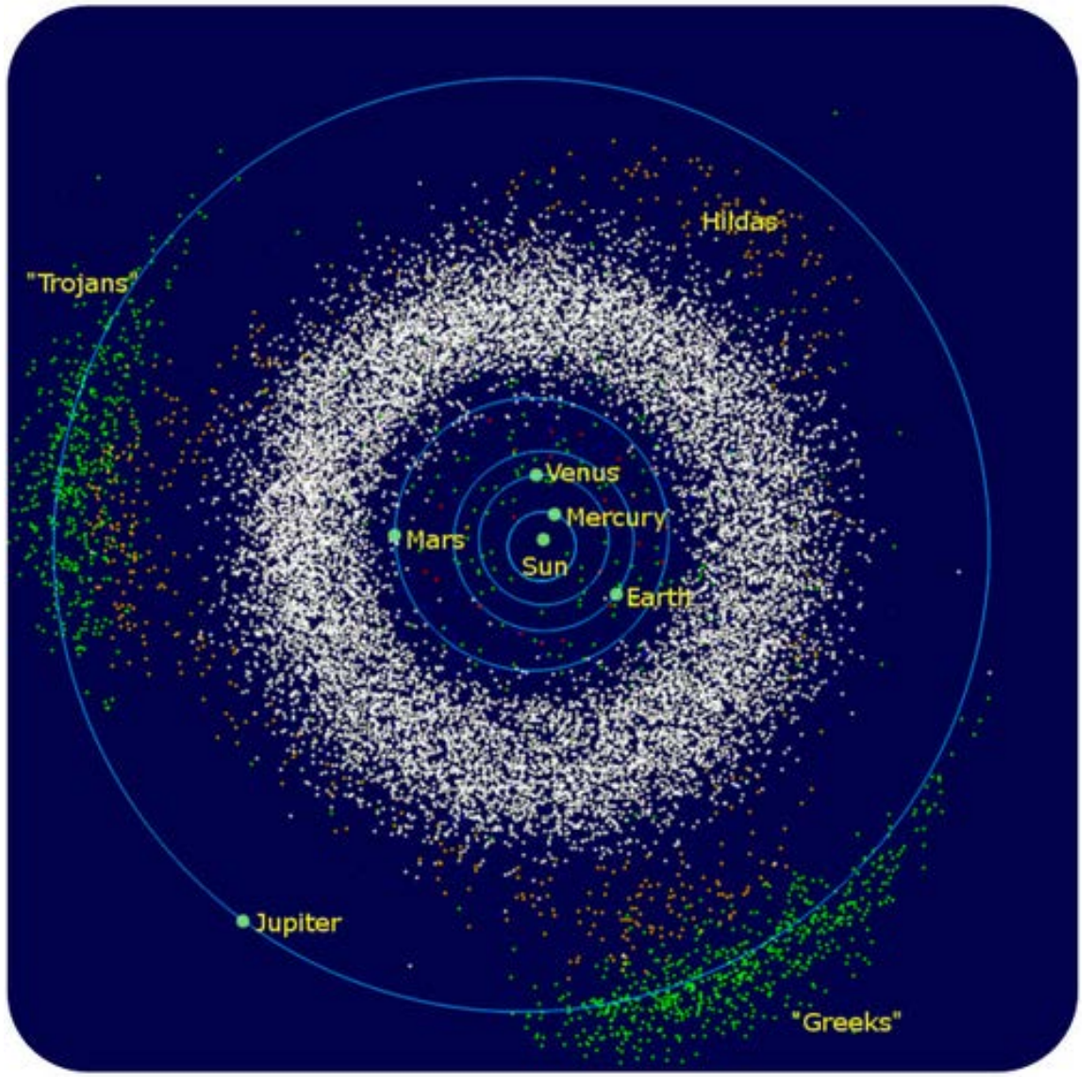


Figure 3.45

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).

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** below). 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.



Figure 3.46

A painting of what an asteroid a few kilometers across might look like as it strikes Earth.

Asteroid Missions

Scientists are interested in asteroids because they are representatives of the earliest solar system (**Figure** below). 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 orbited asteroid Vesta from July 2011 to September 2012 and is on its way to meet dwarf planet Ceres in 2015.

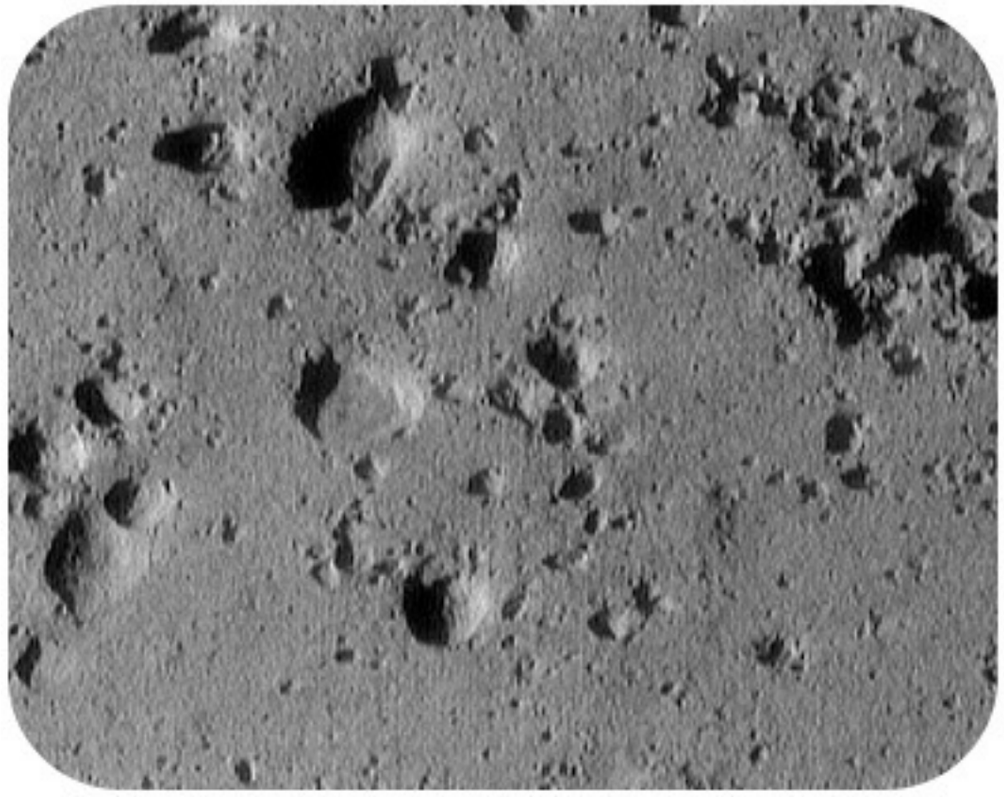


Figure 3.47

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/ .



Click on the image above for more content

Meteors

A **meteor** , such as in **Figure** below , 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.



Figure 3.48

A meteor streaks across the sky.

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** below). 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 3.49

A lunar meteorite originates on the Moon and strikes Earth.

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 (**Figure** below). Early in Earth's history, comets may have brought water and other substances to Earth during collisions.

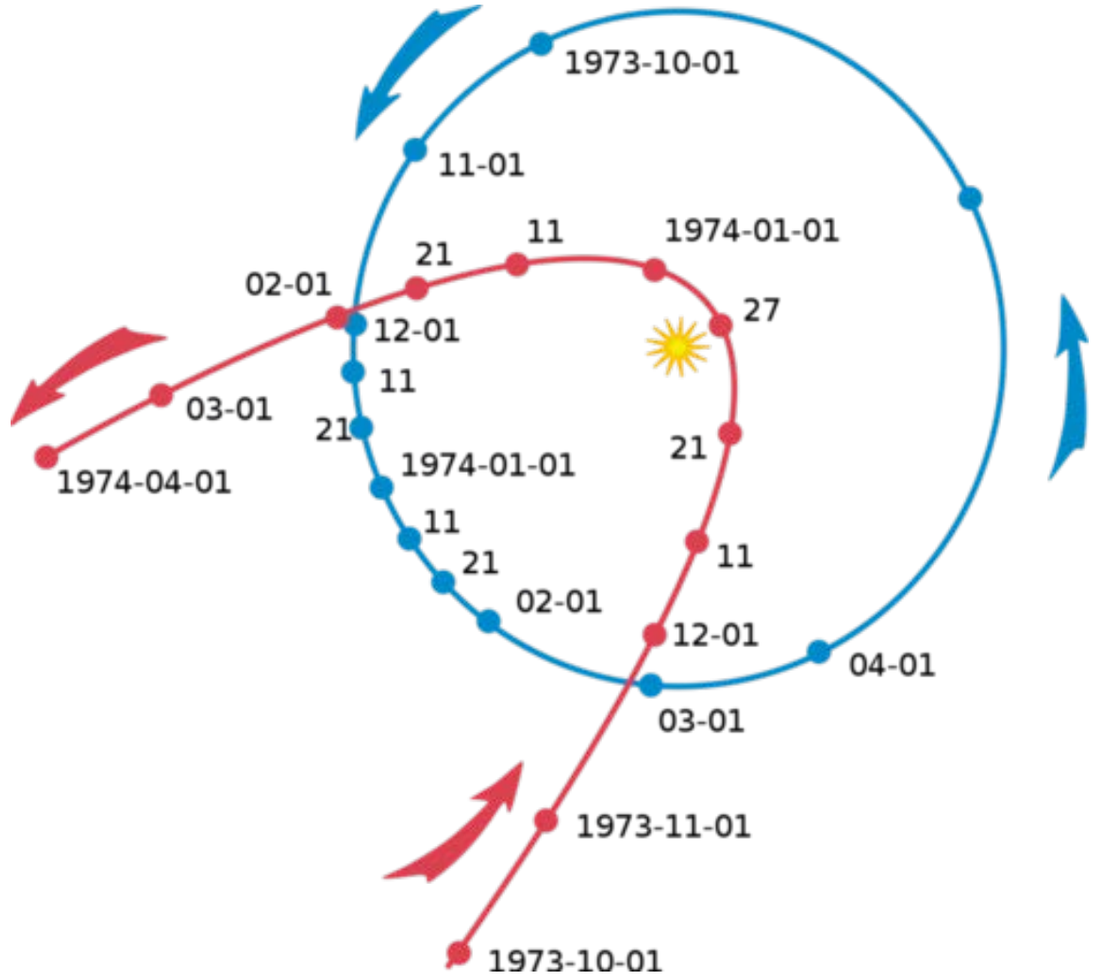


Figure 3.50

The highly elliptical orbit of Kohoutek (red) relative to Earth's more circular orbit (blue) and the position of the Sun.

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** below). 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 3.51

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. The **Kuiper belt** (pronounced "KI-per") contains not only comets, but 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).

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, in 2006, astronomers refined the definition of a planet. Their subsequent 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. The question is: What is and is not a planet?

Pluto

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** below). With better telescopes, astronomers realized that Pluto was much smaller than they had thought.

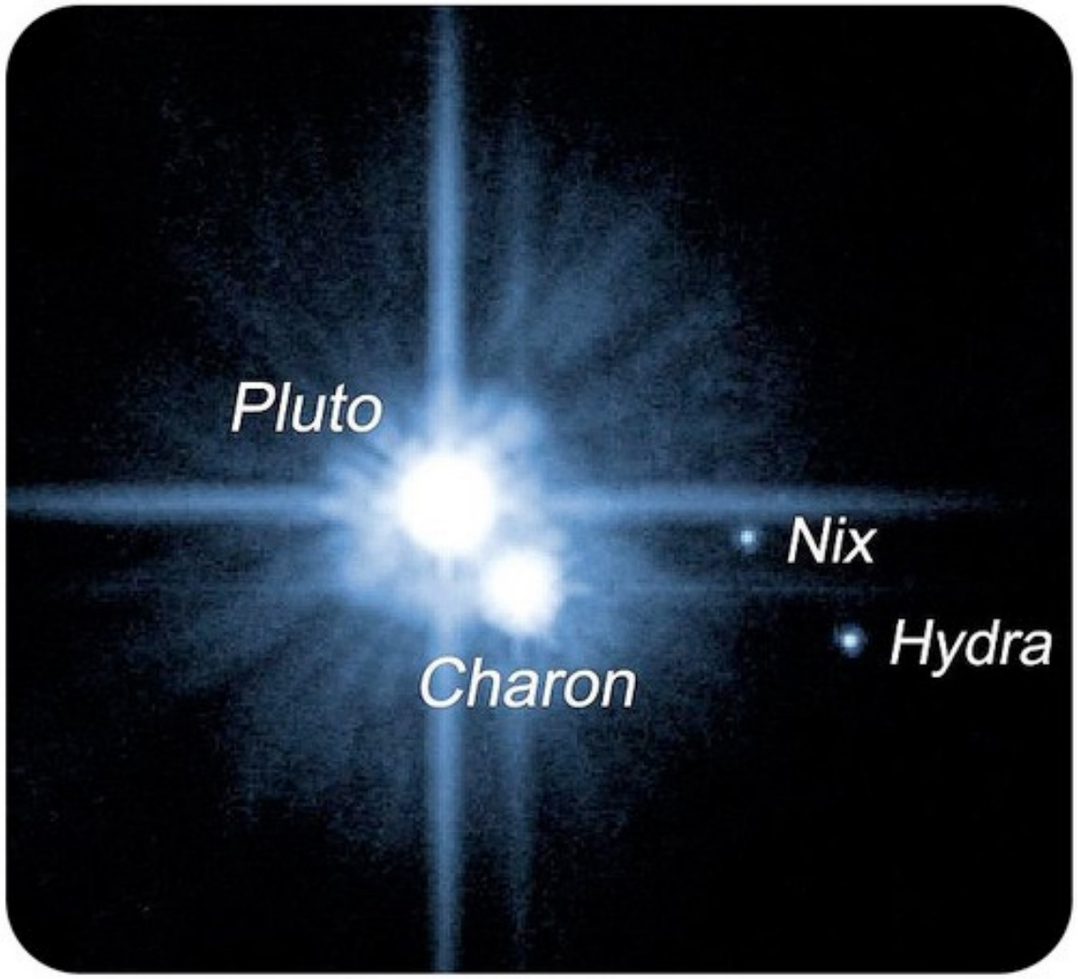


Figure 3.52

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 (**Figure** below).

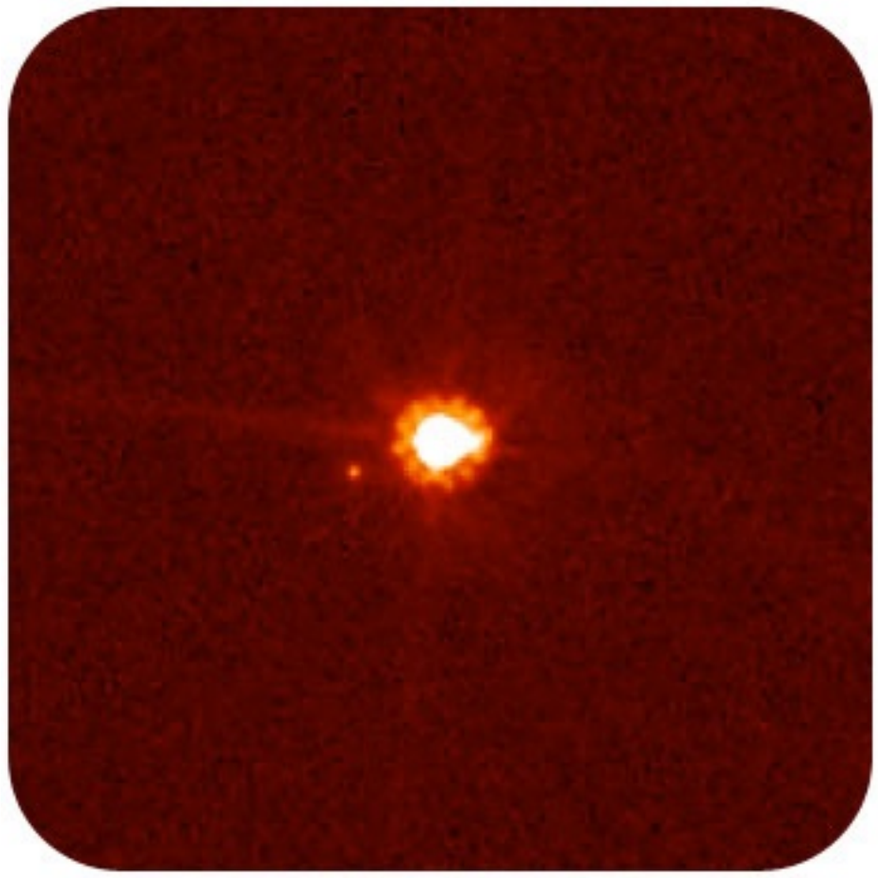


Figure 3.53

Eris and its moon Dysnomia.

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?

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.

A dwarf planet is an object that meets items the first three items in the list above, but not but not the fourth. Pluto is now called a dwarf planet, along with the objects Ceres, Makemake, and Eris.

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.

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** below). Two smaller moons, Nix and Hydra, were discovered in 2005. But having moons is not enough to make an object a planet.

Ceres

Ceres is the largest object in the asteroid belt (**Figure** below). 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 3.54

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** below). 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.

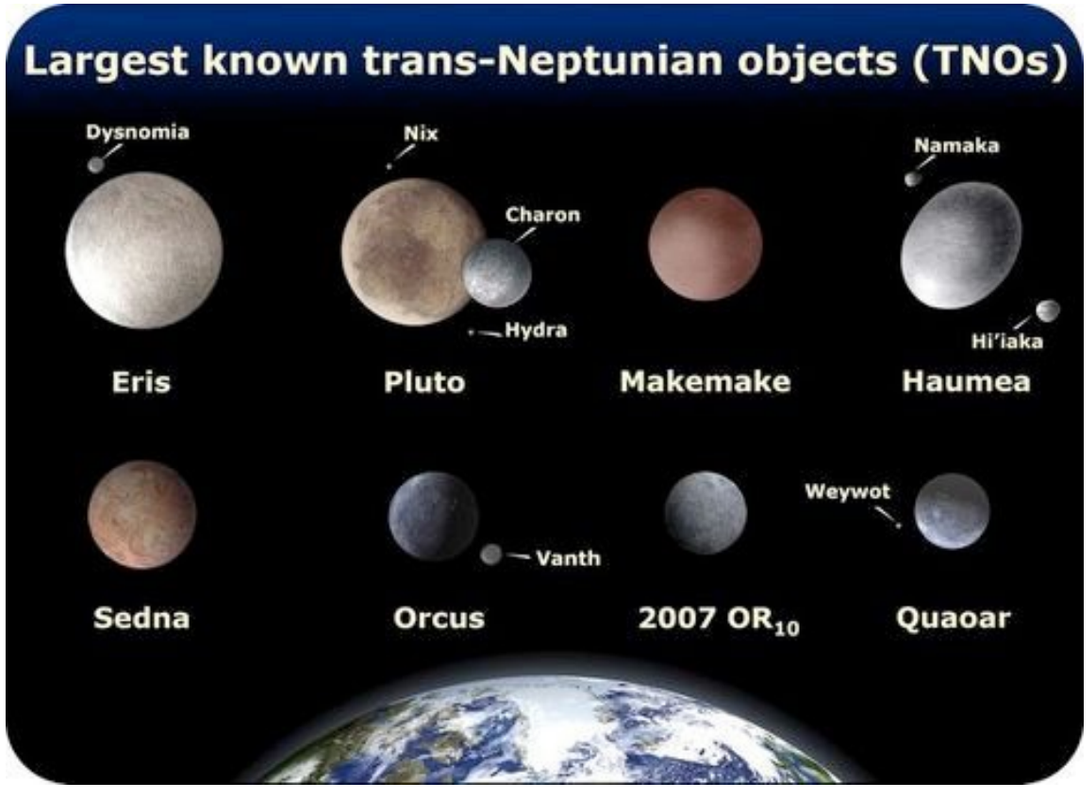


Figure 3.55

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 — about 27% more massive 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 and so now the total is 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.

Lesson Summary

•Asteroids are irregularly shaped, rocky bodies that orbit the Sun. Most are found in the asteroid belt, between the orbits of Mars and Jupiter.
•Meteoroids are smaller than asteroids, ranging from the size of boulders to the size of sand grains. When meteoroids enter Earth's atmosphere, they vaporize, creating a trail of glowing gas called a meteor. If any of the meteoroid reaches Earth, it is a meteorite.
•Comets are small, icy objects that have very elliptical orbits. When they are close to the Sun, they form comas and tails, which glow and make the comet more visible.
•Short-period comets come from the Kuiper belt, beyond Neptune. Long-period comets come from the very distant Oort cloud.
•Dwarf planets are spherical bodies that orbit the Sun, but that have not cleared their orbit of smaller bodies. Ceres is a dwarf planet in the asteroid belt. Pluto, Makemake and Eris are dwarf planets in the Kuiper belt.

Review Questions

1. Arrange the following from smallest to largest: asteroid, star, meteoroid, planet, dwarf planet.

2. Where are most asteroids found?

3. What is the difference between a meteor, a meteoroid, and a meteorite?

4. Why are meteorites extremely valuable to scientists?

5. What objects would scientists study to learn about the composition of the Oort cloud?

6. Why is Pluto no longer considered a planet?

7. Name the four known dwarf planets in our solar system.

Further Reading / Supplemental Links

•NASA worldbook on asteroids: http://www.nasa.gov/worldbook/asteroid_worldbook.html

Points to Consider

•In 2006, astronomers changed the definition of a planet and created a new category of dwarf planets. Do you think planets, dwarf planets, moons, asteroids, and meteoroids are clearly separate groups?
•What defines each of these groups, and what do objects in these different groups have in common? Could an object change from being in one group to another? How?
•We have learned about many different kinds of objects that are found within our solar system. What objects or systems of objects can you think of that are found outside our solar system?

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Ch. 4: Earth, Moon, and Sun



A photograph of Earth taken by an astronaut orbiting the Moon on Christmas Eve, 1968. The three Apollo 8 astronauts were the first humans to ever leave Earth orbit.

In this image, light from the Sun partially illuminates Earth. Earth is partially darkened just as the Moon appears partially darkened to Earth observers during many of its phases.

Courtesy of the Apollo 8 crew and NASA. www.nasa.gov/multimedia/imagegallery/image_feature_102.html. Public Domain.

Section 1

Planet Earth

Planet Earth

Lesson Objectives

- Recognize that Earth is a modified sphere (oblate spheroid), and describe the evidence for this conclusion.
- Explain what causes Earth's magnetism and the effects that magnetism has on the Earth.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- ellipse
- hemisphere
- revolution
- rotation

Introduction

This book so far has been almost entirely about Earth. This chapter is concerned with Earth as a planetary body, a member of the Earth-Moon pair that orbit each other and the Sun.

Earth as a Planetary Body

Earth is an inner planet in the solar system and it is very much like the other inner planets, at least in its size, shape, and composition. But many features make Earth very different from the planets and any other planet that we know of so far.

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. Or 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 but the ship's bottom also starts to disappear as the vessel goes around the arc of the planet (**Figure** below). There are many other ways that early scientists and mariners knew that Earth was not flat.



Figure 4.1

Earth’s curvature is noticeable when objects at a distance are below the arc.

Even the ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. NASA has an animation of a lunar eclipse here: http://science.nasa.gov/media/medialibrary/2003/10/29/04nov_lunareclipse2_resources/reddy1_big.gif .

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 as well.

Earth’s Magnetism

Earth has a **magnetic field** (**Figure** below) 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 and a magnetic field that surrounds it. The magnetic field arises from the convection of molten iron and nickel metal in Earth's outer liquid iron core.

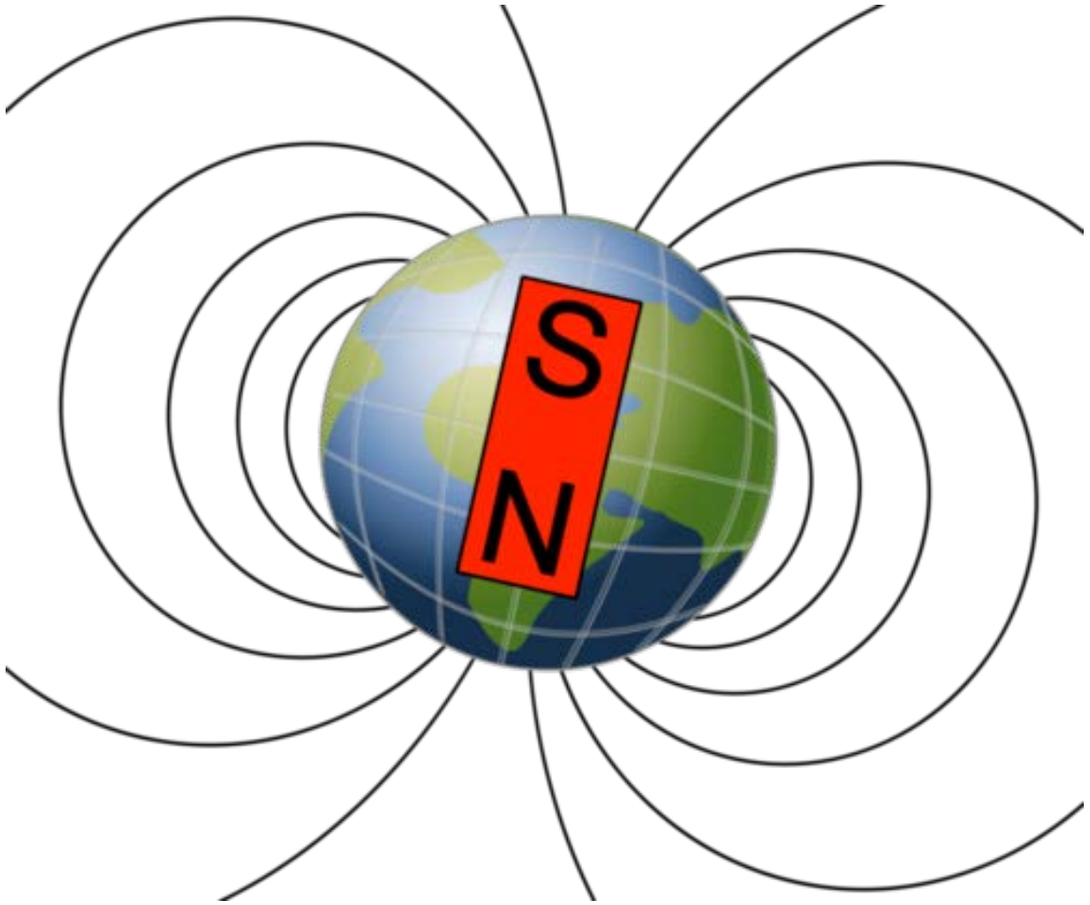


Figure 4.2

Earth's magnetic field.

Earth's magnetic field extends several thousand kilometers into space. The magnetic field shields the planet from harmful radiation from the Sun (**Figure** below).

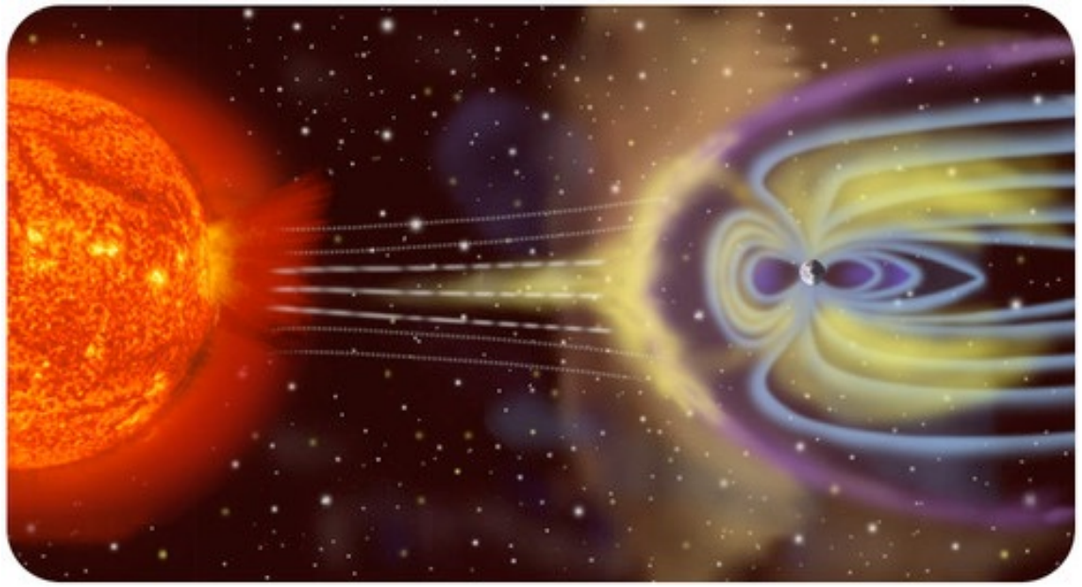


Figure 4.3

Earth, on the right, is tiny in comparison to the Sun, but its magnetic field extends far outward.

Earth's Motions

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** . At the same time that the Earth spins on its axis, it also orbits, or revolves around the Sun. This movement is called **revolution.**

Earth's Rotation

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, letting it swing back and forth in a straight line (**Figure** below). A ball swinging back and forth on a string is called a pendulum.



Figure 4.4

Foucault's pendulum is now on display in the Pantheon in Paris.

A pendulum set in motion will not change its motion, and so the direction of its swinging should not change. However, Foucault observed that his pendulum did seem to change direction. Since he knew that the pendulum could not change its motion, he concluded that the Earth, underneath the pendulum was moving. **Figure** below shows how this might look.



Figure 4.5

Imagine a pendulum at the North Pole. The pendulum always swings in the same direction, but because of Earth's rotation, its direction appears to change to observers on Earth.

An observer in space will see that Earth requires 23 hours, 56 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.

Earth's Revolution

For Earth to make one complete revolution around the Sun takes 365.24 days. This amount of time is the definition of one year. The gravitational pull of the Sun keeps Earth and the other planets in orbit around the star. Like the other planets, Earth's orbital path is an **ellipse** (**Figure** below) so the planet is sometimes farther away from the Sun than at other times. 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. Earth's elliptical orbit has nothing to do with Earth's seasons.

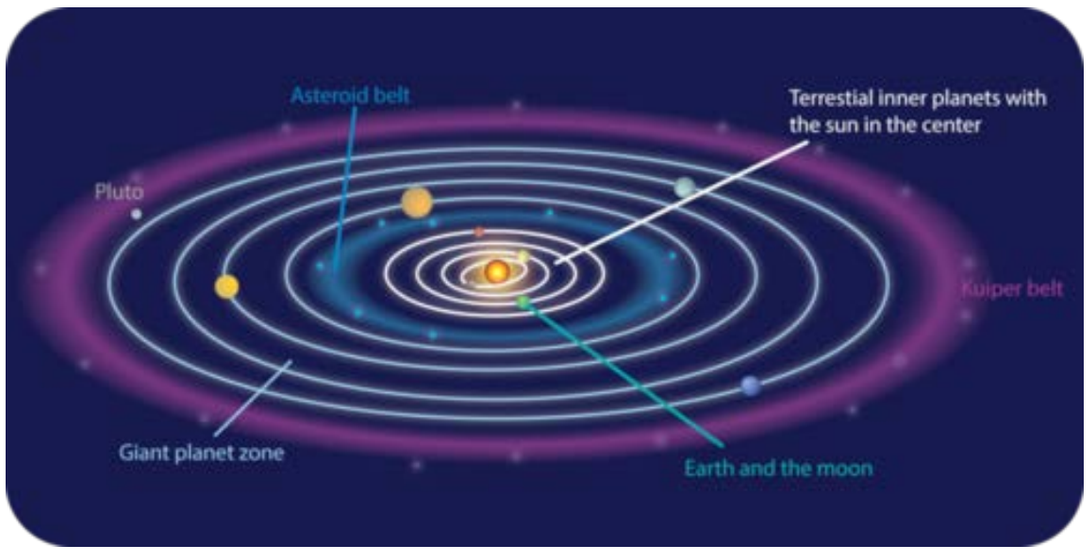


Figure 4.6

Earth and the other planets in the solar system orbit around the Sun. Although the orbits are slightly elliptical, in this image the ellipses are exaggerated.

During one revolution around the Sun, Earth travels at an average distance of about 150 million km. Earth revolves around the Sun at an average speed of about 27 km (17 mi) per second, but the speed is not constant. The planet moves slower when it is at aphelion and faster when it is at perihelion.

The reason the Earth (or any planet) has seasons is that Earth is tilted 23 1/2 ◦on its axis. During the Northern Hemisphere summer the North Pole points toward the Sun, and in the Northern Hemisphere winter the North Pole is tilted away from the Sun (**Figure** below).

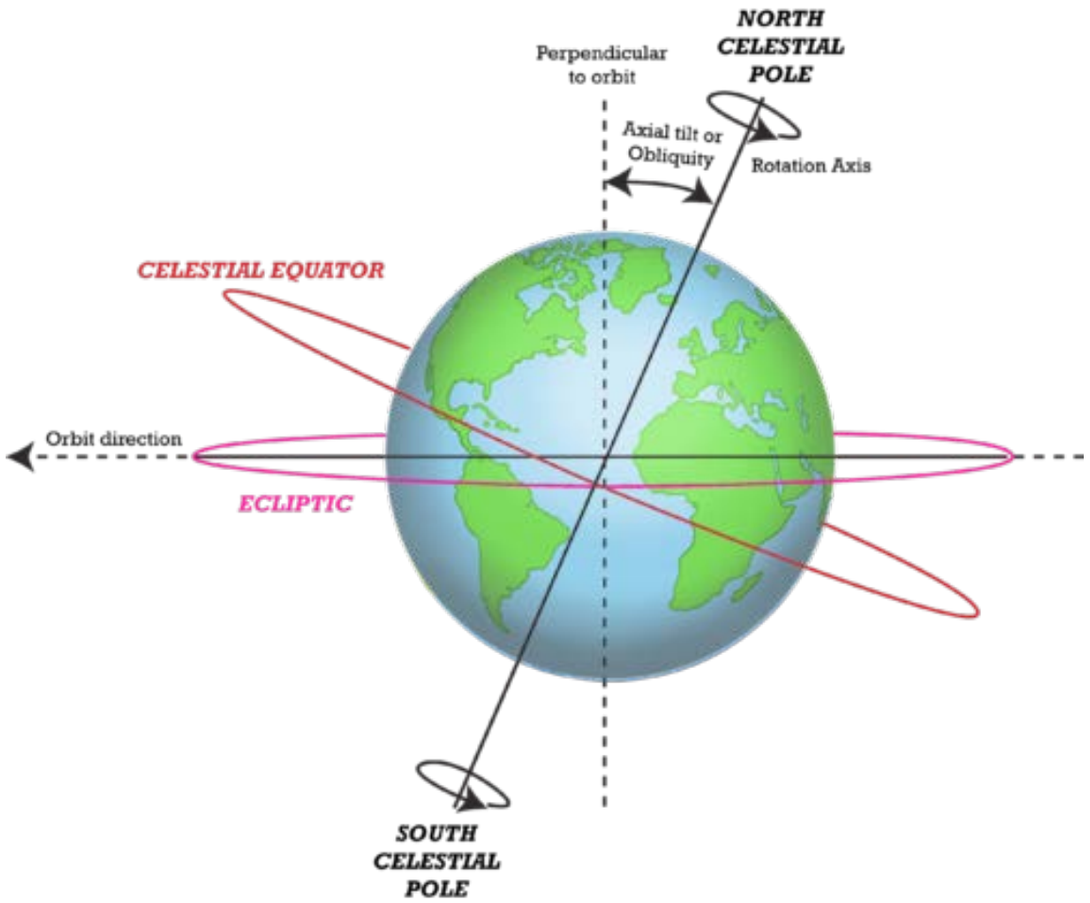


Figure 4.7

The Earth tilts on its axis.

Earth's Precession

In addition to rotation and revolution, Earth's axis rotates (precesses) just as a spinning top does. The period of precession is about 26,000 years. Therefore, the North Celestial Pole will not always be point towards Polaris, the North Star. Around 14,000 A.D., Vega will be the new North Star. Precession is caused by the gravitational pull of the Sun and the Moon on Earth.

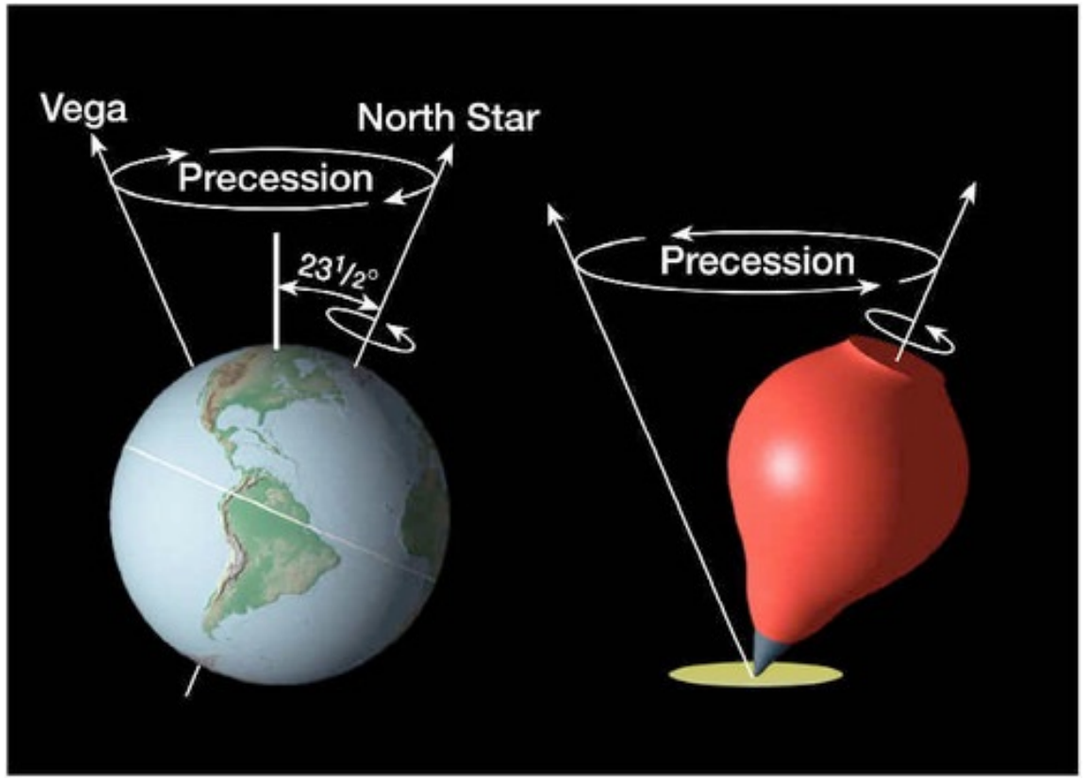


Figure 4.8

Earth's precession

Precession of Earth (3:13)

Lesson Summary

•Earth rotates or spins on its axis approximately once each day and revolves around the Sun approximately once a year.
•Earth's orbit around the Sun is elliptical; the planet is closer at perihelion and farther at aphelion.
•The tilt of Earth's axis produces seasons.
•The Earth and other planets in our solar system are rotating spheres.
•Earth has a magnetic field created by the convection of molten liquid in the outer core.
•The magnetic field shields Earth from harmful solar radiation.

Review Questions

1. When you watch a tall ship sail over the horizon of the Earth, you see the bottom part of it disappear faster than the top part. Why does this happen?

2. Why are we able to use magnets to determine north-south directions on Earth?

3. Describe the difference between Earth's rotation and its revolution.

4. What is the force that keeps the Earth and other planets in their orbital paths?

5. In its elliptical orbit around the Sun, the Earth is closest to the Sun in January. If Earth is closes to the Sun in January, why is January winter in the Northern Hemisphere?

6. Where on Earth would Foucault's pendulum appear to not be moving? Where would it appear to be moving the most?

7. The planet Jupiter is about 778,570,000 kilometers from the Sun; Earth is about 150,000,000 kilometers from the Sun. Does Jupiter take more or less time to make one revolution around the sun? Explain your answer.

Points to Consider

•What type of experiment could you create to prove that the Earth is rotating on its axis?
•If you lived at the equator, would you experience any effects because of Earth's tilted axis?
•If Earth suddenly increased in mass, what might happen to its orbit around the Sun?
•Would life on Earth be impacted if Earth lost its magnetic field?
•Why are the inner planets spherical?

Earth's Moon

Lesson Objectives

- Explain how scientists think the Moon formed.
- Describe the features of the Moon.

Vocabulary

- crater
- lunar
- maria
- terrae

Introduction

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 (**Figure** below). More than 30 years later, the Moon remains the only place that humans have visited outside of our home planet.

Human explorations of the Moon, along with visits by rovers and satellites, have helped scientists learn a great deal about the geology of Earth's only natural satellite. Much of what we know about the Moon was learned by astronauts visiting the Moon and from data collected by the Apollo missions.



Figure 4.9

Astronaut Buzz Aldrin walks on the Moon on July 20, 1969. The footprints are the first signs of life ever on the Moon.

Formation of the Moon

The **giant impact hypothesis** , sometimes called the **Big Splash** , states that the Moon was formed out of the debris left over from an indirect collision between Earth and an astronomical body the size of Mars, approximately 4.5 billion years ago, about 20–100 million years after the solar system coalesced. The colliding body is sometimes called Theia, for the mythical Greek Titan who was the mother of Selene, the goddess of the Moon.

The giant impact hypothesis is currently the favored scientific hypothesis for the formation of the Moon. Supporting evidence includes the Earth's spin and Moon's orbit having similar orientations, Moon samples indicating the surface of the Moon was once molten, the Moon's relatively small iron core, lower density compared to the Earth, evidence of similar collisions in other star systems (that result in debris disks), and that giant collisions are consistent with the leading theories of the formation of the solar system. Finally, the stable isotope ratios of lunar and terrestrial rock are identical, implying a common origin.

There remain several questions/problems concerning the best current models of the giant impact hypothesis, however, so this is still an hypothesis.



Figure 4.10

Big Splash hypothesis

Moon's formation (2:32)

IMPORTANT: Evolution of the Moon (7:06)

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! (By the way, **lunar** means having to do with the Moon.)

The Moon makes one complete orbit around the Earth every 27.3 days, relative to the fixed stars. This is the Moon's orbital period. 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 and so that side of the Moon is what we always see in the night sky (**Figure** below). The Moon makes no light of its own, but instead only reflects light from the Sun.

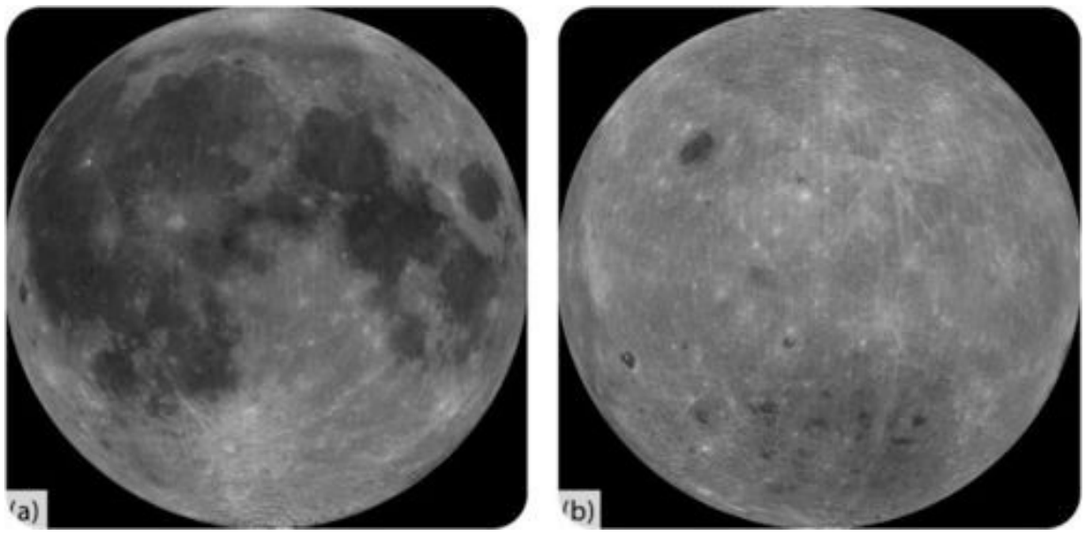


Figure 4.11

(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°F but drops to minus 243°F at night. The coldest temperatures, around minus 397°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. One major lunar surface feature is the bowl-shaped **craters** that are caused by meteorite impacts (**Figure** below). If Earth did not have plate tectonics or erosion, its surface would also be covered with meteorite craters.



Figure 4.12

A crater on the surface of the Moon.

Even from Earth, the Moon has visible dark areas and light areas. The dark areas are called **maria** , which means “seas” since that’s what the ancients thought they were. But 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 filling the craters. Scientists estimate volcanic activity on the Moon ceased about 1.2 billion years ago, but most occurred long before that.

The lighter parts of the Moon are called **terrae** or highlands (**Figure** below). 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.



Figure 4.13

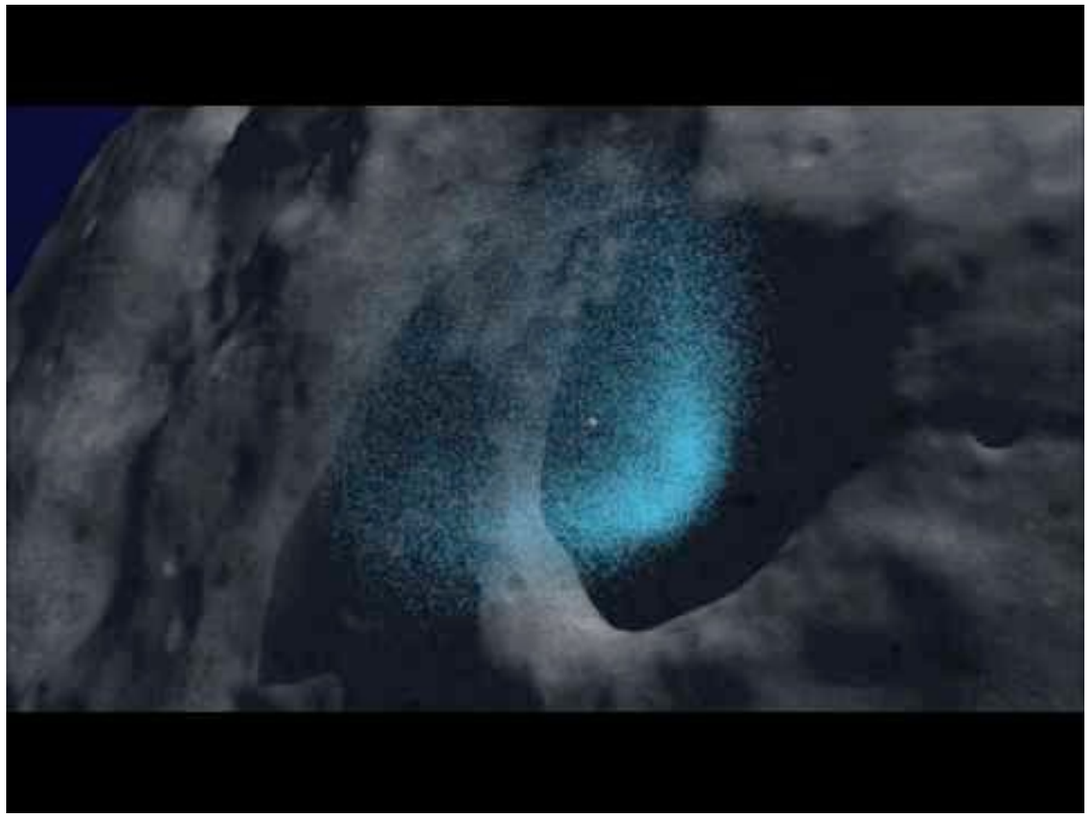
A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon’s surface, mostly on the side of the Moon we see.

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface, but water 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.

KQED: NASA Ames Rocket to the Moon

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! Learn more at: http://science.kqed.org/quest/video/nasa-ames-rocket-to-the-moon/ .



Click on the image above for more content

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 unpiloted spacecraft sent to the Moon (**Figure** below).

- The Moon's small core, 600 to 800 kilometers in diameter is mostly iron with some sulfur and nickel.



Figure 4.14

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.

Lesson Summary

•The Moon makes one rotation on its axis in the time it takes for it to orbit the Earth.
•The Moon has dark areas, called maria, surrounded by lighter colored highland areas, called terrae.
•Because the Moon is geologically inactive and doesn't have an atmosphere, it has many thousands of craters on its surface.
•The Moon is made of many materials similar to Earth and has a crust, mantle, and core, just like the Earth.

Review Questions

1. Compare the composition of the Moon's surface with the composition of Earth's surface.

2. Why is there no weather on the Moon?

3. Rusting is a process that happens when oxygen reacts chemically with iron, in the presence of water. Can rusting occur on the Moon? Explain your answer.

4. What is the difference between maria and terrea?

5. How does the Moon's interior differ from Earth's?

6. How much do landscape features on the Moon change over time compared to landscape features on Earth? Explain your answer.

7. Why is the force of gravity on your body weaker on the Moon than on the Earth?

Points to Consider

•What things would be different on Earth if Earth did not have a moon?
•If the Moon rotated on its axis once every 14 days, would we see anything different than we do now?
•How do we know that the Moon has been geologically inactive for billions of years?

Section 3

The Sun

The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Vocabulary

- chromosphere
- convection zone
- corona
- nuclear fusion
- photon
- photosphere
- plasma
- radiative zone
- solar flare
- solar prominence

Introduction

Consider Earth, the Moon, and all the other planets and satellites in the solar system. The mass of all of those objects together accounts for only 0.2% of the total mass of the solar system. The rest, 99.8% of all the mass in the solar system, is the Sun!

The Sun (**Figure** below) is the center of the solar system and the largest object in the solar system. This nearby star provides light and heat and supports almost all life on Earth.



Figure 4.15

The Sun.

Layers of the Sun

The Sun is a sphere, composed almost entirely of the elements hydrogen and helium. The Sun is not solid or 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** below). From inward to outward they are:

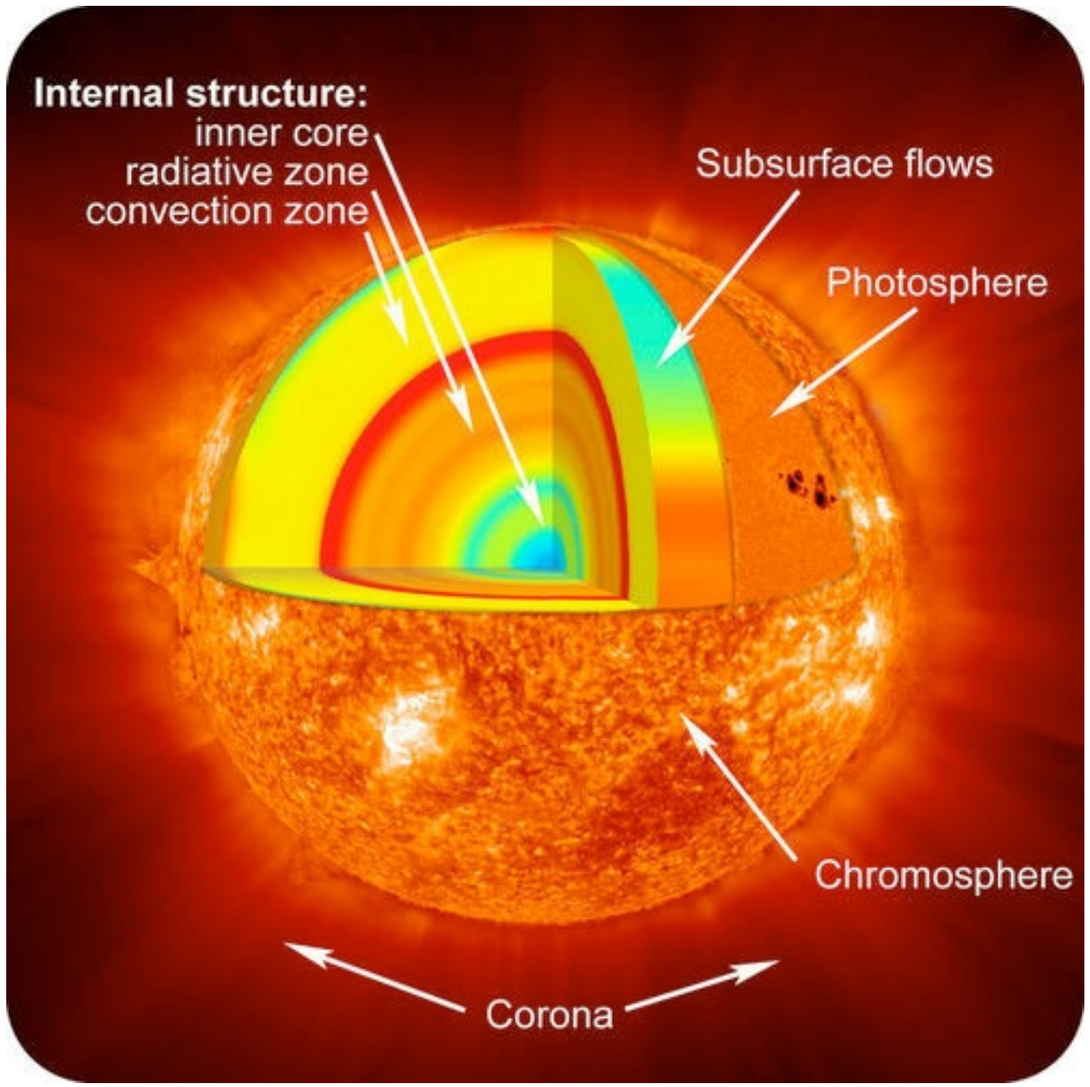


Figure 4.16

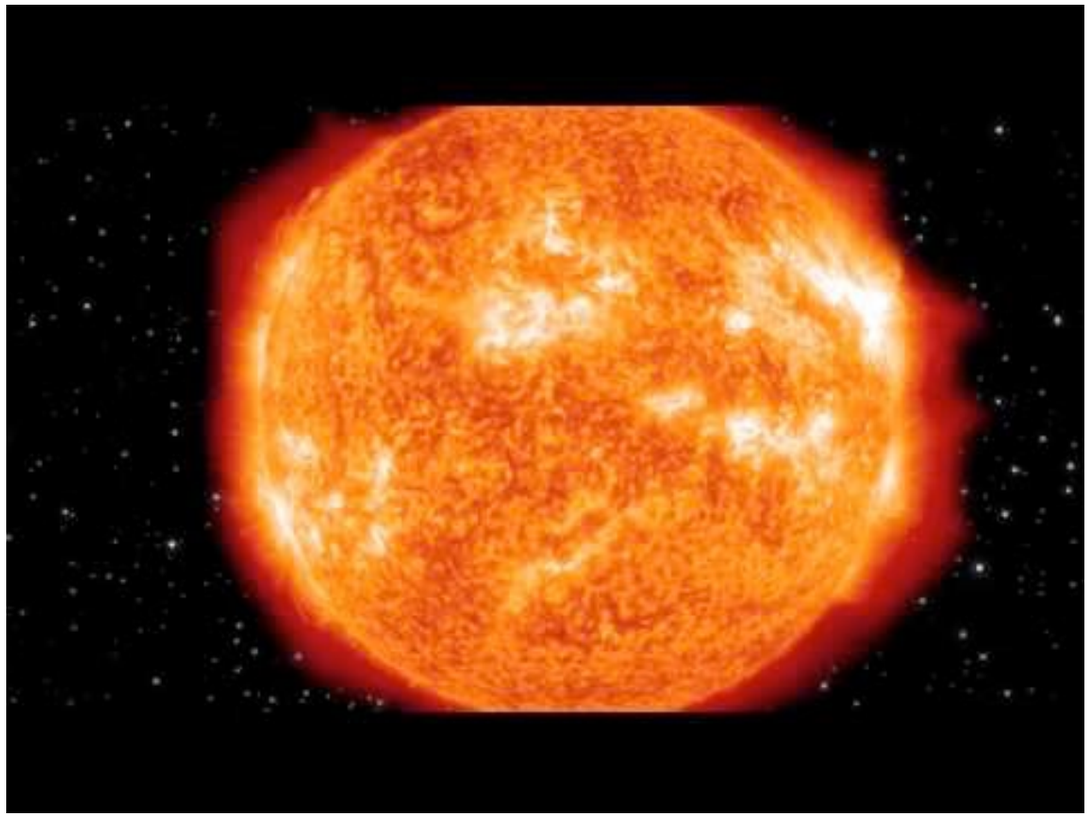
The layers of the Sun.

•The Sun's central core is plasma with a temperature of around 27 million ◦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. Nuclear fusion in stars is discussed more in the *Stars, Galaxies, and the Universe* chapter.

•The **radiative zone** , just outside the core, has a temperature of about 7 million ◦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 **(1e)** : http://www.youtube.com/watch?v=JHf3dG0Bx7I (8:34).



Click on the image above for more content

The second video discusses what powers the sun and what is its influence on Earth and the rest of the solar system **(1e)** : http://www.youtube.com/watch?v=S6VRKKh6gyA (8:25).



Click on the image above for more content

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°C. The photosphere has several different colors; oranges, yellow and reds, giving 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** below). Temperatures in the chromosphere range from about 4,000°C to about 10,000°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 4.17

The chromosphere as seen through a filter.

- The **corona** is the outermost plasma layer -- It is the Sun's halo or 'crown.' The corona's temperature of 2 to 5 million °C is much hotter than the photosphere (**Figure** below).

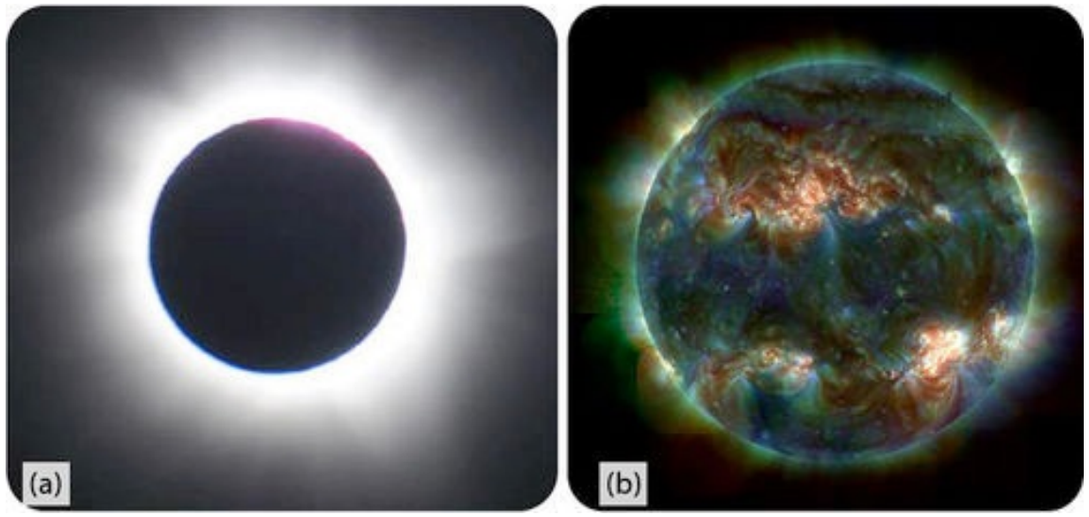


Figure 4.18

(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.

The movie *Seeing a Star in a New Light* can be seen here: http://sdo.gsfc.nasa.gov/gallery/youtube.php .

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 feature of the Sun are cooler, darker areas known as sunspots (**Figure** below). 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 and 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.

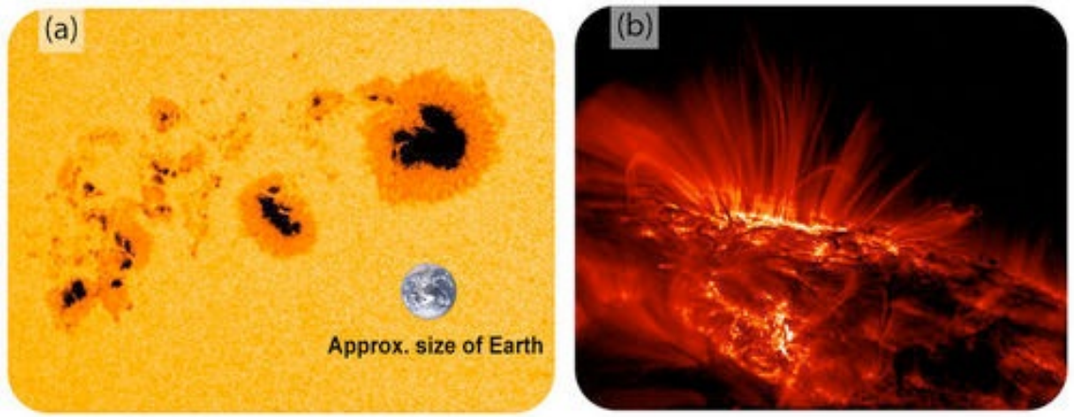


Figure 4.19

(a) 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. (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** below).



Figure 4.20

Magnetic activity leads up to a small solar flare.

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 (**Figure** below).

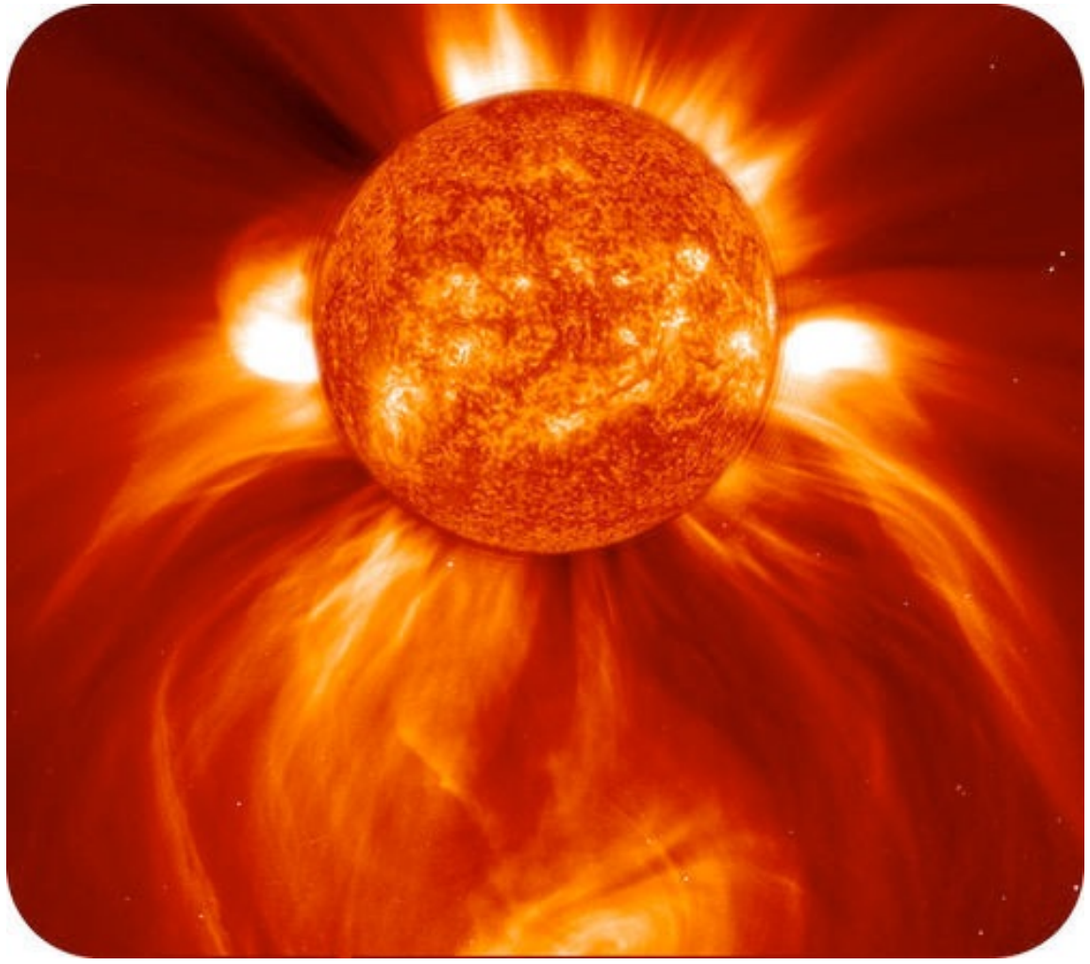


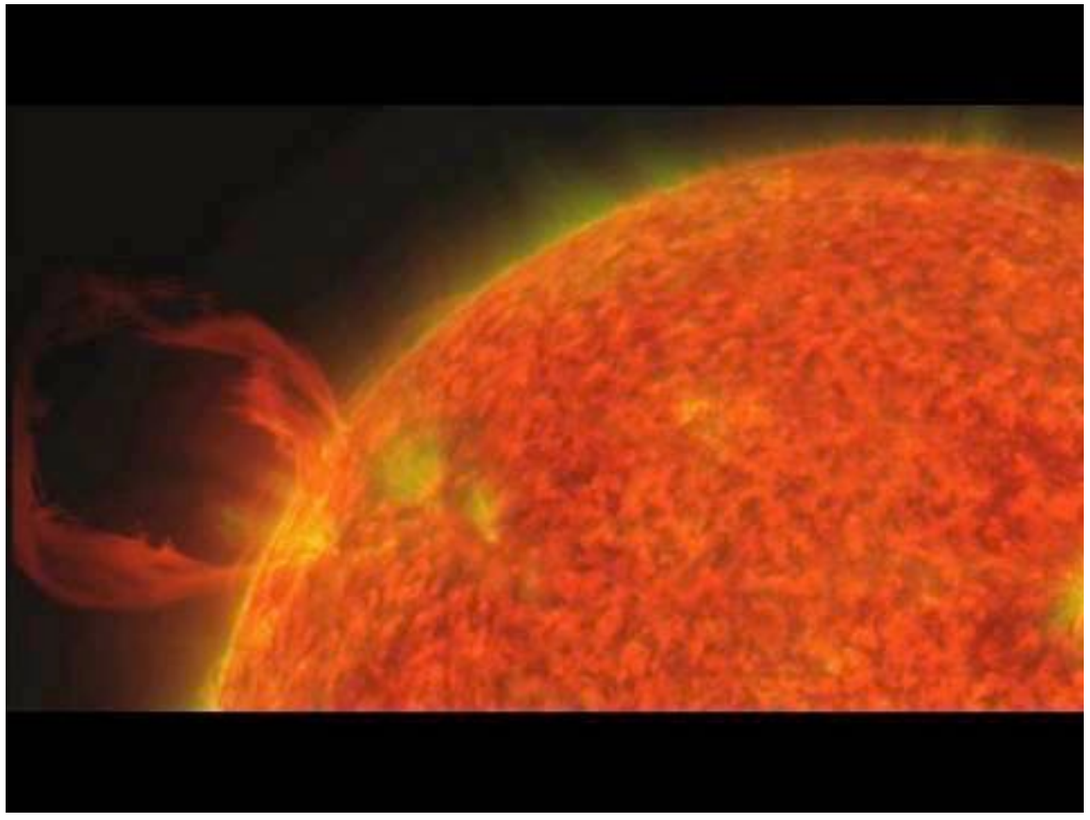
Figure 4.21

A coronal mass ejection is a large ejection of plasma from the star seen in this image.

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.

KQED: Journey Into the Sun

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. Learn more at: http://science.kqed.org/quest/video/quest-quiz-the-sun/ .



Click on the image above for more content

Solar Prominences

Another highly visible feature on the Sun is **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 for 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 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.

Lesson Summary

- The mass of the Sun is 99.8% of the mass of our solar system.
- The Sun is mostly made of hydrogen with smaller amounts of helium in the form of plasma.
- The main part of the Sun has three layers: the core, radiative zone, and convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere, and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Review Questions

1. In what way does the Sun support all life on Earth?

2. Which two elements make up the Sun almost in entirety?

3. Which process is the source of heat in the Sun and where does it take place?

4. Why would human astronauts on a trip to Mars need to be concerned about solar wind? What is solar wind?

5. Describe how movements in the convection zone contribute to solar flares.

6. Do you think fusion reactions in the Sun's core will continue forever and go on with no end? Explain your answer.

Further Reading / Supplemental Links

- To find these videos for download, check out: http://www.nasa.gov/mission_pages/sdo/news/briefing-materials-20100421.html and http://svs.gsfc.nasa.gov/Gallery/SDOFirstLight.html .

•Subscribe to NASA's Goddard Shorts HD podcast: http://svs.gsfc.nasa.gov/vis/iTunes/f0004_index.html .
•To learn more about the SDO mission, visit: http://sdo.gsfc.nasa.gov/ .
•To learn about an older solar mission, SOHO, see: http://sohowww.nascom.nasa.gov/ .

Points to Consider

•If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know? When would we know?
•Are there any types of dangerous energy from the Sun? What might be affected by them?
•If the Sun is made of gases such as hydrogen and helium, how can it have layers?

Going Further - Applying Math

Have would you measure something that you cannot reach? The answer is that you can use simple geometry. We can measure the diameter of the Sun, even though we cannot go to the Sun and even though the Sun is far too large for a human being to measure. To measure the Sun we use the rules of similar triangles. The sides of similar triangles are proportional to each other. By setting up one very small triangle that is proportional to another very large triangle, we can find an unknown distance or measurement as long as we know three out of four of the parts of the equation. If you make a pinhole in an index card and project an image of the Sun onto a clipboard held 1 meter from the index card, the diameter of our projected image of the Sun will be proportional to the true diameter of the Sun. Here's the equation: s / d = S / D, where s = diameter of the projected image of the Sun, S = true diameter of the Sun. The calculation also requires you to know the true distance between the Earth and the Sun, D = 1.496 x 10^{8} km and the distance (d = 1 meter) between the clipboard and the index card. Before you can correctly solve this equation, you will need to be sure all of your measurements are in the same units - in this case, change all your measurements to km. Try this out and see how accurately you can measure the true diameter of the Sun.

The Sun and the Earth-Moon System

Lesson Objectives

- Describe how Earth's movements affect seasons and cause day and night.
- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.
- Explain how movements of the Earth and Moon affect Earth's tides.

Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- shadow
- solar eclipse
- umbra

Introduction

The motions of bodies in the solar system are, for the most part, regular and understandable. From Earth, the Sun rises in the eastern sky in the morning and sets in the western sky in the evening. If the Moon is full on Day 1, it will be full again on Day 28, and new on Day 14. The motions of Earth relative to the Sun, and the motions of the Moon and Sun relative to Earth affect different phenomena on Earth, including day and night, the seasons, tides, and phases of the Moon.

Day-Night Cycle

Earth rotates once on its axis about every 24 hours. To an observer cooling down on 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 time a location is in 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.

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° tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (**Figure** below). 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° N).

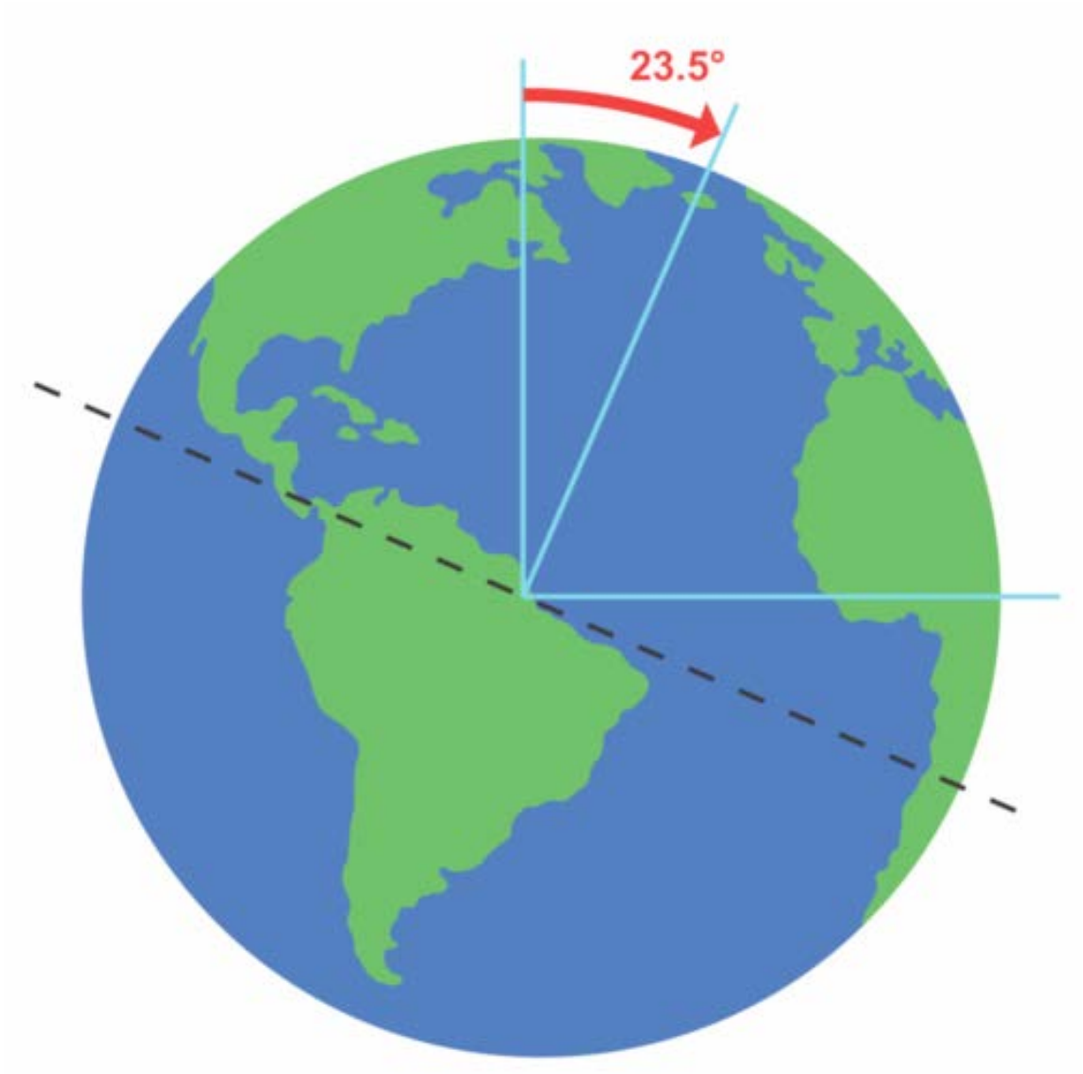


Figure 4.22

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

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 days. The opposite occurs on winter solstice, which begins on December 21. More about seasons can be found in the Earth's Atmosphere chapter.

Check out this video on why earth has seasons to learn more: http://www.youtube.com/watch?v=DuiQvPLWziQ .

Solar Eclipses

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

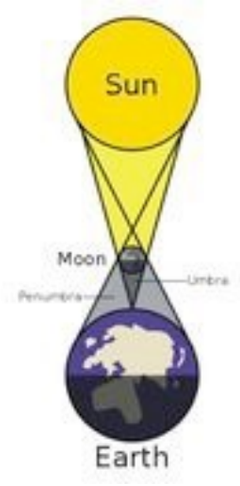


Figure 4.23

A solar eclipse, not to scale.

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

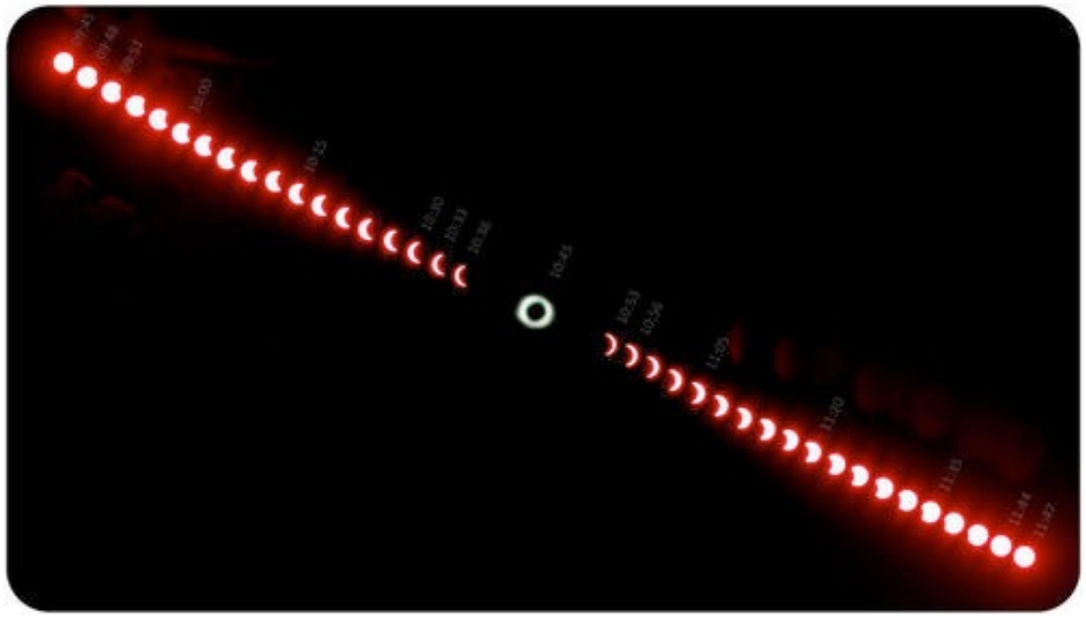


Figure 4.24

A solar eclipse shown as a series of photos.

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

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

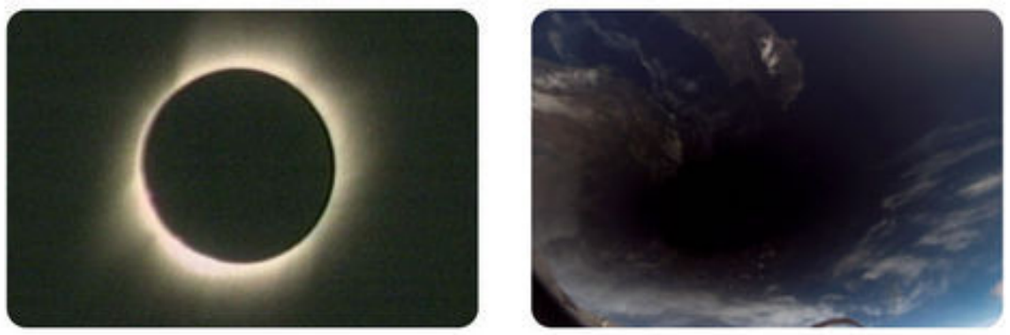


Figure 4.25

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

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.

Solar Eclipses (webpage)

A 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** below). 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.

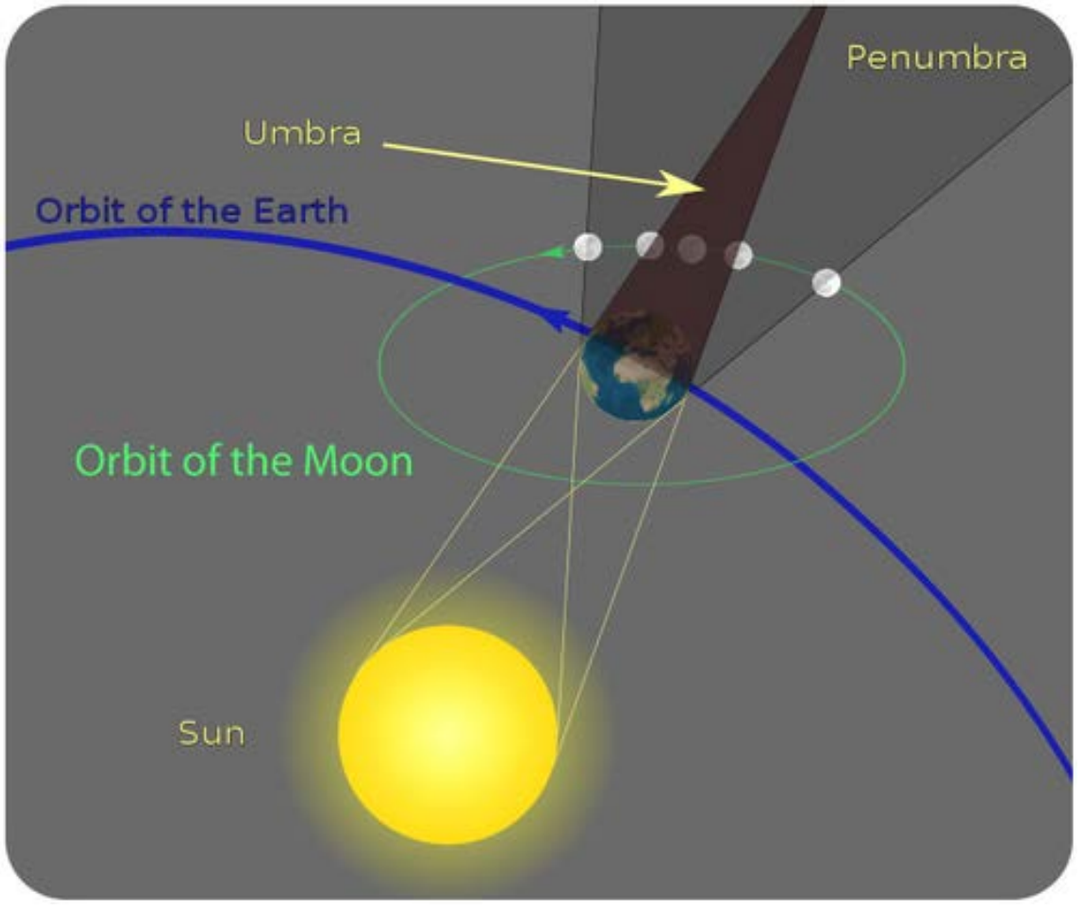


Figure 4.26

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** below).

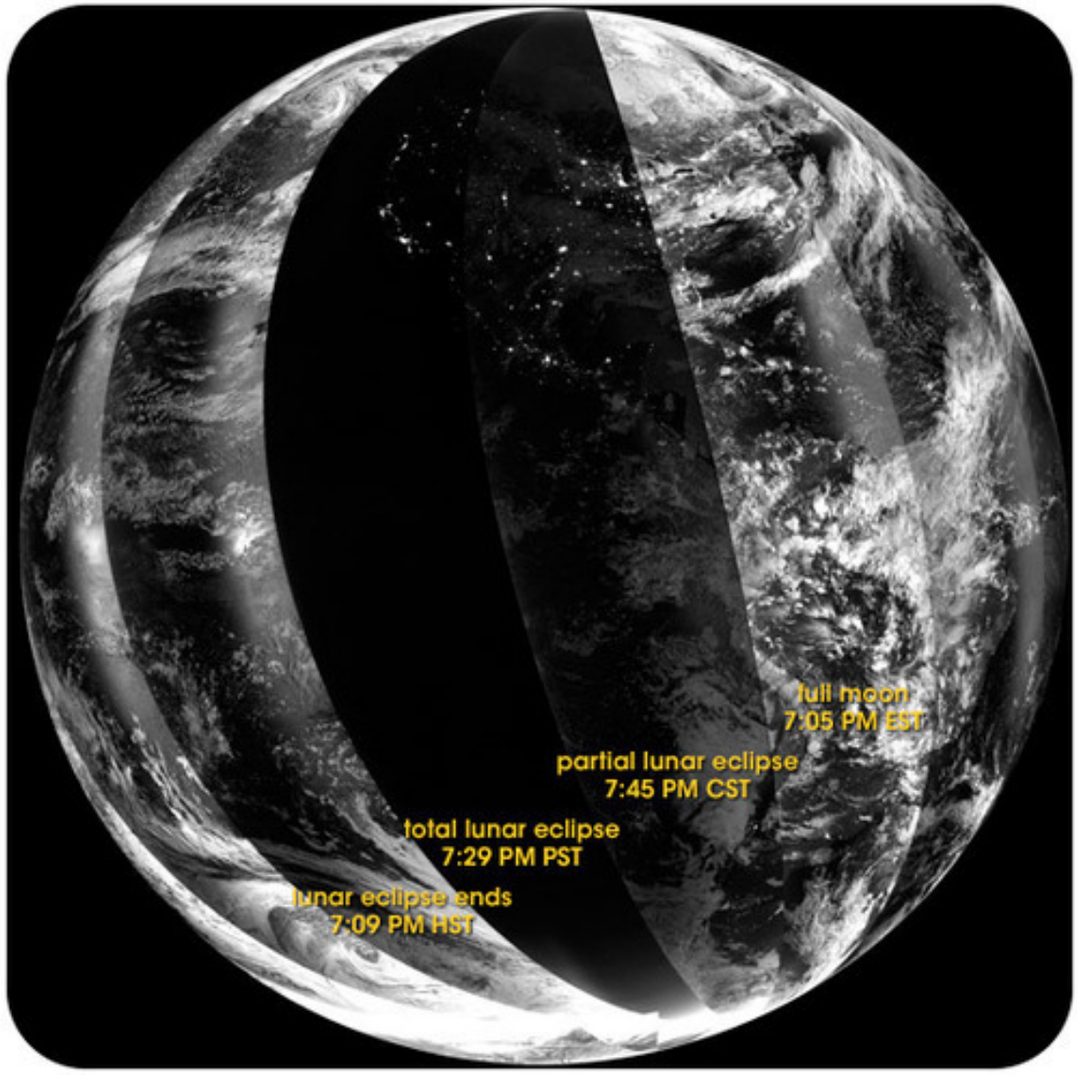


Figure 4.27

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 .

Lunar Eclipse (webpage)

The Phases of the Moon

Like everything in the solar system except the Sun, the Moon does not produce any light of its own — it only reflects sunlight. As the Moon moves around Earth, different portions of the satellite are illuminated. This causes the phases of the Moon, so that our view of the Moon goes from fully lit to completely dark and back again.

- The Moon is full when Earth is between the Moon and the Sun and the Moon's nearside is entirely lit.
- The Moon is at first quarter phase about one week later, when the Moon appears as a half-circle. Only half of the Moon's lit surface is visible from Earth.
- The Moon is in a new moon phase when the Moon moves between Earth and the Sun and the side of the Moon facing Earth is completely dark. Earth observers may be able to just barely see the outline of the new moon because some sunlight reflects off the Earth and hits the moon.
- Before and after the quarter-moon phases are the gibbous and crescent phases. During the **gibbous** moon phase, the moon is more than half lit but not full. During the **crescent** moon phase, the moon is less than half lit and is seen as only a sliver or crescent shape.

It takes about 29.5 days for the Moon to make one cycle relative to the Sun and go through all the phases (**Figure** below). The time between two new Moon phases or two full Moon phases is 29.5 days. Remember that the Moon's orbital period is 27.3 days. The difference of 29.5 and 27.3 is that while the Moon is orbiting the Earth, the Earth is moving along in its orbit so it takes longer for the Moon to reach the same position relative to the Sun.



Figure 4.28

The phases of the moon as if the Sun is above the top of this picture with its rays directed downward.

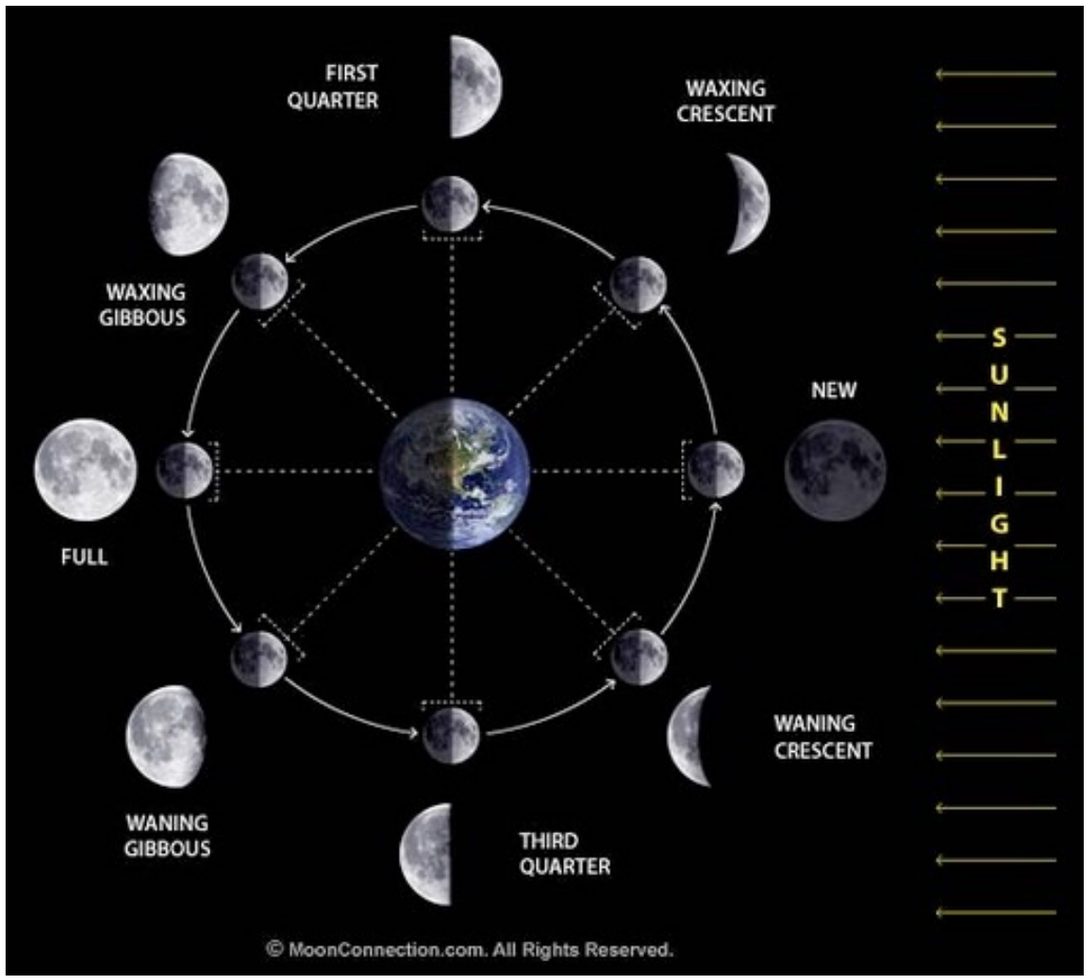


Figure 4.29

Phases of the moon

An animation of lunar phases from the University of Illinois: http://projects.astro.illinois.edu/data/MoonPhases/index.html .

The Tides

Tides are the regular rising and falling of Earth's surface water in response to the gravitational attraction of the Moon and Sun. The Moon's gravity pulls upwards on Earth's water, causing it to bulge out in the direction of the Moon. On the other side of the Earth, a high tide is produced where the Moon's pull is weakest. As the Earth rotates on its axis, the areas directly in line with the Moon experience high tides. The places directly in between the high tides are low tides. There are two high tides and two low tides each tidal day. Since the Earth is rotating on its axis, the high-low-tide cycle moves around the globe in a 24-hour period.

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. When the Sun and Moon are in line, during the new moon and the full moon, their high tides add up and create a spring tide. During a spring tide, high tides are really high, which means that low tides are really low (**Figure** below).

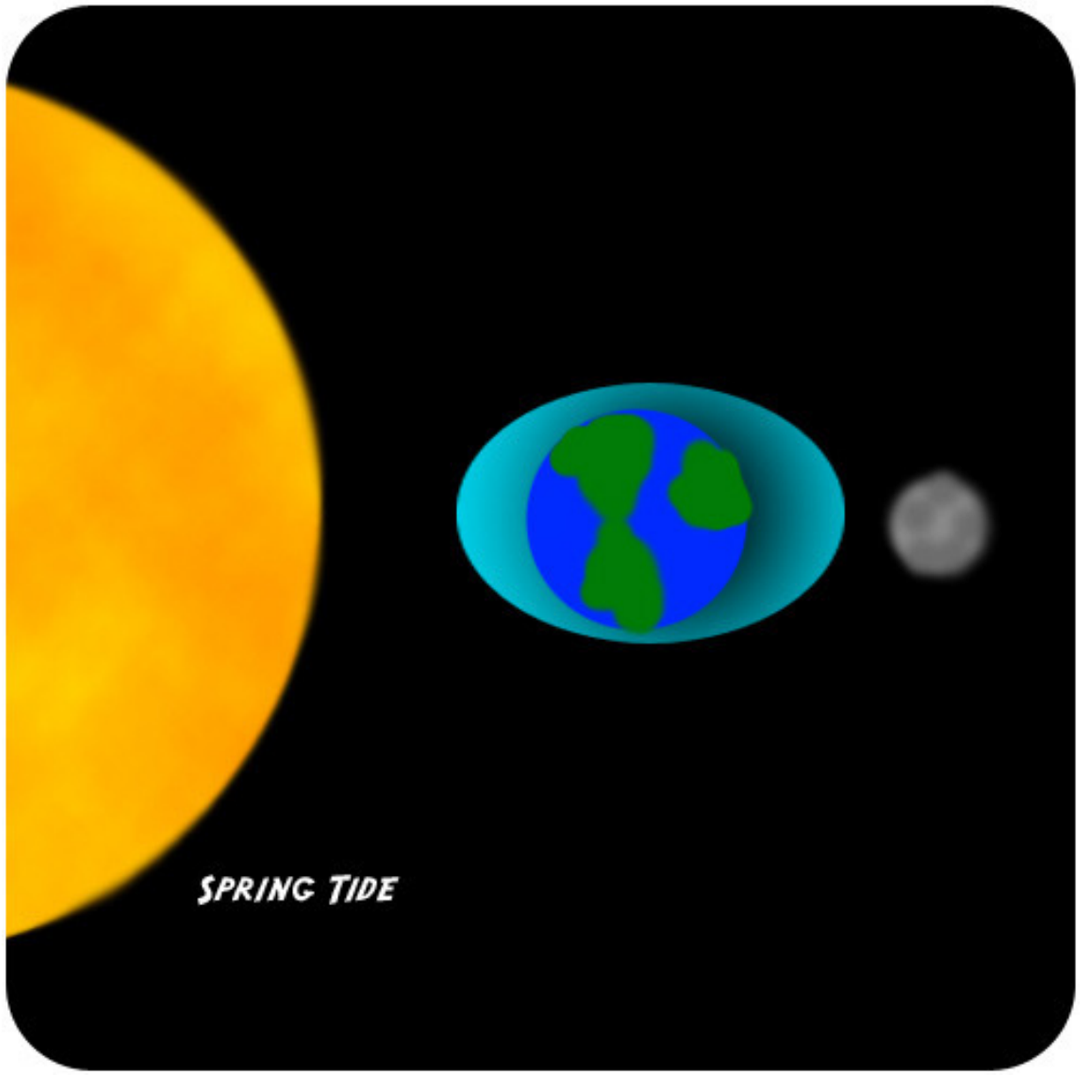


Figure 4.30

A spring tide is the added highs produced by the Moon and Sun and the added lows, creating a large tidal range.

When the Earth and Sun are in line but the Moon is perpendicular to the Earth a neap tide occurs. This happens when the moon is at first or last quarter-moon phase. In a neap tide the difference between high and low tides is not very large since the pull of gravity from the Sun partially cancels out the pull of gravity from

the Moon. Neap tides produce less extreme tides than the normal tides (**Figure** below).

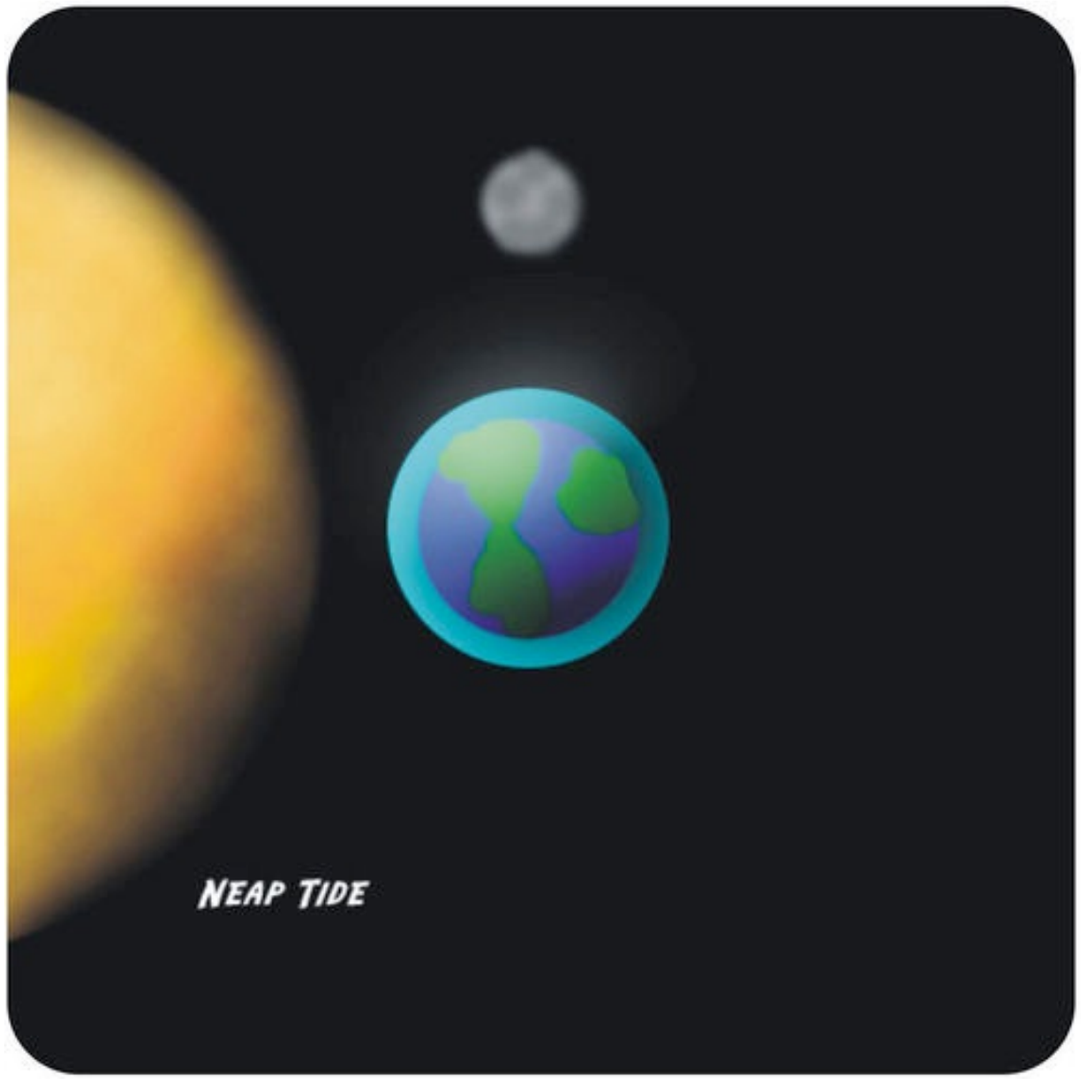


Figure 4.31

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.

More about tides is found in the chapter *Earth's Ocean* .

Lesson Summary

•As the Earth rotates on its axis and revolves around the Sun, day and night and seasons result.
•When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
•When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
•Observing the Moon from Earth, there is a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again every 29.5 days.
•As the Moon orbits Earth, tides align with its gravitational pull.
•The Sun produces a smaller tide. When the solar and lunar tides align, at new and full moons, higher than normal tidal ranges called spring tides occur.
•At first and last quarter moons, the solar tide and lunar tide interfere with each other, producing lower than normal tidal ranges called neap tides.

Review Questions

1. The globe is divided into time zones, so that any given hour of the day in one time zone occurs at a different time in other time zones. For example, New York City is in one time zone and Los Angeles is in another time zone. When it is 8:00 a.m. in New York City, it is only 5:00 a.m. in Los Angeles. Explain how Earth’s motions cause this difference in times.

2. Explain how Earth’s tilt on its axis accounts for seasons on Earth.

3. Explain how the positions of the Earth, Moon, and Sun vary during a solar eclipse and a lunar eclipse.

4. Draw a picture that shows how the Earth, Moon, and Sun are lined up during the new moon phase.

5. Why are neap tides less extreme than spring tides?

Further Reading / Supplemental Links

- Watch this video to understand the difference between solar and lunar eclipses: http://www.youtube.com/watch?v=tIE1MTGz4eI .

Points to Consider

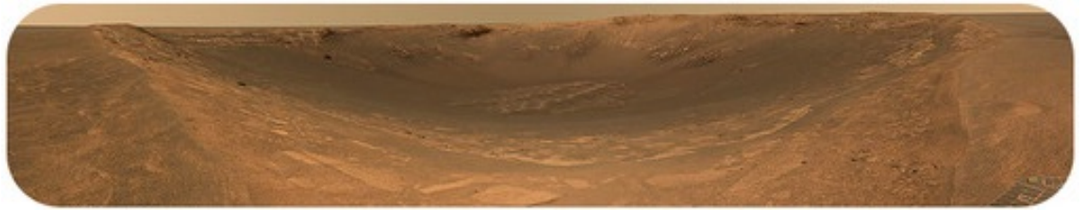
- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

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Ch. 5: Observing and Exploring Space



Pretend you are a planetary geologist and the image above appears in front of you. Where in the solar system is this? Perhaps you should start with the simplest possibility. Is it Earth? What clues would you look for to decide?

Earth is the only planet we know of in the solar system with life. Is it possible to get a view of earth in which absolutely nothing alive appears?



Nothing alive appears on these sand dunes in Colorado, although there are plants on the hills beyond the dunes.

Maybe the next step is to decide what the feature is. It appears to be a crater. Is it a volcano or a meteor impact crater?



On Earth volcanic crater usually has some sort of volcanic cone. Is it a meteor crater? It seems more likely.

The red color appears to be the most distinctive feature of the image. What causes red color in rocks?



Iron oxide makes rocks red. Like the famous red rocks of Sedona, Arizona.

You may have figured out that this is an impact crater on a lifeless red planet. This panorama of the Endurance Crater on Mars was created from 258 individual images taken by the Mars Exploration Rover, Opportunity. The vertical cliffs will allow planetary geologists to study the rocks exposed there for clues to the geology and geologic history of the planet.

Panorama: Courtesy of NASA/JPL/Cornell, Public Domain.

Dunes: Phil Armitage, may be used for any purpose. Crater: Courtesy of National Park Service, Public Domain.

Rocks: Miles Orchinik/CK-12, CC BY-NC 3.0.

Telescopes

Telescopes

Lesson Objectives

- Explain how astronomers use the whole electromagnetic spectrum to study the universe beyond Earth.
- Identify different types of telescopes.
- Describe historical and modern observations made with telescopes.

Vocabulary

- astronomer
- constellation
- electromagnetic (EM) radiation
- electromagnetic spectrum
- frequency
- gamma ray
- infrared light
- light-year
- microwave
- planet
- radio telescope
- radio wave
- reflecting telescope
- refracting telescope
- space telescope
- spectrometer
- ultraviolet (UV)
- visible light
- wavelength
- X-ray

Introduction

Many scientists interact directly with what they are studying. Biologists can collect cells, seeds, or sea urchins and put them in a controlled laboratory environment. Physicists can subject metals to stress or smash atoms into each other. Geologists can chip away at rocks to see what is inside. But **astronomers** , scientists who study the universe beyond Earth, rarely have a chance for direct contact with their subject. Astronomers observe their subjects at a distance, usually a very large distance!

Electromagnetic Radiation

Earth is separated from the rest of the universe by very large expanses of space. Very rarely matter from outside Earth's environment reaches us, such as when a meteorite makes it through the atmosphere from elsewhere in the solar system. But for the most part, astronomers have one main source for their data — light. Light can travel across empty space, and as it does, so it carries both energy and information. Light is one type of **electromagnetic (EM) radiation** , energy that is transmitted through space as a wave.

These videos discuss infrared, ultraviolet, and radio telescopes, as well as telescopes that detect visible light, and reveal tremendous features of the stars and galaxies around the Universe **(2d)** : http://

www.youtube.com/watch?v=AK-gtuAJ-B4 (2:19), http://www.youtube.com/watch?v=aQJQH7lS27s (5:30).



Click on the image above for more content



Click on the image above for more content

The Speed of Light

Light travels faster than anything else in the universe. In the almost completely empty vacuum of space, light travels at a speed of approximately 300,000,000 meters per second (670,000,000 miles per hour). To give you an idea of how fast that is, a beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even though light travels extremely fast, objects in space are so far away that it takes a significant amount of time for light from those objects to reach us. For example, light from the Sun takes about 8 1/3 minutes to reach Earth.

Light-Years

Since astronomical distances are so large, it helps to have a unit of measurement that is good for expressing those large distances. A **light-year** is a unit of distance that is defined as the distance that light travels in one year. One light-year is approximately equal to 9,500,000,000,000 (9.5 trillion) kilometers, or 5,900,000,000,000 (5.9 trillion) miles (**Figure** below). That's a long way! But by astronomical standards, it's actually a pretty short distance.

Proxima Centauri, the closest star to us after the Sun, is 4.24 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. The galaxy we live in, the Milky Way Galaxy, is about 100,000 light-years across. How long does it take light to travel from one side of the galaxy to the other? 100,000 years! If an astronomer looks through a telescope at a star that is 1,000 light years away, is she seeing the star as it is now?

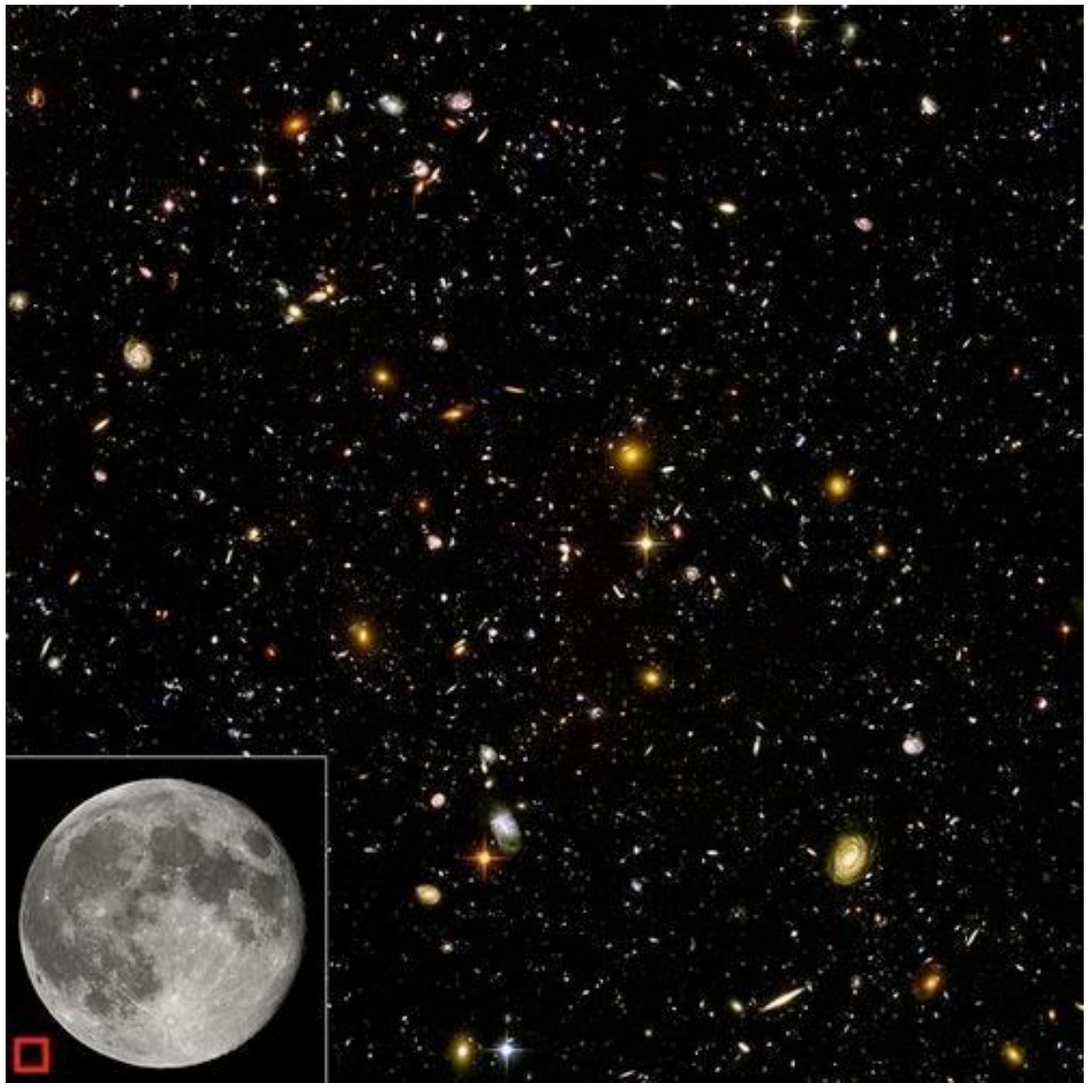


Figure 5.1

The smallest red-shifted galaxies are among the most distant galaxies we have detected so far at 13 billion light-years away. That's over a hundred-billion-trillion (100,000,000,000,000,000,000,000) kilometers!

Looking Back in Time

When we look at astronomical objects such as stars and galaxies, we are not just seeing over great distances—we are also seeing back in time. Because light takes time to travel, the image we see of a distant galaxy is an image of how the galaxy used to look. For example, the Andromeda Galaxy, shown in (**Figure** below), is about 2.5 million light years from Earth. If you look at the Andromeda Galaxy through a telescope, what are you seeing? You are seeing the galaxy as it was 2.5 million years ago. If the galaxy ceased to exist 1 million years ago, when would you know that? If you want to see the galaxy as it is now, you will have to wait and look again 2.5 million years into the future.



Figure 5.2

This recent picture of the Andromeda Galaxy actually shows the galaxy as it was about 2.5 million years ago.

Electromagnetic Waves

Visible light is one type of electromagnetic (EM) radiation; light is energy that travels in the form of an *electromagnetic wave* . (**Figure** below) shows a diagram of an electromagnetic wave. An EM wave has two components: an electric field and a magnetic field. Each of these components oscillates between positive and negative values, which is what makes the "wavy" shape in the diagram.

The distance between two adjacent oscillations is called **wavelength** . A related value is **frequency** , which 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.

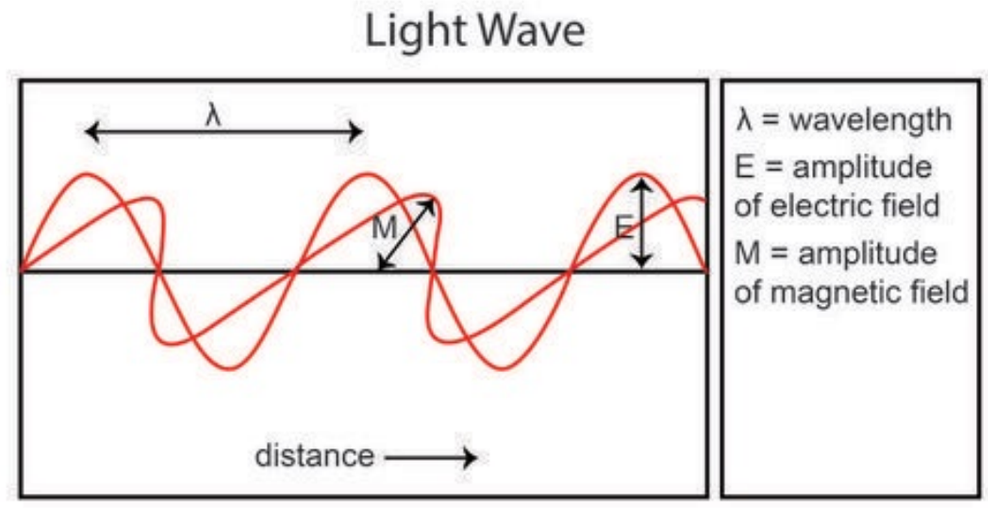


Figure 5.3

An electromagnetic wave consists of oscillating electric and magnetic fields.

The Electromagnetic Spectrum

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 ("n" is the prefix nano which is equivalent to 10^{-9} m) 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 **Figures** below .

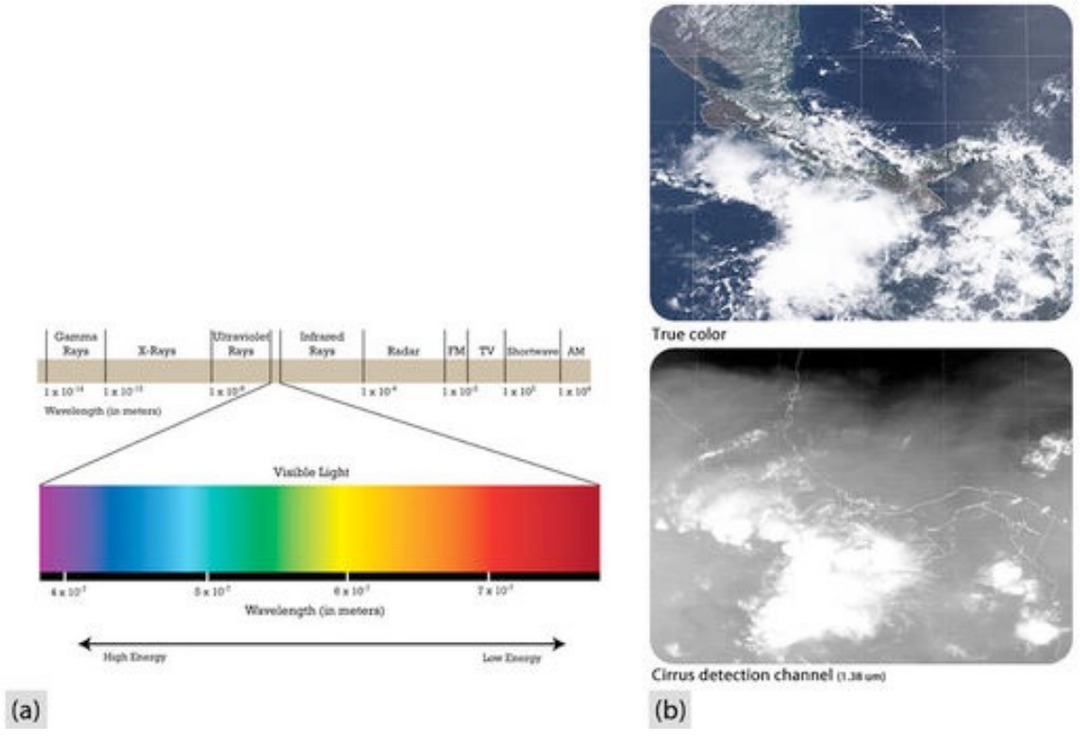


Figure 5.4

(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.

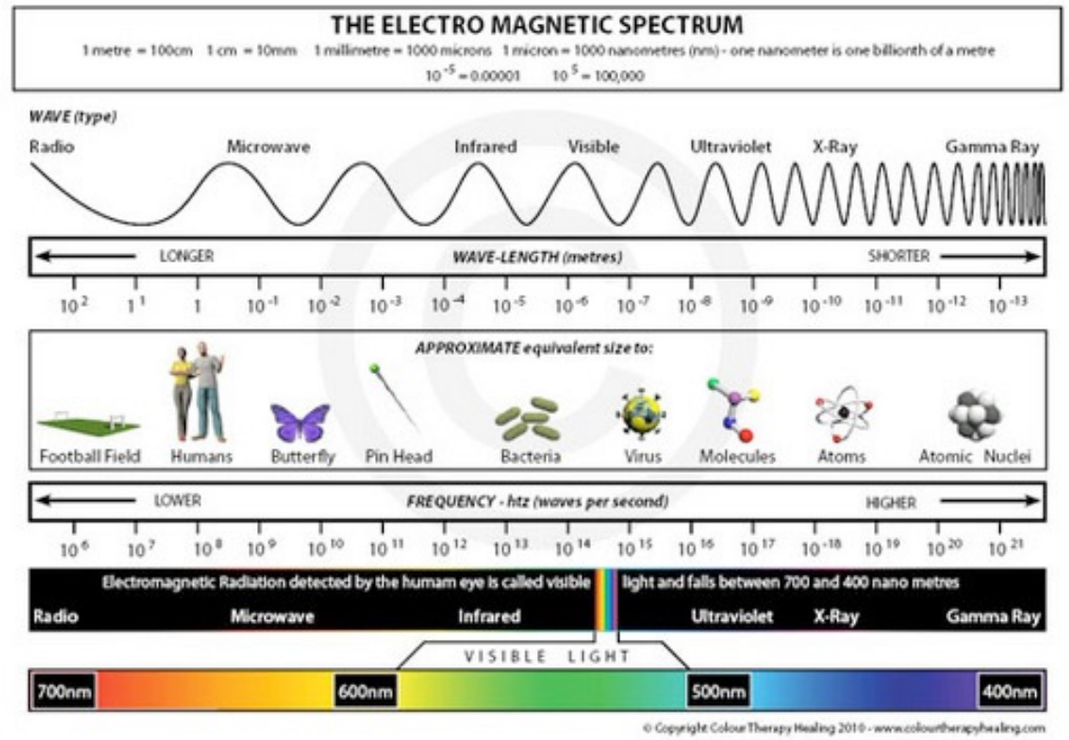


Figure 5.5

EM spectrum

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.

Some very hot stars emit light primarily at **ultraviolet (UV)** wavelengths, while some very cool stars emit mostly in the **infrared** . There are extremely hot objects that emit **X-rays** and even **gamma rays** . Light from some of the faintest, most distant objects is in the form of **radio waves** . In fact, a lot of the objects most interesting to astronomers today can't even be seen with the naked eye. Astronomers use telescopes to detect the faint light

from distant objects and to see objects at wavelengths all across the electromagnetic spectrum.

Types of Telescopes

Optical Telescopes

People have been making and using lenses for magnification for thousands of years. However, the first true telescopes were made in Europe in the late 16th century. A German-Dutch lens-maker by the named of Hans Lippershey is credited with inventing the telescope in 1608. These telescopes used a combination of two lenses to make distant objects appear both nearer and larger. The term *telescope* was coined by the Italian scientist and mathematician Galileo Galilei (1564–1642). Galileo built his first telescope in 1609 and subsequently made many improvements to telescope design.

Telescopes that rely on the refraction, or bending, of light by lenses are called **refracting telescopes** , or simply *refractors* . The earliest telescopes, including Galileo's, were all refractors. Many of the small telescopes used by amateur astronomers today are refractors. Refractors are particularly good for viewing details within our solar system, such as the surface of Earth's moon or the rings around Saturn (**Figure** below).

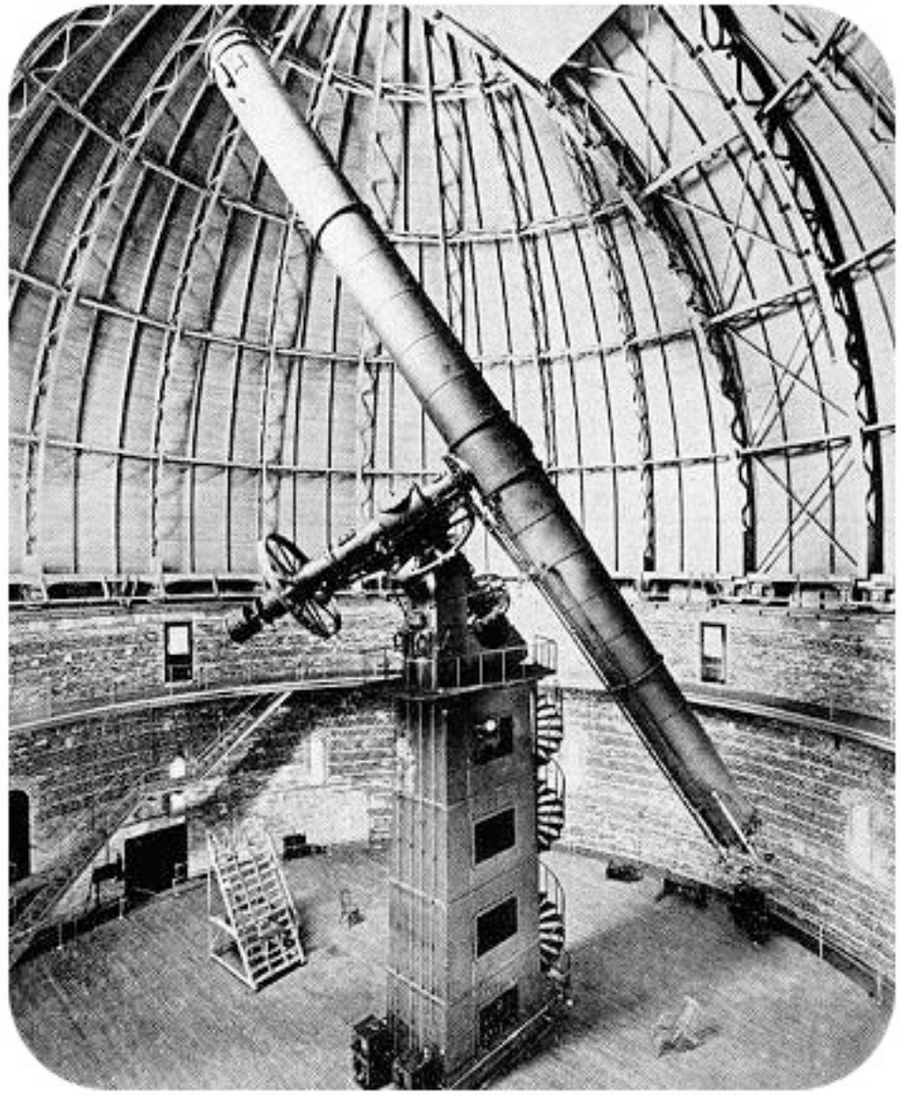


Figure 5.6

The largest refracting telescope in the world is at the University of Chicago's Yerkes Observatory in Wisconsin and was built in 1897. Its largest lens has a diameter of 102 cm.

Around 1670, another famous scientist and mathematician — Sir Isaac Newton (1643–1727) — built a different kind of telescope. Newton used curved mirrors to focus light and so created the first **reflecting telescopes** , or *reflectors* (**Figure** below). 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.



Figure 5.7

(a) Reflecting telescopes used by amateur astronomers today are similar to the one designed by Isaac Newton in the 17th century. (b) The South African Large Telescope (SALT) is one of the largest reflecting telescopes on Earth. SALT's primary mirror consists of 91 smaller hexagonal mirrors, each with sides 1 m long. (c) Many amateur astronomers today use combination telescopes.

Radio Telescopes

Notice it says above that the largest *optical* telescopes in the world are reflectors. Optical telescopes collect visible light. Even larger telescopes are built to collect light at longer wavelengths — radio waves. What do you think these telescopes are called? **Radio telescopes** look a lot like satellite dishes because both are designed to do the same thing — to collect and focus radio waves or **microwaves** (the shortest wavelength waves) from space.

The largest single telescope in the world is at the Arecibo Observatory in Puerto Rico (**Figure** below). This telescope is located in a naturally occurring sinkhole that formed when water flowing underground dissolved the limestone rock. If this telescope were not supported by the ground, it would 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.



Figure 5.8

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

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

For more on radio telescopes and radio astronomy in general, go to http://www.nrao.edu/whatisra/index.shtml .



Figure 5.9

The Very Large Array in New Mexico has 27 radio dishes, each 25 m in diameter. When all the dishes are pointed at the same object, they are like a single telescope with a diameter of 22.3 mi.

Space Telescopes

Telescopes on Earth all have one significant limitation: the electromagnetic radiation they gather must pass through Earth's atmosphere. The atmosphere blocks some radiation in the infrared part of the spectrum and almost all radiation in the ultraviolet and higher frequency ranges. Furthermore, motion in the atmosphere distorts light. That distortion is why stars twinkle in the night sky. To minimize these problems, many observatories are built on high mountains, where there is less atmosphere above the telescope. Even better, **space telescopes** avoid such problems completely because they orbit outside Earth's atmosphere in space. 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. X-ray telescopes, such as the Chandra X-ray Observatory, use X-ray optics to observe remote objects in the X-ray spectrum.

The Hubble Space Telescope (HST), shown in (**Figure** below), is perhaps the best known space telescope. The Hubble was put into orbit by the Space Shuttle Atlantis in 1990. Once it was in orbit, scientists discovered that there was a flaw in the shape of the mirror. A servicing mission to the Hubble by the Space Shuttle Endeavor in 1994 corrected the problem. Since that time, the Hubble has provided huge amounts of data that have helped to answer many of the biggest questions in astronomy.

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

The National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit, comprising what NASA calls the 'Great Observatories'. Each of these telescopes specializes in a different part of the electromagnetic spectrum (**Figure** below). NASA is planning for another telescope, the James Webb Space Telescope, to serve as a replacement for the aging Hubble. The James Webb is scheduled to launch in 2018.

To learn more about NASA's great observatories, check out http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html .

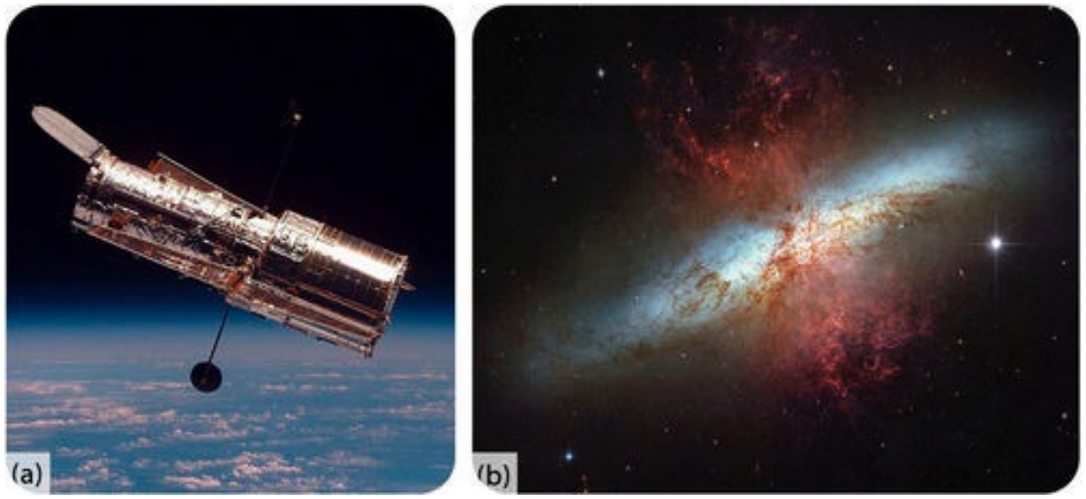


Figure 5.10

(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.

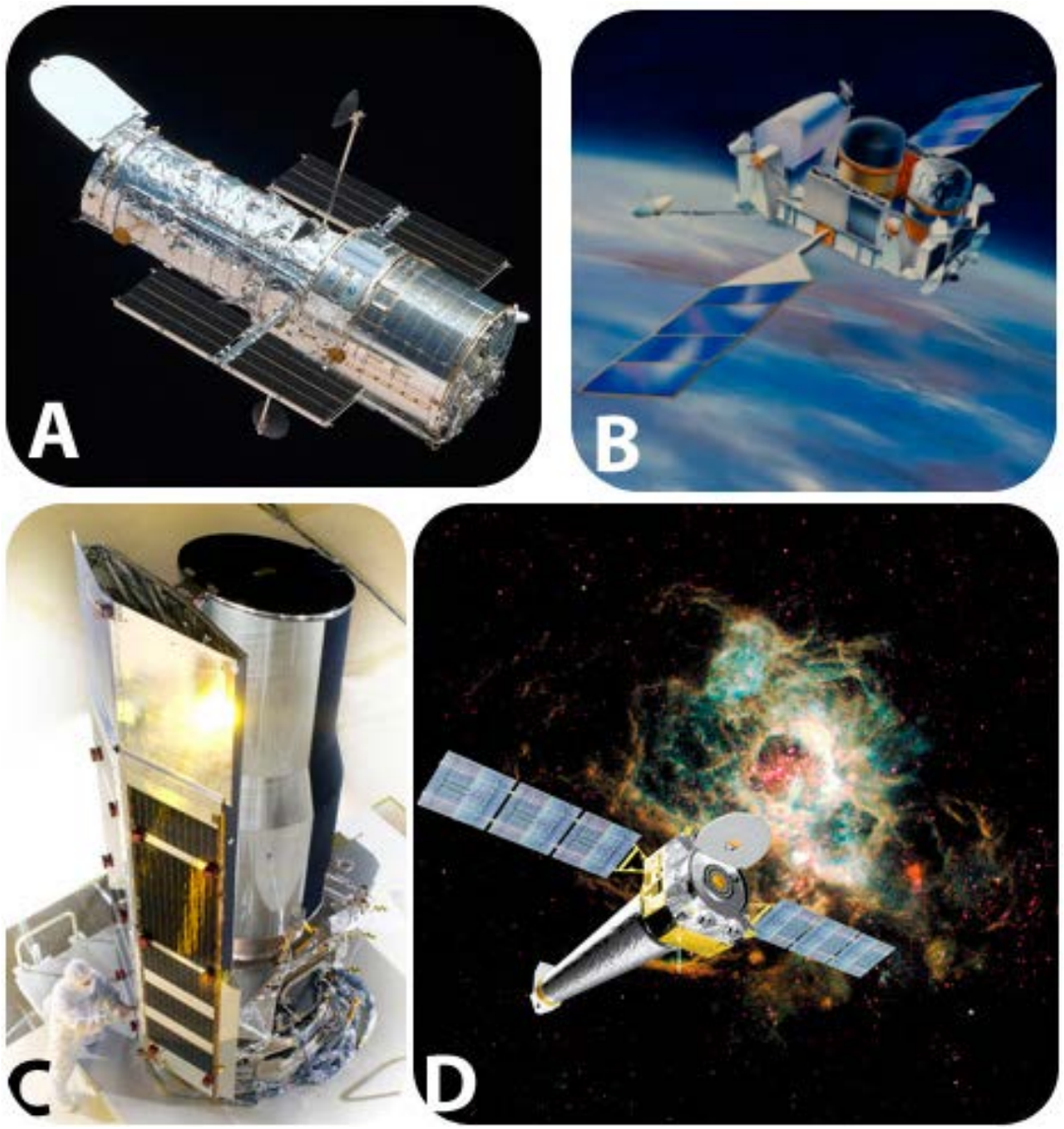


Figure 5.11

NASA's four space-based Great Observatories were designed to view the universe in different ranges of the electromagnetic spectrum. A. Hubble Space Telescope: visible, infrared and ultraviolet light; B. Compton Gamma Ray Observatory (inactive): gamma ray; C. Spitzer Space Telescope: infrared; D. Chandra X-ray Observatory: X-ray.

Observations with Telescopes

Ancient Astronomers

Humans have been studying the night sky for thousands of years. Observing the patterns and motions in the sky helped ancient peoples keep track of time (**Figure** below). By understanding annual rhythms, people could know when to plant crops. They also timed many of their religious ceremonies to coincide with events in the heavens.



Figure 5.12

Many archaeologists think that Stonehenge was used to observe the movement of the moon and the sun.

The ancient Greeks made careful observations of the locations of stars in the sky. They noticed that some of the 'stars' moved against the background of other stars. They called these bright and odd bodies in the sky **planets** , which in Greek means "wanderers." Today we know that the planets are not stars, but members of our solar system that orbit the Sun. Greeks also identified **constellations** , patterns of stars in the sky (**Figure** below). They associated the constellations with stories and myths from their culture.



Figure 5.13

Stars in the constellation Orion. Constellations help astronomers today identify different regions of the night sky.

Galileo's Observations

Ancient astronomers knew a lot about the patterns of stars and the movement of objects in the sky, but they did not know what these objects actually were. That understanding began in the year 1610, when Galileo turned a telescope toward the heavens. With his telescope, Galileo made the following discoveries (among others):

- There are more stars in the night sky than the naked eye can see.
- The band of stars called the Milky Way consists of many stars.
- The Moon has craters (**Figure** below).
- Venus has phases like the Moon.
- Jupiter has orbiting moons.
- There are dark spots that move across the surface of the Sun.

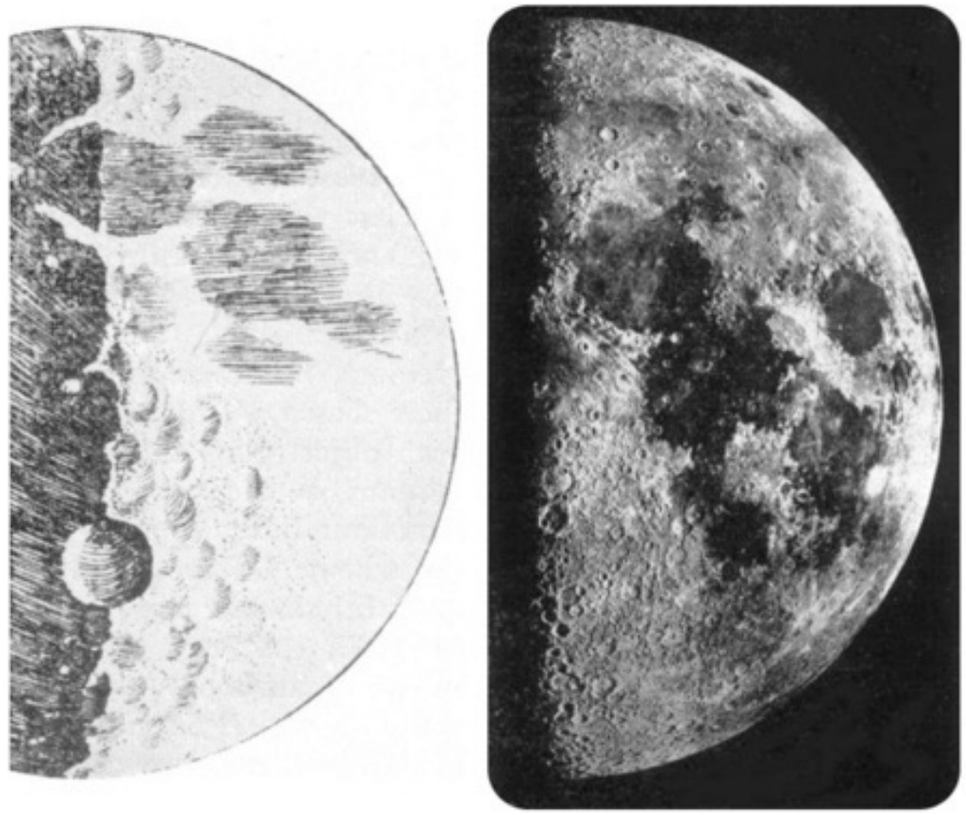


Figure 5.14

Galileo was the first person known to look at the Moon through a telescope. Galileo made the drawing on the left in 1610; on the right is a modern photograph of the Moon.

Galileo’s observations challenged people to think in new ways about the universe and Earth’s place in it. About 100 years before Galileo, Nicolaus Copernicus had proposed a controversial new model of the universe in which Earth and the other planets revolve around the Sun. In Galileo's time, most people still believed that the Sun and planets revolved around Earth. Galileo’s observations provided direct evidence to support Copernicus’ model.

Observations with Modern Telescopes

Equipped with no more than a good pair of binoculars, you can see all of the things Galileo saw, and more. You can even see sunspots, but be sure to use special filters on the lenses to protect your eyes. With a basic telescope like those used by many amateur astronomers, you can see more than Galileo saw, such as polar caps on Mars, the rings of Saturn, and bands in the atmosphere of Jupiter.

All of the objects mentioned above are within our solar system. With a telescope you can also see many times more stars than without a telescope. However, because they are so far away, the stars will appear as points of light. This is true even of the most powerful professional telescopes, with one rare exception (**Figure** below).



Figure 5.15

This ultraviolet image of the red supergiant star Betelgeuse taken with the Hubble Space Telescope in 1996 was the first direct image taken of the disk of a star other than the Sun.

Very few professional astronomers today look directly through the eyepiece of a telescope. Instead, they attach to the telescopes sophisticated instruments that capture and process the light. The astronomers then look at the images or data shown on these instruments. Most often the instruments then pass the data on to a computer where the data can be stored for later use. An astronomer may take weeks or months to analyze all the data collected from just a single night.

Astronomers use **spectrometers** to study the light from a telescope. A spectrometer uses a prism or other device to break light down into its component colors. The spectrum produced can be observed directly, captured on film, or stored digitally on a computer (**Figure** below).



Figure 5.16

A simplified example of starlight after it passes through a spectrometer. The dark lines in a star's spectrum are caused by gases absorbing light in the star's outer atmosphere.

From a single spectrum of a star, an astronomer can tell:

- How hot the star is (by the relative brightness of different colors).
- What elements the star contains (by the pattern of dark lines).
- Whether and how fast the star is moving toward or away from Earth (by how far the dark lines are shifted from their normal positions).

Using telescopes, astronomers can also learn how stars evolve, what kind of matter is found throughout the universe, how that matter is distributed, and even how the universe might have formed.

Lesson Summary

- Astronomers study light from distant objects.
- Light travels at 300,000,000 meters per second — faster than anything else in the universe.
- A light-year is equal to the distance light travels in one year, 9.5 trillion kilometers.
- When we see distant objects, we see them as they were in the past, because their light has been traveling to us for many years.
- Visible light is part of the electromagnetic spectrum.
- Telescopes make distant objects appear both nearer and larger.
- Optical telescopes collect visible light. The three main types are reflecting telescopes, refracting telescopes, and combination telescopes.
- Radio telescopes collect and focus radio waves from distant objects.
- Space telescopes orbit Earth, collecting wavelengths of light that are normally blocked by the atmosphere.
- Galileo was the first person known to use a telescope to study the sky. His discoveries helped change the way humans think about the universe.
- Modern telescopes collect data that can be stored on a computer.
- Astronomers can learn a lot about a star by studying its spectrum.

Review Questions

1. Betelgeuse is around 640 light-years from Earth. Light travels 9.5 trillion kilometers in one year. How far away is Betelgeuse in kilometers?
2. Identify four regions of the electromagnetic spectrum that astronomers use when observing objects in space.
3. List the three main types of optical telescopes, and describe their differences.
4. Explain the advantages of putting a telescope into orbit around Earth.

5.Describe two observations that Galileo was the first to make with his telescope.
6.List three things that an astronomer can learn about a star by studying its spectrum.

Further Reading / Supplemental Links

•Lots of news and information from NASA at http://www.nasa.gov/
•The first stars in the Universe: http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm
•How many stars can you observe? http://www.stargazing.net/David/constel/howmanystars.html
•An activity found online with directions for how to determine if that bright point you see in the sky is a planet or a star: http://cse.ssl.berkeley.edu/SegwayEd/lessons/findplanets/Find-hmpg2.html

Points to Consider

•Radio waves are used for communicating with spacecraft. A round-trip communication from Earth to Mars takes anywhere from 6 to 42 minutes. What challenges does this present for sending unmanned spacecraft and probes to Mars?
•The Hubble Space Telescope is a very important source of data for astronomers. The fascinating and beautiful images from the Hubble also help to maintain public support for science. However, the Hubble is growing old. Missions to service and maintain the telescope are extremely expensive and put the lives of astronauts at risk. Do you think there should be another servicing mission to the Hubble?

Section 2

Early Space Exploration

Early Space Exploration

Lesson Objectives

- Explain how a rocket works.
- Describe different types of satellites.
- Outline major events in early space exploration, including the Space Race.

Vocabulary

- low Earth orbit
- orbit
- rocket
- satellite
- space probe
- thrust

Introduction

Humans have long dreamed of traveling into space. Greek mythology tells of Daedelus and Icarus, a father and son who took flight using wings made of feathers and wax (**Figure** below). Icarus, thrilled with the feel of flying, got too close to the Sun, the wax melted, and he fell into the sea. In a time before airplanes and hot air balloons, we can relate to the excitement Icarus would have felt. Much later, science fiction writers, such as Jules Verne (1828–1905) and H.G. Wells (1866–1946), wrote about technologies that explore the dream of traveling beyond Earth into space.



Figure 5.17

Daedelus and Icarus.

Rockets

Humans did not reach space until the second half of the 20th century. However, the main technology that makes space exploration possible, the **rocket** , has been around for a long time. A rocket is propelled by particles flying out of one end at high speed. We do not know who built the first rocket, or when, but there are records of the Chinese using rockets in war against the Mongols as early as the 13th century. The Mongols then spread rocket technology in their attacks on Eastern Europe. Early rockets were also used to launch fireworks and for other ceremonial purposes.

How Rockets Work

Rockets were used for centuries before anyone could explain exactly how they worked. The theory to explain rockets did not arrive until 1687, when Isaac Newton (1643–1727) described the three basic laws of motion, now referred to as Newton's Laws of Motion:

1. An object in motion will remain in motion unless acted upon by a net force.
2. Force equals mass multiplied by acceleration.
3. To every action, there is an equal and opposite reaction.

Newton's third law of motion is particularly useful in explaining how a rocket works. To better understand this law, consider the skate boarder in (**Figure** below).



Figure 5.18

When the skate boarder pushes the wall, his force - the action - is matched by an equal force by the wall on the skate boarder in the opposite direction - the reaction.

Once the skate boarder is moving, however, he has nothing to push against and he will soon stop because of friction. Imagine now that he is is holding a fire extinguisher. When he pulls the trigger on the extinguisher, a fluid or powder flies out of the extinguisher, and he moves backward. In this case, the action force is the pressure pushing the material out of the extinguisher. The reaction force of the material against the extinguisher pushes the skate boarder backward.

Since space is a vacuum, how does a rocket work if there is nothing for the rocket to push against? A rocket in space moves like the 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 (**Figure** below). The reaction force of the gases on the rocket pushes the rocket forward. The force pushing the rocket is called **thrust** .



Figure 5.19

Explosions in a chamber create pressure that pushes gases out of a rocket. This in turn produces thrust that pushes the rocket forward. The rocket shown here is a Saturn V rocket, used for the Apollo 11 mission - the first to carry humans to the Moon.

A Rocket Revolution

For centuries, rockets were powered by gunpowder or other solid fuels and could travel only fairly short distances. At the end of the 19th century and the beginning of the 20th century, several breakthroughs in rocketry led to rockets that were powerful enough to carry the rockets—and humans—beyond Earth. During this period, three people independently came up with similar ideas for improving rocket design.

The first person to establish many of the main ideas of modern rocketry was a Russian schoolteacher, named Konstantin Tsiolkovsky (1857–1935). Most of his work was done before the first airplane flight, which took place in 1903. Tsiolkovsky realized that in order for rockets to have enough power to escape Earth's gravity, they would need liquid fuel instead of solid fuel. He also realized that it was important to find the right balance between the amount of fuel a rocket uses and how heavy the rocket is. He came up with the idea of using multiple stages when launching rockets, so that empty fuel containers would drop away to reduce mass. Tsiolkovsky had many great ideas and designed many rockets, but he never built one.

The second great rocket pioneer was an American, Robert Goddard (1882–1945). Goddard independently came up with using liquid fuel and using multiple stages for rockets. He also designed a system for cooling the gases escaping from a rocket, which made the rocket much more efficient. Goddard built rockets to test his ideas, such as the first rocket to use liquid fuel (**Figure** below). Over a lifetime of research, Goddard came up with many innovations that are still used in rockets today.

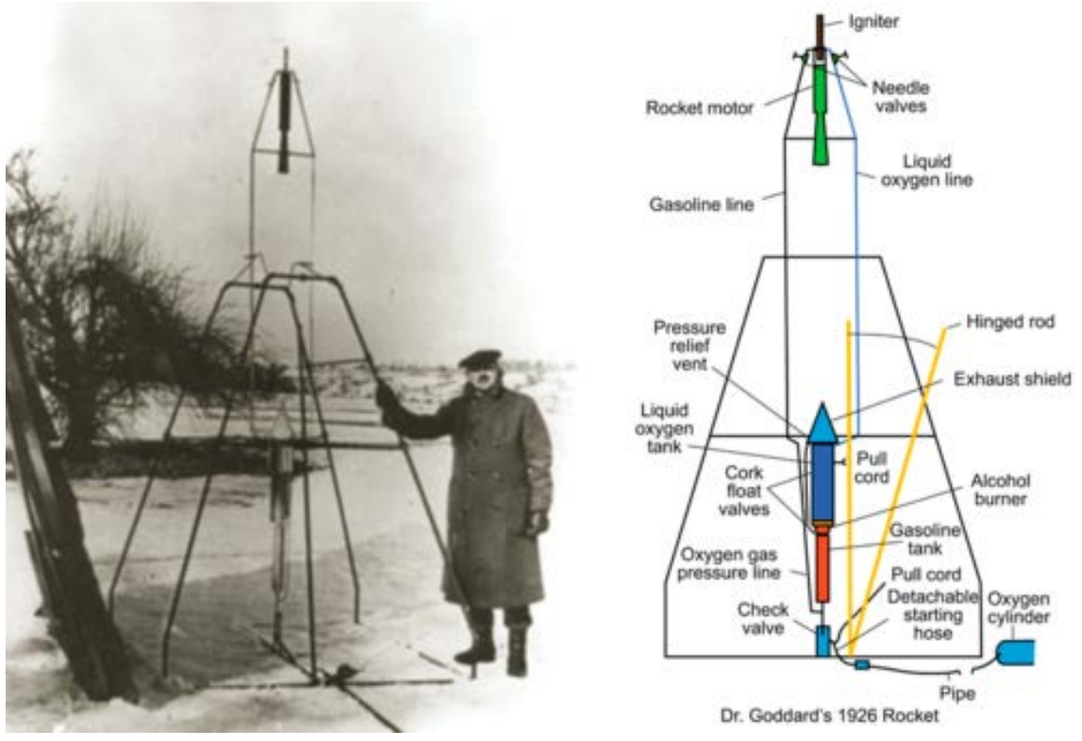


Figure 5.20

Left: Robert Goddard launched the first liquid-fueled rocket on March 16, 1926, in Massachusetts; Right: This schematic shows details of Goddard's rocket.

The third great pioneer of rocket science was a Romanian-born German, named Hermann Oberth (1894–1989). In the early 1920's, Oberth came up with many of the same ideas as Tsiolkovsky and Goddard. Oberth built a liquid-fueled rocket, which he launched in 1929. Later, he joined a team of scientists that designed the rocket shown in (**Figure** below) for the German military. This rocket played a major role in World War II. The Germans used the V-2 as a missile to bomb numerous targets in Belgium, England, and France. In 1942, the V-2 was launched to an altitude of 176 km (109 miles), making it the first human-made object to travel into space (an altitude of 100 km (62 miles).

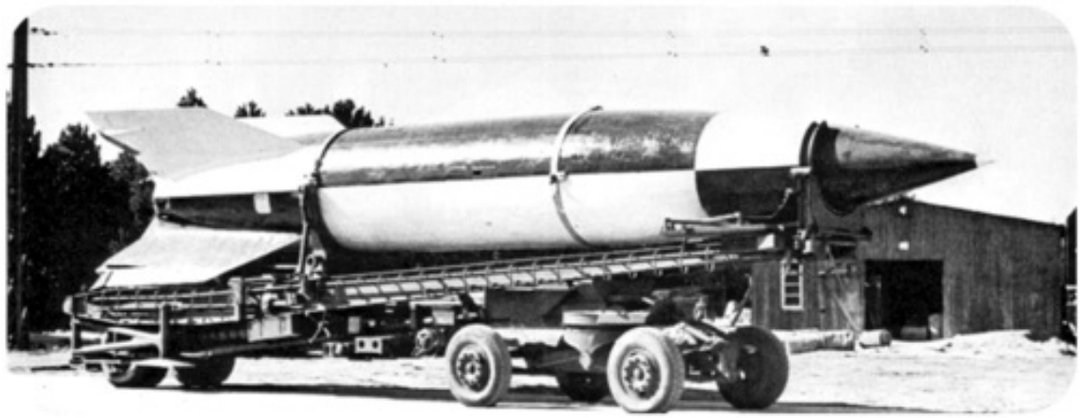


Figure 5.21

Explosions in a chamber create pressure that pushes gases out of the rocket. This in turn produces thrust that pushes the rocket forward.

The leader of the V-2 team was a German scientist named Wernher von Braun. von Braun later fled Germany and came to the United States, where he helped the United States develop missile weapons. He then joined NASA to design rockets for space travel including the Saturn V rocket (**Figure** below), which was eventually used to send the first men to the Moon.



Figure 5.22

Wernher von Braun in front of the F1 engines in front of the Saturn V rocket's first stage.

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.

Newton's Law of Universal Gravitation

Isaac Newton also developed the theory that explains why satellites stay in orbit. Newton's *law of universal gravitation* describes how every object in the universe is attracted to every other object. The same gravity that makes an apple fall to the ground and keeps a person from floating away into the sky, also holds the Moon in orbit around Earth, and Earth in orbit around the Sun.

Newton used the following example to explain how gravity makes orbits possible. Consider a cannonball launched from a high mountain (**Figure** below).

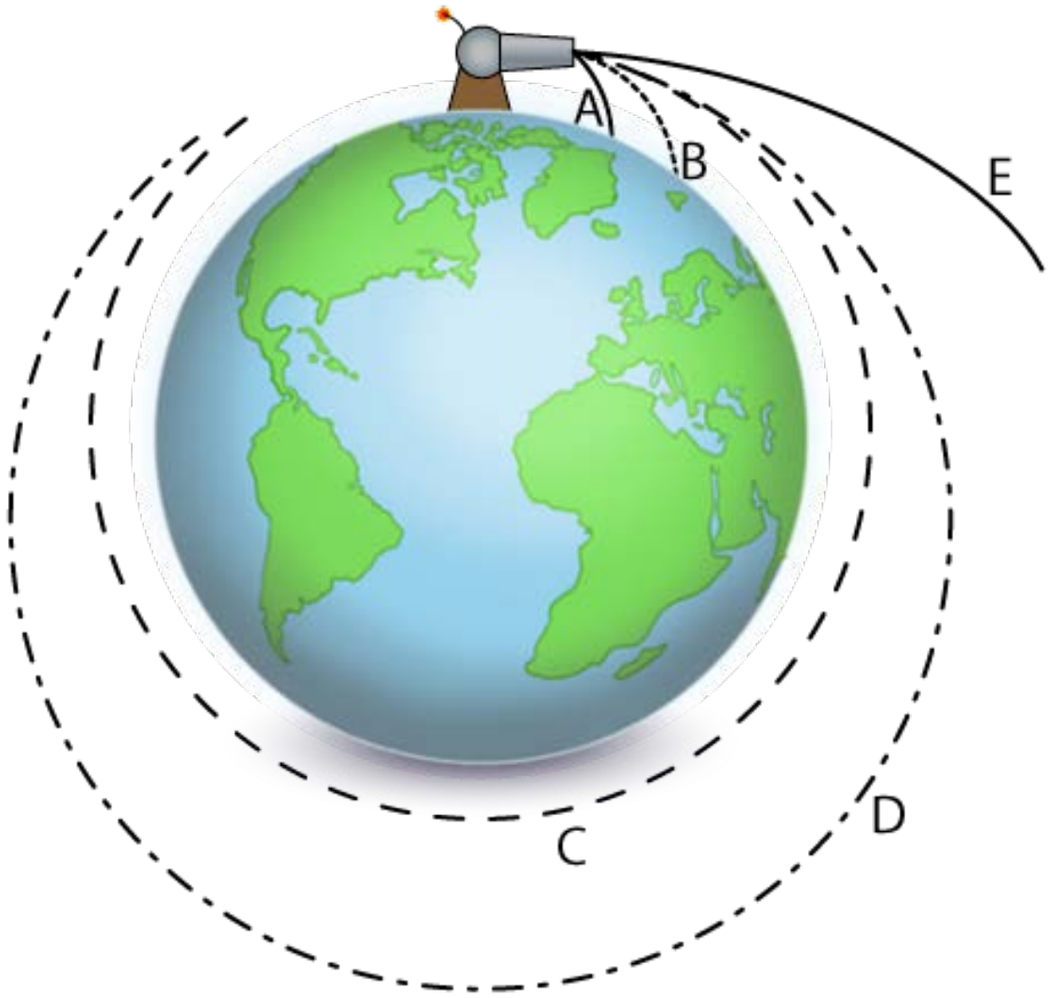


Figure 5.23

If a cannonball is launched off a high mountain at a slow speed, it will fall back to Earth (A, B) If the cannonball is launched at a fast enough speed, the Earth below curves away at the same rate that the cannonball falls, and the cannonball goes into a circular orbit (C). If the cannonball is launched even faster, it goes into an elliptical orbit (D) or leaves Earth's gravity entirely (E).

Not that Newton's idea would actually work in real life: A cannonball launched from Mt. Everest would burn up in the atmosphere if launched at the speed required to put it into orbit. However, a rocket can launch straight up, then steer into an orbit. A rocket can also carry a satellite above the atmosphere and then release the satellite into orbit.

To further understand how satellites work, visit http://science.howstuffworks.com/satellite.htm .

Types of Satellites

Since the first satellite was launched more than 50 years ago, 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 to be used by the military, when taken by spy satellites; or for scientific purposes, such as meteorology, if taken by weather satellites. Astronomers use imaging satellites to study the Moon and other planets.
- Communications satellites, such as the one in (**Figure** below), are designed to 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.

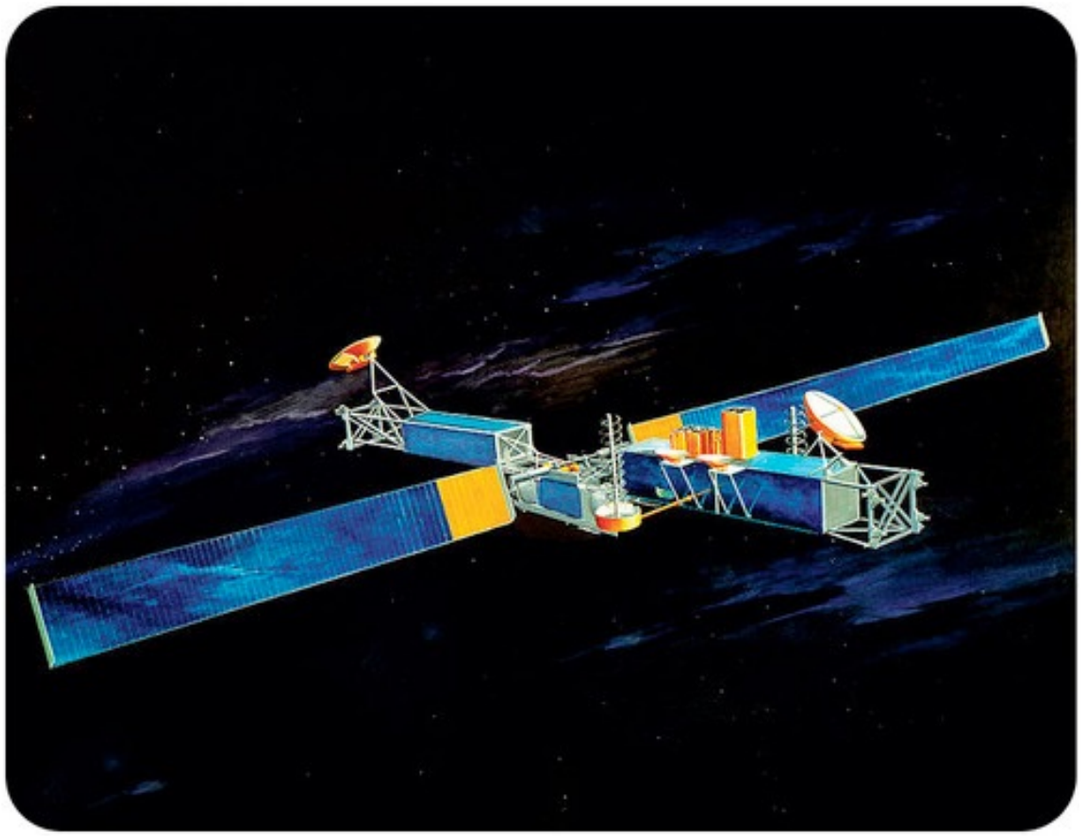


Figure 5.24

This is a Milstar communications satellite used by the U.S. military. The long, flat solar panels provide power for the satellite. The antennas are for sending or receiving signals.

Types of Orbits

The speed of a satellite depends on how high it is above the object it is orbiting (**Figure** below). Satellites that are relatively close to Earth are said to be in **low Earth orbit** (LEO). Satellites in LEO are often in polar orbit; they orbit over the North and South Poles, perpendicular to Earth's spin. Because Earth rotates underneath the orbiting satellite, a satellite in polar orbit is over a different part of Earth's surface each time it circles. Imaging satellites and weather satellites are often put in low-Earth, polar orbits.

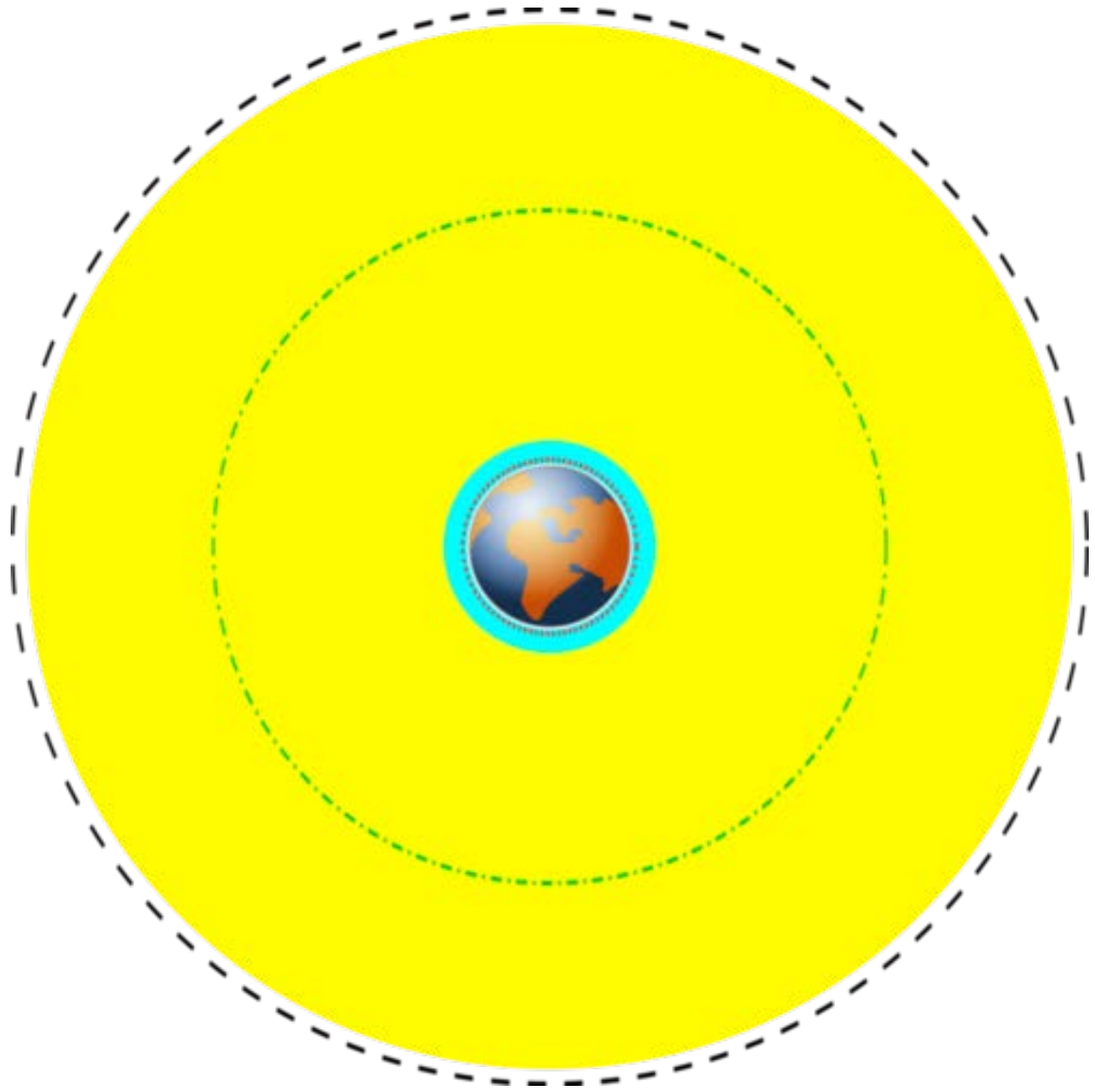


Figure 5.25

Different orbits of Earth: ISS orbit = red dotted line; LEO = filled blue; Medium Earth Orbit = filled yellow; GPS = green dash-dot; geostationary = black dash.

An animation of GPS satellites orbiting Earth is seen here: http://en.wikipedia.org/wiki/File:ConstellationGPS.gif

An animation of roughly half the orbit of the ISS from sunrise to sunset: http://en.wikipedia.org/wiki/File:Sunrise_To_Sunset_Aboard_The_ISS.OGG

A satellite placed at just the right distance above Earth — 35,786 km (22,240 miles) — orbits at the same rate that Earth spins. The satellite is always in the same position over Earth's surface, called a geostationary orbit (GEO). Many communications satellites are in geostationary orbits.

Satellites 101 (7:29)

The Space Race

From the end of World War II in 1945 to the breakup of the Soviet Union (USSR) in 1991, the Soviet Union and the United States were in a military, social, and political conflict, known as the Cold War. Although there were very few actual military confrontations, each of the two countries was in an arms race — continually developing new and more powerful weapons to try to best the other. While the arms race had many social and political consequences, it helped to drive technology. For example, the development of missiles during the Cold War significantly sped up the development of rocket technologies.

More information about the Space Race can be found here. .

Sputnik

On October 4, 1957, the USSR launched the first artificial satellite ever put into orbit. Sputnik 1 (**Figure** below) was 58 cm in diameter and weighed 84 kg (184 lb). Antennas trailing behind the satellite sent out radio signals, which were detected by scientists and amateur radio operators around the world. Sputnik 1 orbited in an LEO on an elliptical path every 96 minutes. After about 3 months, the satellite slowed down enough to descend into Earth's atmosphere where it burned up as a result of friction.



Figure 5.26

The Soviet Union launched Sputnik 1, the first artificial satellite, on October 4, 1957.

The launch of Sputnik 1 triggered the *Space Race* between the USSR and the United States. Many Americans were shocked that the Soviets had the technology to put a satellite in orbit, and they worried that the Soviets might also be winning the arms race. On November 3, 1957, the Soviets launched Sputnik 2, which carried the first animal to go into orbit—a dog named Laika (**Figure** below).

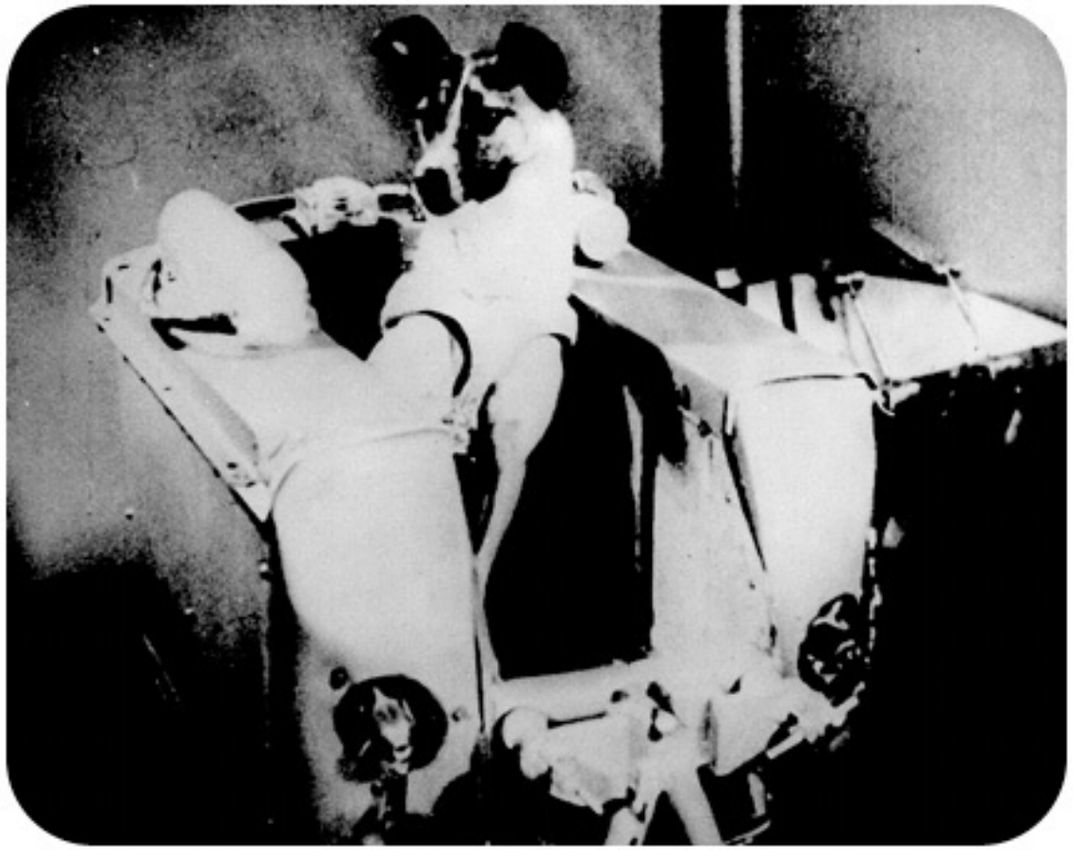


Figure 5.27

Laika was a stray trained for space flight. No one yet knew how to bring a satellite out of orbit and Laika was not expected to survive the flight.

The Race Is On

In response to the Sputnik program, the United States launched its first satellite, Explorer I, on January 31, 1958, and its second, Vanguard 1, on March 17, 1958. Later that year, the U.S. Congress and President Eisenhower established NASA.

The Soviets stayed ahead of the United States for many notable "firsts," but the United States soon followed with some firsts of its own. The timeline in **Table** below shows many Space Race firsts.



Click on the image above to view the table

The Space Race reached a peak in 1969 when the United States put the first human on the Moon. However, the competition between the two countries' space programs continued for many more years.

Reaching the Moon

On May 25, 1961, shortly after the first American went into space, President John F. Kennedy presented the following challenge to the U.S. Congress (**Figure** below):



Figure 5.28

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him back safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

Eight years later, NASA's Apollo 11 mission achieved Kennedy's ambitious goal. On July 20, 1969, astronauts Neil Armstrong and Buzz Aldrin were the first humans to set foot on the moon (**Figure** below).

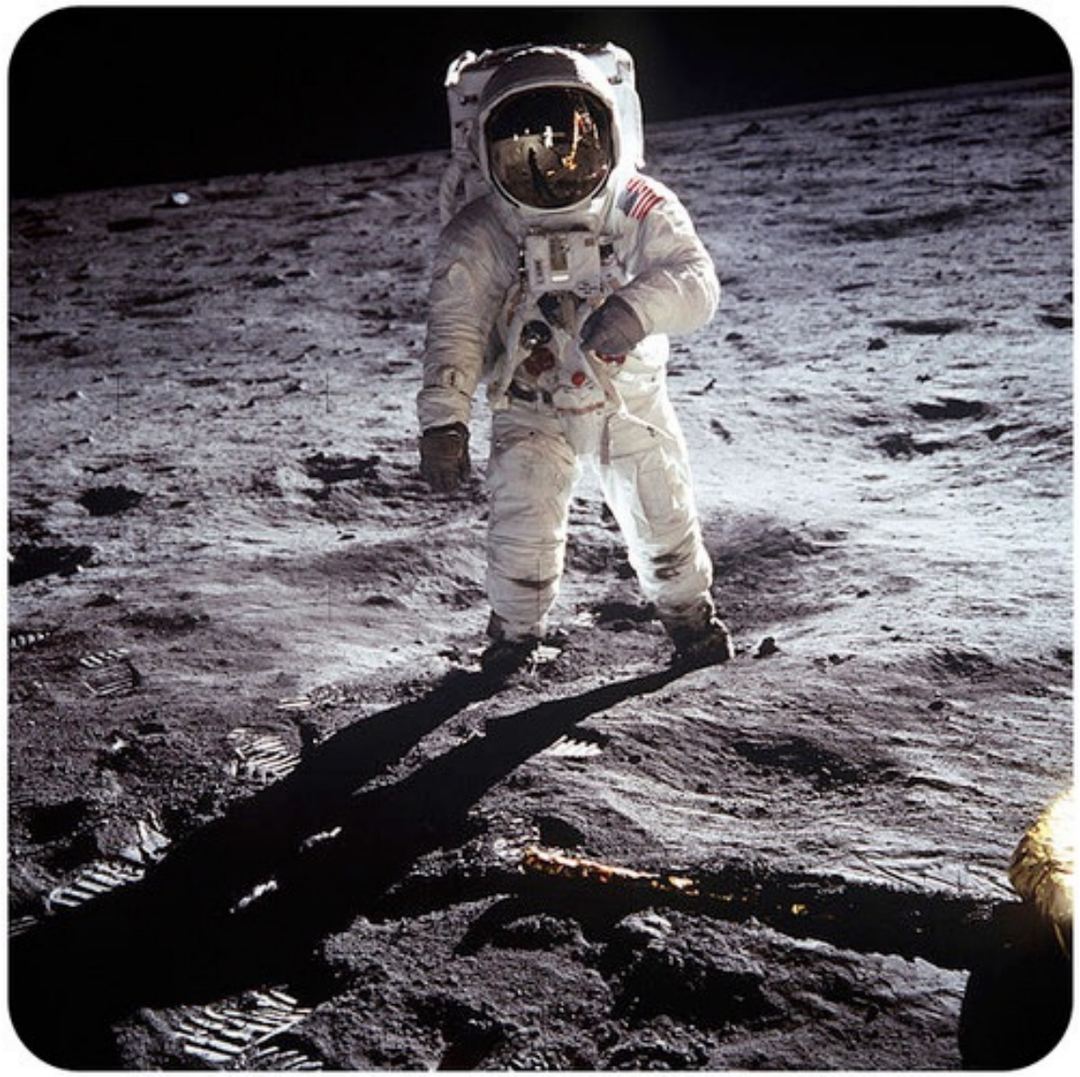


Figure 5.29

Neil Armstrong took this photo of Buzz Aldrin on the Moon during the Apollo 11 mission. Armstrong and the Lunar Module can be seen in the reflection in Aldrin's helmet.

Following the Apollo 11 mission, four other American missions successfully put astronauts on the Moon. The last manned mission to the moon was Apollo 17, which landed on December 11, 1972. To date, no other country has put a person on the Moon.

In July 1975, the USSR and the United States carried out a joint mission called the Apollo-Soyuz Test Project. During the mission, an American Apollo spacecraft docked with a Soviet Soyuz spacecraft (**Figure** below).

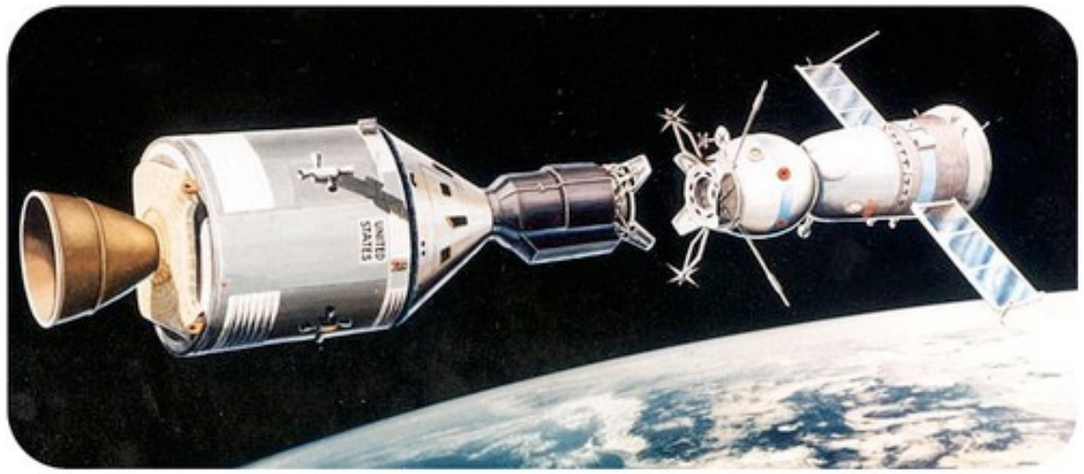


Figure 5.30

The docking of an Apollo spacecraft with a Soyuz spacecraft in 1975. Many considered this to be the symbolic end of the Space Race.

Exploring Other Planets

Both the United States and the USSR sent probes to other planets during the Space Race. A **space probe** is a an unmanned spacecraft that is sent to collect data by flying near or landing on an object in space, such as a planet, moon, asteroid, or comet. During the Venera missions, the USSR sent several probes to Venus, including some that landed on the surface. The United States sent probes to Mercury, Venus, and Mars in the Mariner missions (**Figure** below), and landed two probes on Mars in the Viking missions.

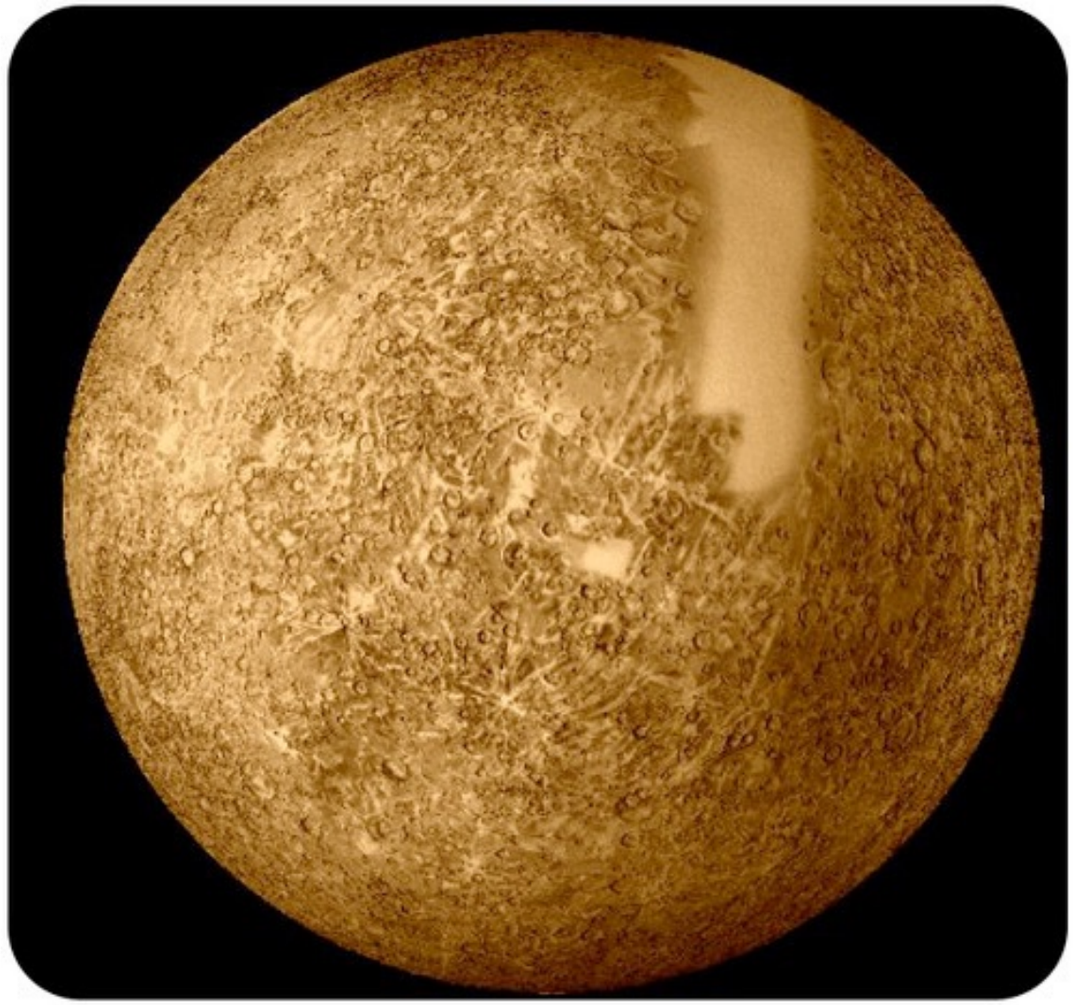


Figure 5.31

Data from Mariner 10 was used to create this image of Mercury.

In the Pioneer and Voyager missions, the United States also sent probes to the outer solar system, including flybys of Jupiter, Saturn, Uranus, and Neptune. The Pioneer and Voyager probes are still traveling, and are now beyond the edges of our solar system. We have lost contact with the two Pioneer probes, but expect to have contact with the two Voyager probes until at least 2020 (**Figure** below).

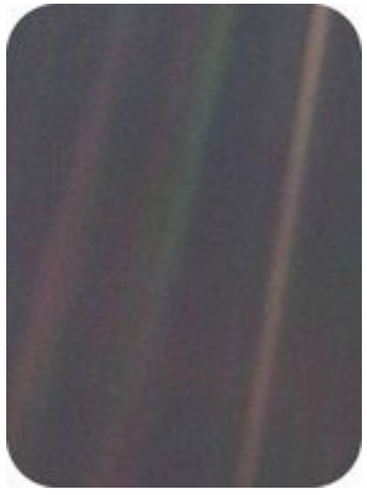


Figure 5.32

A portrait of the solar system more than 4 billion miles from Earth was taken by Voyager I. The pale blue dot halfway down the brown band on the right side is Earth.

As of late 2012, Voyager 1 was about 11 billion miles from Earth. The spacecraft was about to leave the Sun's influence and enter interstellar space.

The rovers sent to Mars and the New Horizons Mission to Pluto are two of the more recent planetary probes. The rovers will be discussed in the chapter on Planets. For more information about New Horizons, go here.

Lesson Summary

- Rockets have been used for warfare and ceremonies for many centuries.
- Newton's third law explains how a rocket works. The action force of the engine on the gases is accompanied by a reaction force of the gases on the rocket.
- Konstantin Tsiolkovsky, Robert Goddard, and Hermann Oberthall came up with similar ideas for improving rocket design, such as using liquid fuel and multiple stages.
- A satellite orbits a larger object. Moons are natural satellites; humans make artificial satellites.
- Newton's law of universal gravitation explains how satellites enter an orbit.
- Artificial satellites are used for imaging planets, for navigation, and for communication.
- The launch of Sputnik 1 started a Space Race between the United States and the USSR.
- The United States' Apollo 11 mission put the first humans on the Moon.
- The United States and USSR sent several probes to other planets during the Space Race.

Review Questions

1. Use Newton's third law to explain how a rocket moves.
2. List the three great pioneers of rocket science and their contributions.
3. What is the difference between a rocket and a satellite? How are they related?
4. What is the name of Earth's natural satellite?
5. Explain why a satellite in polar orbit can take pictures of all parts of the Earth over time.
6. Describe three different types of orbits.
7. What event launched the Space Race?
8. What goal did John F. Kennedy set for the United States in the Space Race?
9. What are the advantages of a multi-stage rocket instead of a single-stage rocket?

Further Reading / Supplemental Links

- In Wikipedia, www.wikipedia.org: Hermann_Oberth; Wernher_von_Braun; V-2_rocket; Satellites; Natural_satellite; Newton_cannonball; Sputnik_1; Sputnik_program; Space_Race; Cold_War; John_F._Kennedy; Apollo_program; List_of_planetary_probes.
- A history of lunar exploration from NASA

Points to Consider

- The Space Race and the United State's desire to get to the Moon brought about many advances in science and technology. Can you think of any challenges we face today that are, could be, or should be a focus of science and technology?
- If you were in charge of NASA, what new goals would you set for space exploration?
- Do you think that a space program is a good use of government funding?

Recent Space Exploration

Recent Space Exploration

Lesson Objectives

- Outline the history of space stations and space shuttles.
- Describe recent developments in space exploration.

Vocabulary

- orbiter
- space shuttle
- space station

Introduction

Even since the end of the Space Race, space exploration has continued. Humans have a presence in space at the International Space Station, and the Russian space station, Mir.

Space Shuttles and Space Stations

While the United States continued missions to the Moon in the early 1970s, the Soviets had another goal: to build a **space station** . A space station is a large spacecraft on which humans can live for extended periods.

Early Space Stations

The Soviet Union put the first space station, Salyut 1, into orbit on April 19, 1971, with no crew. On June 7, 1971, three cosmonauts boarded the station and stayed for 22 days. Unfortunately, the cosmonauts died during their return to Earth and Salyut 1 left orbit and burned up in the Earth's atmosphere later that year.

Between 1971 and 1982, the Soviets put a total of seven Salyut space stations into orbit (**Figure** below). Several of the stations were used to study the problems of living in space and for a variety of experiments in astronomy, biology, and Earth science.

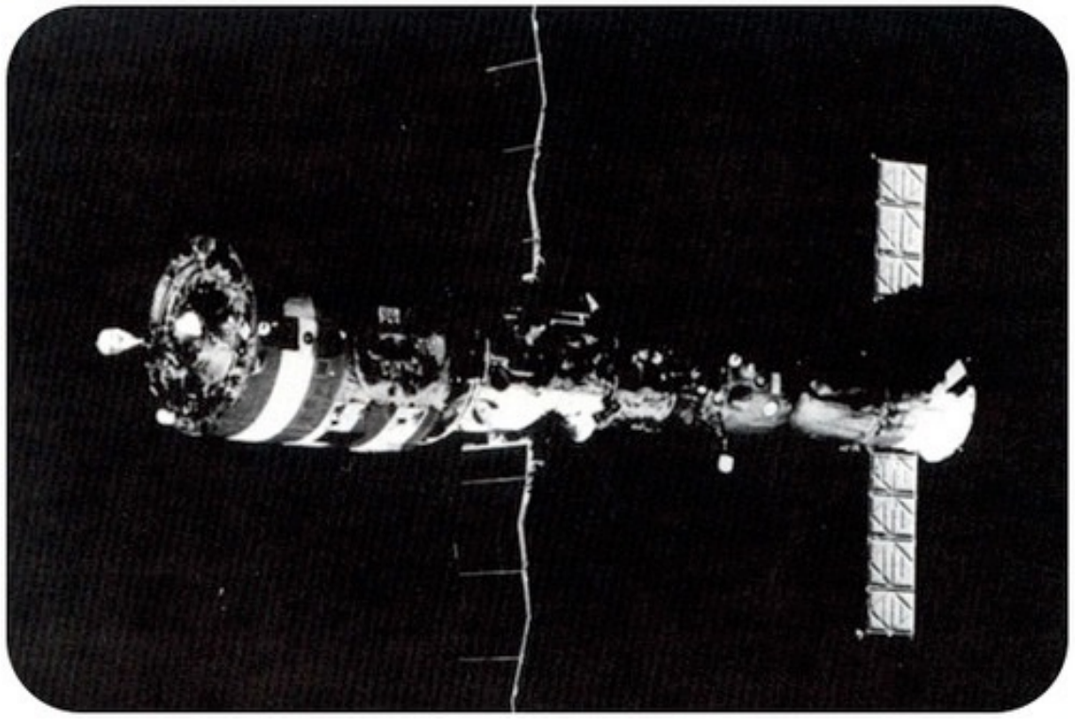


Figure 5.33

Salyut 6 and Salyut 7 each had two docking ports, so a crew could dock a spacecraft to one end, and a replacement crew could dock

to the other end. This Soviet Salyut 7 space station was in orbit from 1982 to 1991.

The United States only launched one space station during this time. In May 1973, Skylab was launched (**Figure** below). Three crews visited Skylab, all within its first year in orbit. Skylab was used to study the effects on humans of staying in space for long periods, and was used for studying the Sun.

More about Skylab can be found at http://starchild.gsfc.nasa.gov/docs/StarChild/space_level2/skylab.html .



Figure 5.34

This image of Skylab was taken as the last crew left the station in January of 1974.

Modular Space Stations

The first space station designed for long-term use was the Mir space station (**Figure** below). Mir was a *modular* space station. The USSR launched Mir's core in 1986 and the station was put together in several phases over the next decade. Mir holds the current record for the longest continuous occupation (although not by the same astronauts), nearly 10 years. Mir was taken out of orbit in 2001 and fell into the Pacific Ocean, as planned.

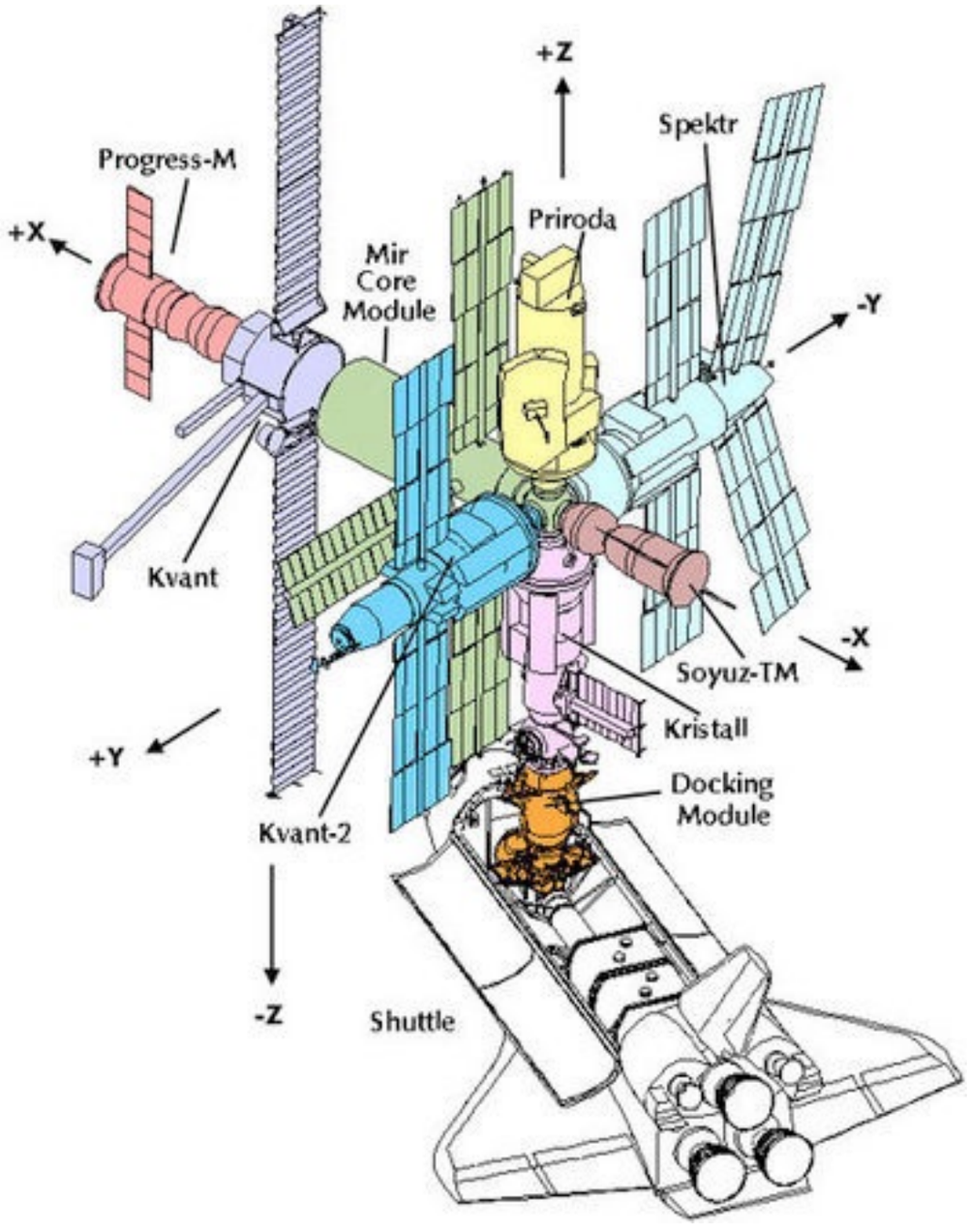


Figure 5.35

The Soviet/Russian space station Mir was designed to have several different parts attached to a core.

Early space exploration was driven by competition between the United States and the USSR. However, since the end of the Cold War, space technology and space exploration have benefited from a spirit of cooperation. In 1993, the United States and Russia announced American involvement in Mir and plans for what became the International Space Station (ISS). Space shuttles would transport supplies and people to and from Mir, and American astronauts would live on Mir for many months. This cooperation allowed the United States to learn from Russia's experience with long-duration space flights. (**Figure** below) shows Mir with an American space shuttle attached.

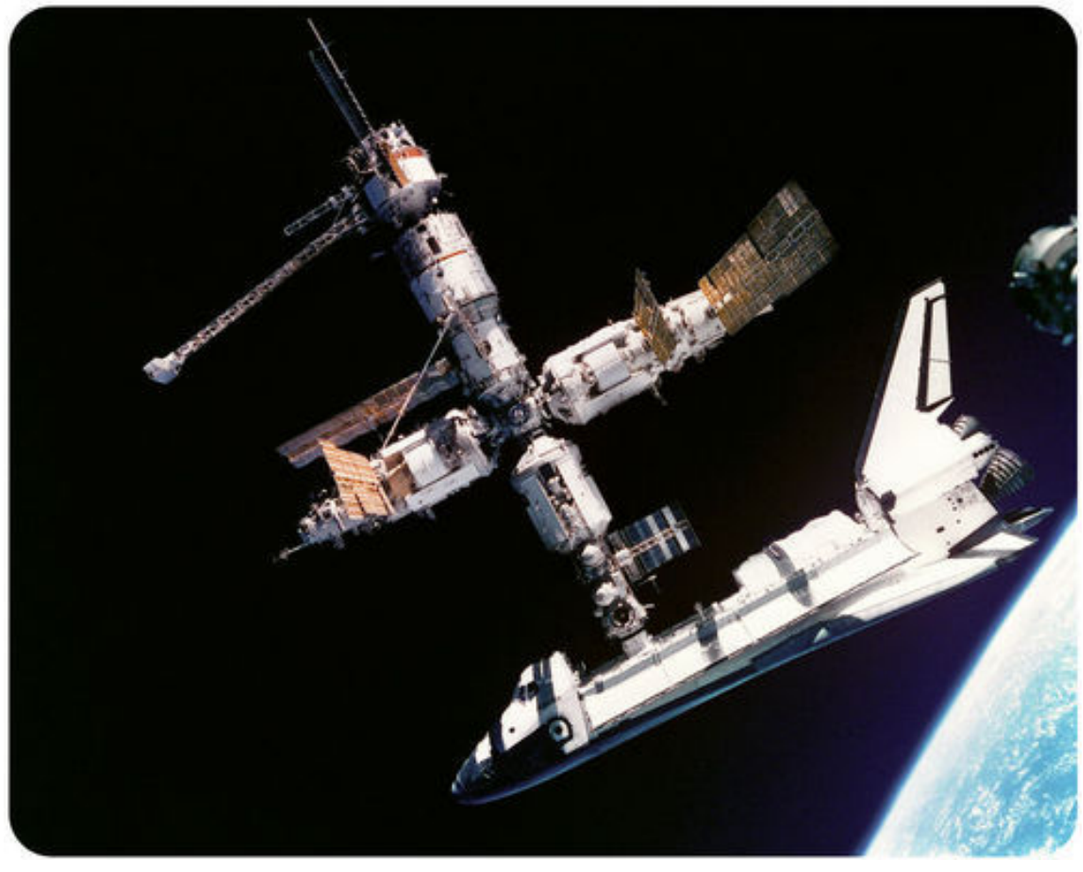


Figure 5.36

Russian cosmonauts took this photograph from their Soyuz spacecraft as they flew around Mir and the ISS.

The International Space Station

The International Space Station, shown in (**Figure** below), is a joint project between the space agencies of the United States (NASA), Russia (RKA), Japan (JAXA), Canada (CSA) and several European countries (ESA). The Brazilian Space Agency also contributes.

The first piece of the ISS was launched in 1997 and it has been constructed piece by piece over time since then. It is a large station with many different sections. The station has had people on board since the first crew arrived in 2000. American space shuttles transport most of the supplies and equipment to the station, while Russian Soyuz spacecraft carry people. The primary purpose of the station is scientific research, especially in biology, medicine, and physics.

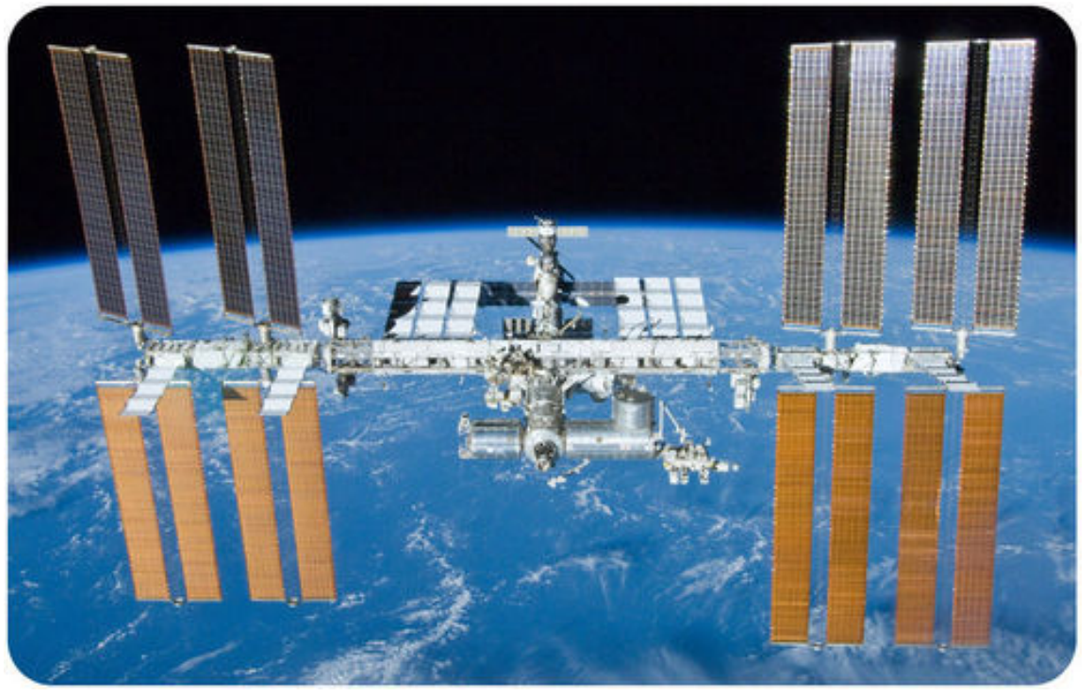


Figure 5.37

A photograph of the International Space Station was taken from the space shuttle Atlantis in June 2007. Construction of the station was completed in 2011.

Space Shuttles

Although the spacecraft used for the Apollo missions were very successful, they were also very expensive, could not carry much cargo, and could be used only once. NASA wanted a new kind of space vehicle, one that 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** below), and there have been five — Columbia, Challenger, Discovery, Atlantis, and Endeavor. The Soviet Union built a similar shuttle called Buran, but it never flew a mission with humans aboard.



Figure 5.38

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.

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* .

(**Figure** below) shows the stages of a normal space shuttle mission. The launch takes place at Cape Canaveral in Florida. The booster rockets provide extra power to get the orbiter out of Earth's atmosphere. When they are done, they parachute down into the ocean so they can be recovered and used again. When the fuel tank is empty, it also falls away, but it burns up in the atmosphere. Once in space, the orbiter can be used to release equipment, such as a satellite, or supplies to the International Space Station, or to repair existing equipment such as the Hubble Space Telescope, or to do experiments directly on board the orbiter.



Figure 5.39

In a typical space shuttle mission, the orbiter takes off like a rocket and lands like an airplane.

When the mission is complete, the orbiter re-enters Earth's atmosphere. As it passes through the atmosphere, the outside of the orbiter heats up to over 1,500 ◦C. The rockets do not fire during re-entry, so the shuttle is more like a glider than an airplane. Pilots have to steer the shuttle to the runway very precisely. Space shuttles usually land at Kennedy Space Center in Cape Canaveral, Florida, or at Edwards Air Force Base in California. However, if weather is bad at both these landing sites, a shuttle can land at one of many backup sites around the world and then hauled back to Florida on the back of a jet airplane.

To further understand how space shuttles work, check out http://science.howstuffworks.com/space-shuttle.htm .

Space Shuttle Disasters

The space shuttle program has been very successful. Space shuttles have made possible many scientific discoveries and other great achievements in space. However, the program has also had some tragic disasters.

After more than 20 successful missions from 1981 to the end of 1985, disaster struck on January 28, 1986. Just 73 seconds after launch, the space shuttle Challenger started to break apart, and most of it disintegrated in mid-air, as shown in (**Figure** below). All seven crew members on board, including the first teacher in space, Christa McAuliffe, died. The problem was found to be an O-ring, a small part in one of the rocket boosters.



Figure 5.40

Plume of smoke from the Challenger disaster.

Safety was reviewed and improved. Shuttle missions started again in 1988, and more than 87 missions were completed without a major accident. Then during takeoff of the space shuttle Columbia on January 16, 2003, a small piece of insulating foam broke off the fuel tank, smashed into the front edge of one wing of the orbiter and damaged a tile. These tiles are heat-shield tiles that protect the shuttle from extremely high temperatures. When Columbia returned to Earth on February 3, 2003, it could not withstand the high temperature, and broke apart. Pieces of the shuttle were found throughout the southern United States. As in the Challenger disaster, all seven crew members died.

Again, shuttle missions were stopped for two years while NASA worked on safety. The Space Shuttle program was terminated in 2011 and the shuttles have all been retired. You can see them in various locations around the country:

- Atlantis: Kennedy Space Center Visitor Complex; Cape Canaveral, Florida
- Discovery: Smithsonian Institution National Air and Space Museum; Chantilly, Virginia
- Endeavour: California Science Center, Los Angeles
- Enterprise (test orbiter): Intrepid Sea-Air Space Museum; New York City
- Explorer (orbiter mockup): Johnson Space Center; Houston, Texas.

Future missions to the ISS will be aboard the Russian Soyuz and eventually from a new American craft.

Recent Space Missions

Many missions since the Challenger disaster have been designed without a crew. These missions are less expensive, less dangerous, and more flexible than manned mission and they provide a great deal of valuable information.

Earth Science Satellites

NASA and space agencies from other countries have launched dozens of satellites that collect data on the current state of Earth's systems. NASA's Landsat satellites take detailed images of Earth's continents and coastal areas, such as those in (**Figure** below). Other satellites study the oceans, the atmosphere, the polar ice sheets, and other Earth systems. This data helps us to monitor climate change and understand how Earth's systems affect one another. Many of the images used in this text are from satellites.



Figure 5.41

The two images here are from NASA's Landsat 7 satellite and show New Orleans and Lake Pontchartrain on April 26, 2000, (left) and on August 30, 2005, (right), shortly after Hurricane Katrina. Dark blue areas in the city are underwater.

More about the Landsat program can be found at http://landsat.gsfc.nasa.gov/ .

Space Telescopes

Some of the greatest astronomical discoveries — and greatest pictures, such as the one in (**Figure** below), have come from the Hubble Space Telescope. The Hubble was put into orbit by the space shuttle Discovery in 1990. Several shuttle missions returned to the Hubble to make repairs.



Figure 5.42

This image, taken by the Hubble Space Telescope, shows the Cat's Eye Nebula. Hubble has produced thousands of beautiful pictures that are also very valuable for scientific research.

NASA has also put several other telescopes in space as described in the "Telescopes" lesson. The James Webb Telescope, scheduled to be launched into orbit in 2018, will replace the Hubble and have an even greater ability to view distant objects. Other countries, including Russia, Japan, and several European countries, have also put space telescopes in orbit.

Solar System Exploration

The United States and other nations have had many missions around the solar system in recent years (**Figure** below). Rovers, essentially spacecraft on wheels have been sent to roam over Mars to collect data. The Mars Pathfinder, which landed in 1997, and Spirit and Opportunity, which landed in 2004, all lasted far longer than they were designed to. Curiosity, which landed on August 6, 2012, is currently exploring Martian climate and geology, specifically if there were once conditions in which life could exist. Several spacecraft are currently in orbit around Mars studying its surface and thin atmosphere.



Figure 5.43

(a) The Mars Pathfinder carried a rover, the Sojourner, to the surface. Here Sojourner takes a measurement of a rock scientists named Yogi. (b) Sunset on Mars, taken by Spirit in May 2005. (c) This artist's painting of Opportunity shows the six wheels, as well as a set of instruments being extended forward by a robotic arm.

The Cassini mission has been studying Saturn, including its rings and moons, since 2004 and will be directed to crash into Saturn in 2017 (**Figure** below). The Huygens probe, built by the European Space Agency, is studying Saturn's moon Titan. Titan has some of the conditions that are needed to support life.



Figure 5.44

An eclipse of Saturn taken by Cassini.

Some missions are studying the smaller objects in our solar system. The Deep Impact probe was sent to collide with a comet. The probe and telescopes on Earth and in space all collected data The impact was recorded by Deep Impact's flyby spacecraft: http://upload.wikimedia.org/wikipedia/commons/9/90/121520main_HRI-Movie.gif .

The Stardust mission collected tiny dust particles from another comet. Missions are currently underway to study some of the larger asteroids and Pluto. Studies of smaller objects in the solar system may help us to understand how the solar system formed.

A manned trip to Mars to take place in the 2030s is being discussed, as are other possible missions.

Lesson Summary

•The Space Race propelled space exploration for several decades.
•The United States' first space station was Skylab. Skylab was in orbit from 1973 to 1979.
•The Soviet (later Russian) space station Mir was the first modular space station. Both Russian and American crews lived on Mir.
•The ISS is a huge project that involves many countries. It was assembled over several years.
•Space shuttles are reusable vehicles for American astronauts to get into space. A space shuttle takes off like a rocket and lands like a glider plane.
•The space shuttle program has had two major disasters—the Challenger disaster in 1986 and the Columbia disaster in 2003. In each case, the spacecraft was destroyed and a crew of 7 people died.
•Recent space missions have mostly used small spacecraft, such as satellites and space probes, without crews.

Review Questions

1.Which space station was built and launched by the United States alone?
2.How many years was the Mir space station in orbit?
3.Which space station was the first to involve several countries working together?
4.Describe two ways in which space shuttles were an improvement over the spacecraft used for the Apollo missions?
5.Name the five fully functional space shuttles that the United States built. Which of these were destroyed?
6.Describe the space shuttle Columbia disaster, including its cause.
7.Describe two recent or ongoing space missions.
8.Is the Space Shuttle more like a rocket or a plane? Explain your answer.

Further Reading / Supplemental Links

•Fantastic images of Earth: http://earthobservatory.nasa.gov/
•NASA's mission to study Earth: http://science.hq.nasa.gov/missions/earth.html
•Find out what it's like to live in Space: http://spaceflight.nasa.gov/living/index.html
•http://en.wikipedia.org/wiki/Orion_%28spacecraft%29

Points to Consider

•To date, a total of 22 people have died on space missions. In the two space shuttle disasters alone, 14 people died. However, space exploration and research have led to many great discoveries and new technologies. Do you think sending people into space is worth the risk? Why or why not?
•In the past several years, private companies have been developing vehicles and launch systems that can take people into space. What applications can you think of for such vehicles? What advantages and disadvantages are there to private companies building and launching spacecraft?

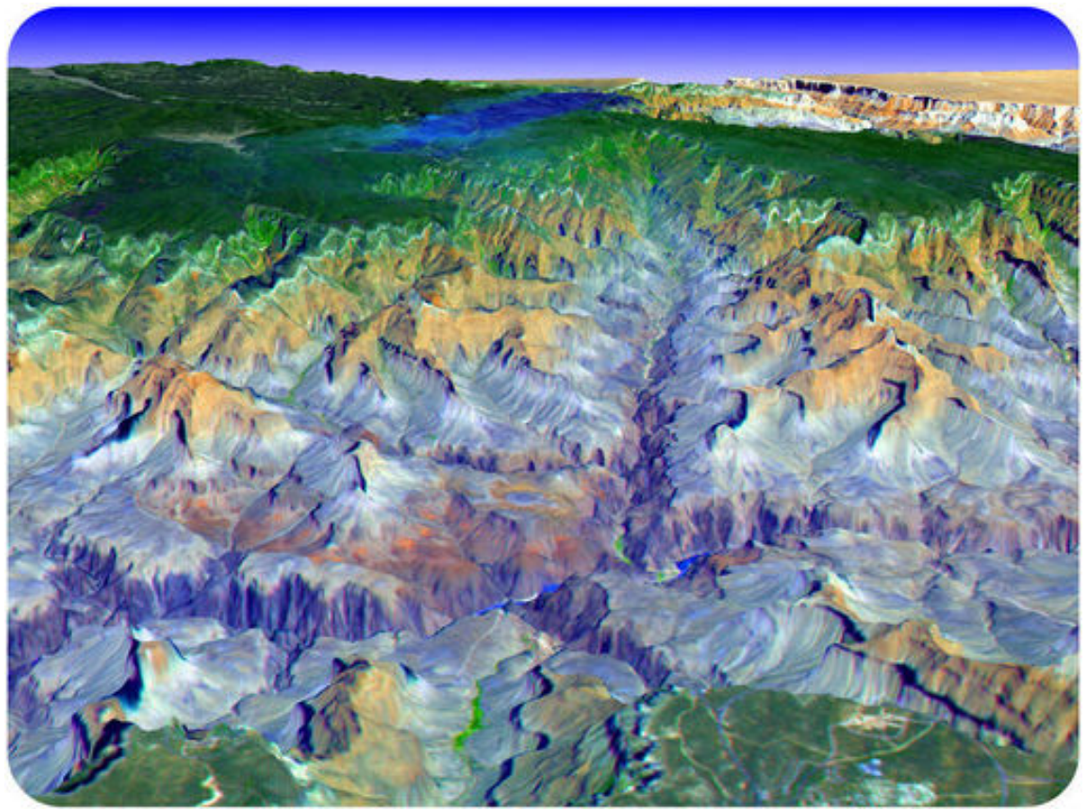
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Ch. 6: Studying Earth's Surface



If you've seen the Grand Canyon or a photo of the Grand Canyon, you'll know that this is not the Grand Canyon. Or is it? The rock colors seen above are not what a person standing at the rim on the canyon would see. From the rim, the Grand Canyon is mostly red with the prominent white stripe of the Coconino Sandstone near the top. The cliffs are more angular than the cliffs pictured here. NASA produced this image using data from the Advanced Spaceborne Thermal Emissions and Reflection Radiometer (ASTER), one of five remote sensing devices aboard the Terra spacecraft. ASTER measures 14 different wavelengths of the electromagnetic spectrum, ranging from visible to infrared light, to give information on land surface temperature, reflectance, and elevation. The resolution is between 15 and 90 meters.

So, is this the Grand Canyon? Any image or map of the Earth's surface is just a representation. All maps show the data the map maker intended at the best level of accuracy possible. Each representation is valuable in its own way but has limitations. The only real Grand Canyon is the one you are looking at from the rim of the canyon. Or is that image altered by the tint of your sunglasses?

NASA/GSFC/MITI/ERSDAC/JAROS and U.S./Japan ASTER Team. www.nasa.gov/multimedia/imagegallery/image_feature_769.html. Public Domain.

Earth's Surface

Lesson Objectives

- Briefly identify different features of continents and ocean basins.

•Define constructive forces and give a few examples.
•Define destructive forces and give a few examples.

Vocabulary

•constructive forces
•continent
•continental margin
•destructive forces
•landform
•mid-ocean ridge
•ocean basin
•ocean trench

Introduction

Earth's surface features are the result of constructive and destructive forces. Constructive forces cause landforms to grow. The eruption of a new volcano creates a new landform. Destructive forces wear landforms down. The slow processes of mechanical and chemical weathering and erosion work over time to change once high mountains into smooth flat plateaus.

Earth's Features

Figure below is a slice through a relief map of Earth's surface without the water in the oceans. What are its two most distinctive features?

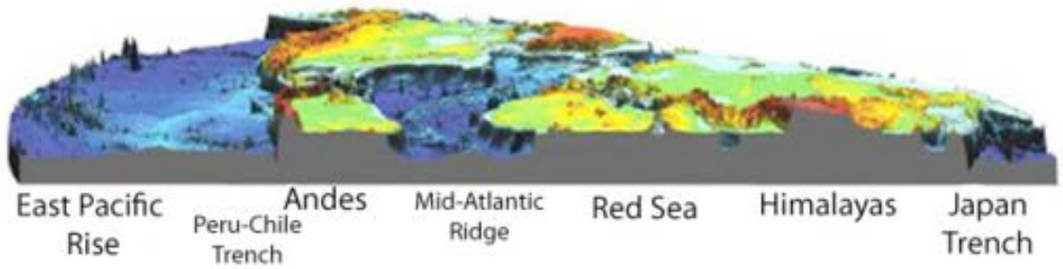


Figure 6.1

In this figure, color indicates elevation. Red represents the highest mountains with orange, yellow, and green indicating lower elevations. Light blue to darker blue to bluish-purple descends to the deepest ocean floor.

•The **continents** are large land areas extending from high mountaintops to sea level.
•The **ocean basins** extend from the edges of the continents down steep slopes to the ocean floor and into deep trenches.

Continents

The oldest continental rocks are billions of years old, so the continents have had a lot of time for things to happen to them. **Constructive forces** cause physical features on Earth's surface known as **landforms** to grow. Crustal deformation – when crust compresses, pulls apart, or slides past other crust – results in hills, valleys, and other landforms. Mountains rise when continents collide, when one slab of ocean crust plunges beneath another or a slab of continental crust to create a chain of volcanoes. Sediments are deposited to form landforms, such as deltas.

Volcanic eruptions can also be **destructive forces** that blow landforms apart. The destructive forces of weathering and erosion

modify landforms. Water, wind, ice, and gravity are important forces of erosion.

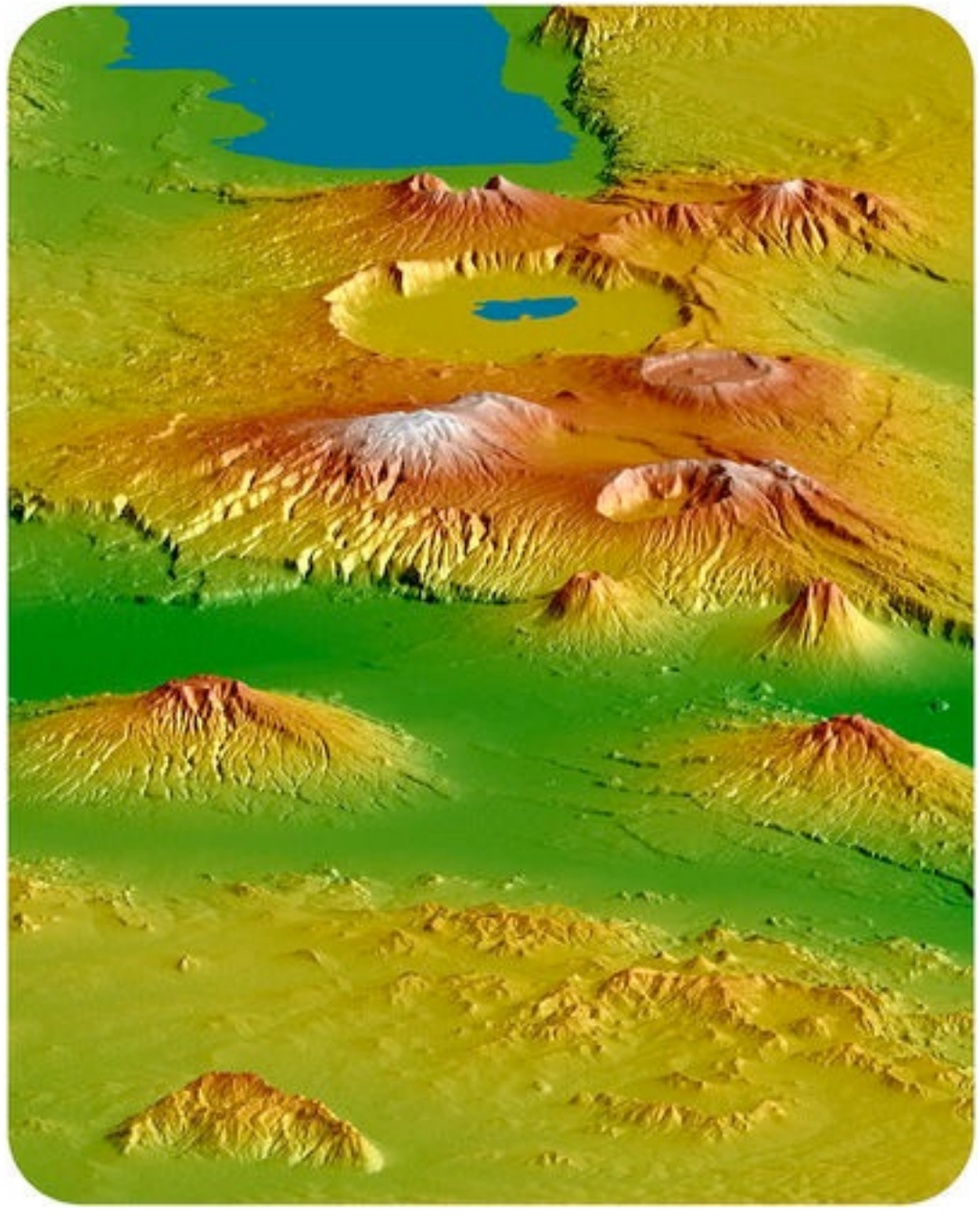


Figure 6.2

Landforms in this radar image of the Crater Highlands of Tanzania are accentuated by 2x vertical relief and also by color. The highest elevations are white and lowest elevations are green.

Look for constructive and destructive landforms in **Figure** above . This scene is within the East African Rift where the crust is being pulled apart to form a large valley.

- Which features result from constructive forces? Volcanoes have been constructed within the valley by rising magma.
- Which features result from destructive forces? Volcanic explosions or collapses have destroyed volcanic mountains to form craters. Fractures caused by the rifting in the valley are signs that the valley is breaking apart. Streams are eroding downward into the slopes of the volcanoes. Landslides erode the steep volcanoes. A landslide scar is seen on left side of the small, very steep volcanic cone near the center of the image, and landslide deposits have traveled outward from the scar.

Ocean Basins

The **ocean basins** are all younger than 180 million years. Although the ocean basins begin where the ocean meets the land, the continent extends downward to the seafloor, so the **continental margin** is made of continental crust.

The ocean floor itself is not totally flat, as illustrated in **Figure** below . The most distinctive feature is the mountain range that runs through much of the ocean basin, known as the **mid-ocean ridge** . The deepest places of the ocean are the **ocean trenches** , many of which are located around the edge of the Pacific Ocean. Chains of volcanoes are also found in the center of the oceans,

such as in the area of Hawaii. Flat plains are found on the ocean floor with their features covered by mud.

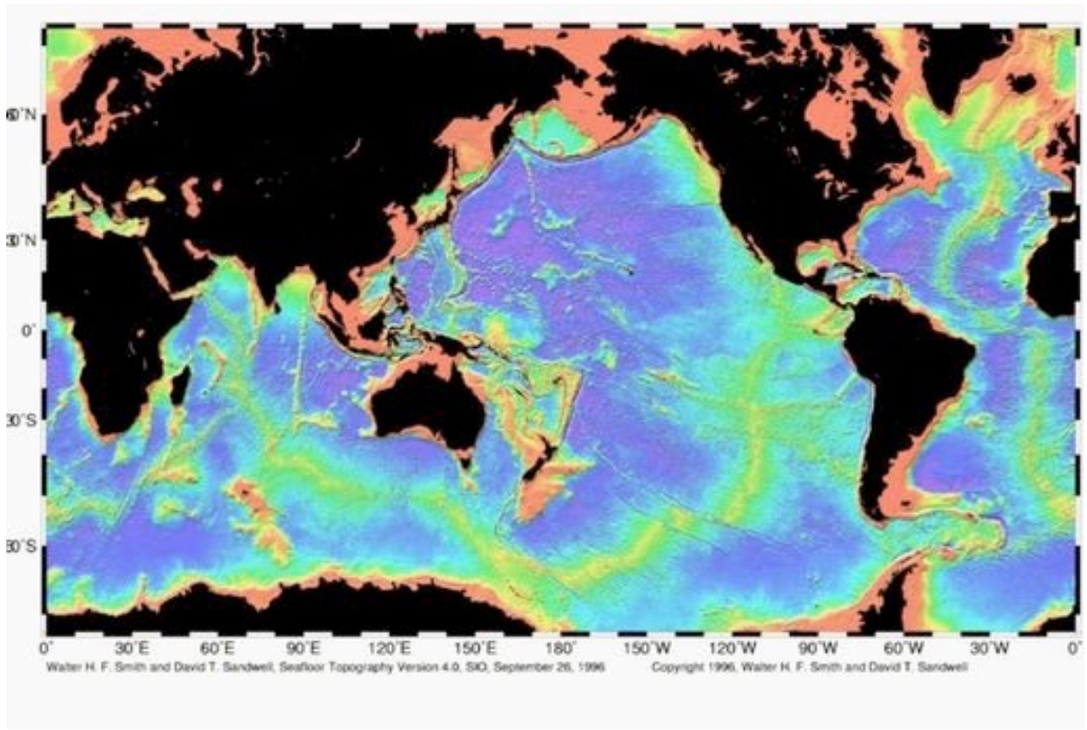


Figure 6.3

Major features of the world's ocean basins. Salmon = continental margins, yellow-green = the mid-ocean ridge system, deep purple = trenches, and bluish purple = flat regions.

Changing Earth

Earth's surface changes over short and long periods of time. Constructive forces cause new features to form by volcanic activity or uplift of the crust. Existing landforms are modified by destructive forces, perhaps even eroded away by water, wind, ice, and gravity. Beneath the oceans, volcanic activity forms new seafloor while old seafloor is destroyed at the trenches. You will explore many ways that the Earth's surface changes as you proceed through this book.

Lesson Summary

- For the most part, continents are much older than ocean basins.
- Both the continents and ocean basins are covered by many types of landforms, including mountains and flat plains.
- Constructive forces cause landforms to grow.
- Destructive forces modify or even destroy landforms.
- Earth's surface is constantly changing. Change can happen rapidly, as when a volcano blows itself apart, or slowly, as in the grain by grain erosion of a stream into a canyon.

Review Questions

1. What are constructive forces and what landforms do they create?
2. What are destructive forces and what landforms do they create?
3. In a single region, are only constructive or only destructive forces at work?
4. In terms of Earth's surface, what is the only thing that is constant?
5. What are some of the landforms found in the ocean basins?
6. Until recently, scientists thought the seafloor was just flat and muddy. Why do you think they thought this? What do they think now?

Further Reading / Supplemental Links

•Current ocean research with videos and explanations is found at http://oceanexplorer.noaa.gov/ .

Points to Consider

•If erosion is constantly eating away at landforms, why isn't Earth's land surface completely flat?
•Why do you think some regions of some continents, such as the middle part of the United States, are almost entirely flat?
•Why are continents higher than ocean basins?

Where in the World Are You?

Lesson Objectives

•Understand the difference between location and direction.
•Know how a compass works and how to use one.
•Know how to determine location using latitude and longitude.

Vocabulary

•compass
•compass rose
•direction
•elevation
•latitude
•location
•longitude
•relief
•sea level
•topography

Introduction

Without being able to pinpoint a location, understanding Earth's surface would be of little value. Scientists, and even people on the move, must have a system to locate themselves and important features on the Earth.

Location

Perhaps you are sitting in the front office at Clovis West High School in California (**Figure** below). There are many ways to indicate your **location** , any of which can be used to find you.

1.Street address: 1070 East Teague, Fresno, California.
2.Latitude and longitude: 36.85926°N, 119.76468°W.
3.Triangulation: 168 miles from Santa Barbara, 122 miles from San Jose, and 24 miles from Auberry.

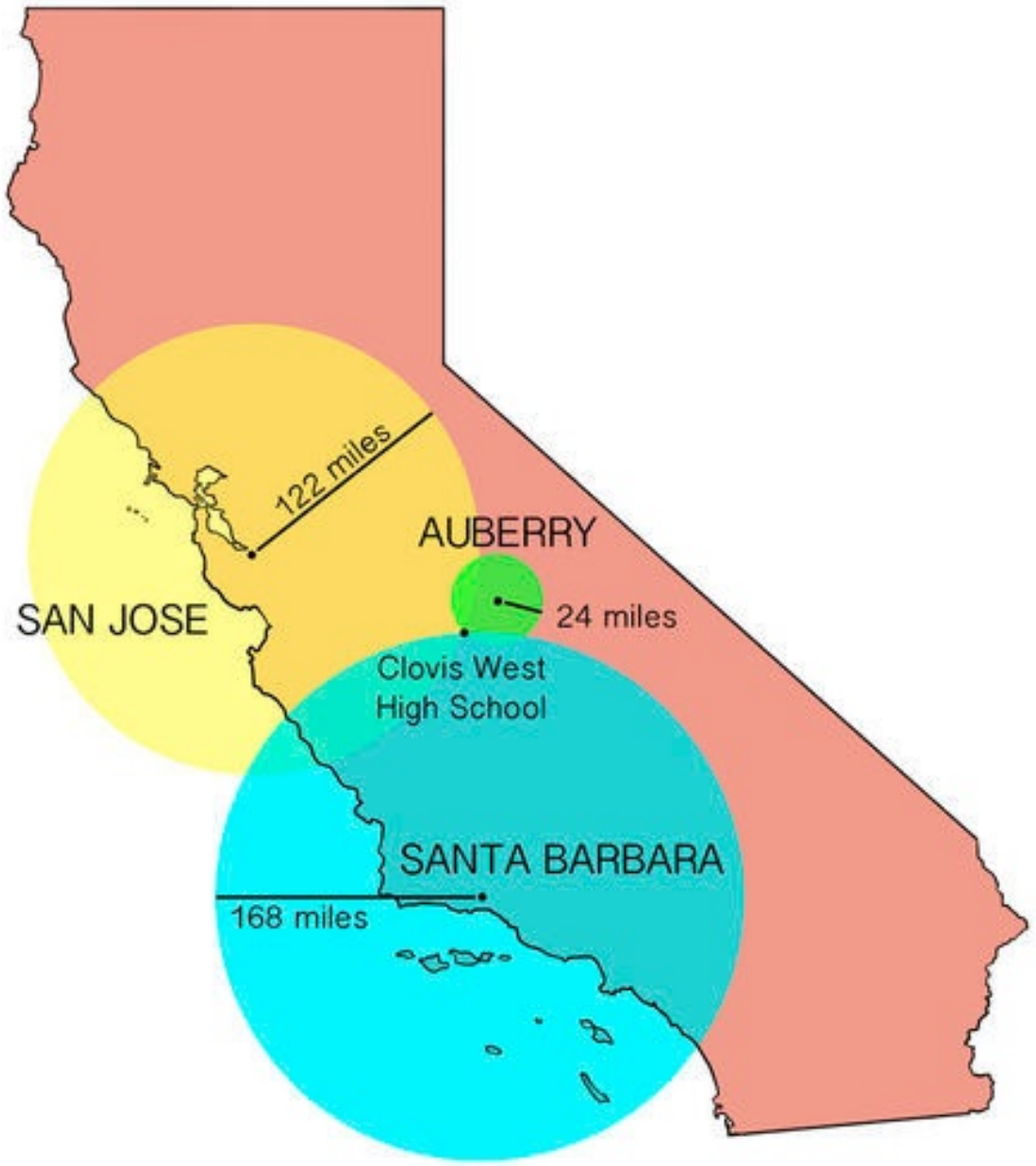


Figure 6.4

A triangulation map for Clovis West High School.

Any of these locations can be used and each has a different purpose. A postal worker might prefer to have a street address than to have to triangulate when delivering the mail. A geologist might want to know the latitude and longitude of an important feature.

Triangulation is useful for locating where earthquakes and other things occur.

Direction

A line connecting two different locations has **direction** . Directions are expressed as north (N), east (E), south (S), and west (W) with gradations in between. Clovis West High School is north of Santa Barbara, east-southeast of San Jose, and southwest of Auberry. Direction is important for describing moving objects. For example, the wind may be blowing from southwest to northeast.

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, as demonstrated in the **Figure** below . A **compass rose** (**Figure** below) is a figure drawn on a map or nautical chart that shows directions or degrees.

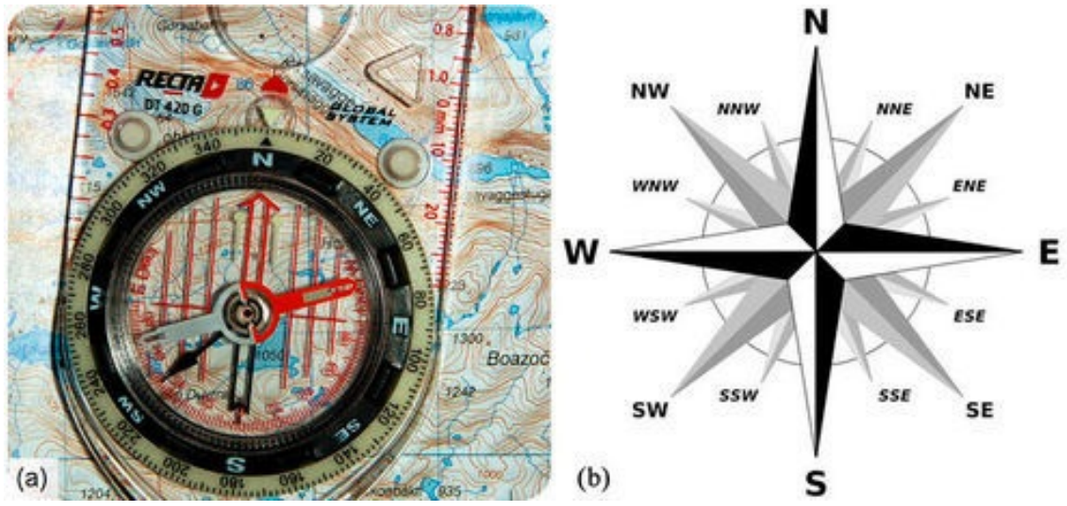


Figure 6.5

(a) A compass is used to determine direction. A compass overlaid on a map can be used to show the directions the features are from each other. (b) This compass rose shows the major directions at 90 degrees and divides them into halves at 45 degrees – northeast (NE), southeast (SE), southwest (SW), and northwest (NW) - and then divides them in half again at 22.5 degrees – NNE, ENE, ESE, SSE, SSW, WSW, WNW, and NNW. Sometimes a compass rose just shows degrees.

Earth's magnetic north pole is different from its geographic North Pole, known as true north. The geographic North Pole is the point where the axis upon which Earth rotates intersects the planet's surface in the north. To find directions on a map using a compass you must correct for this discrepancy. The **Figure** below illustrates this offset between geographic and magnetic north.

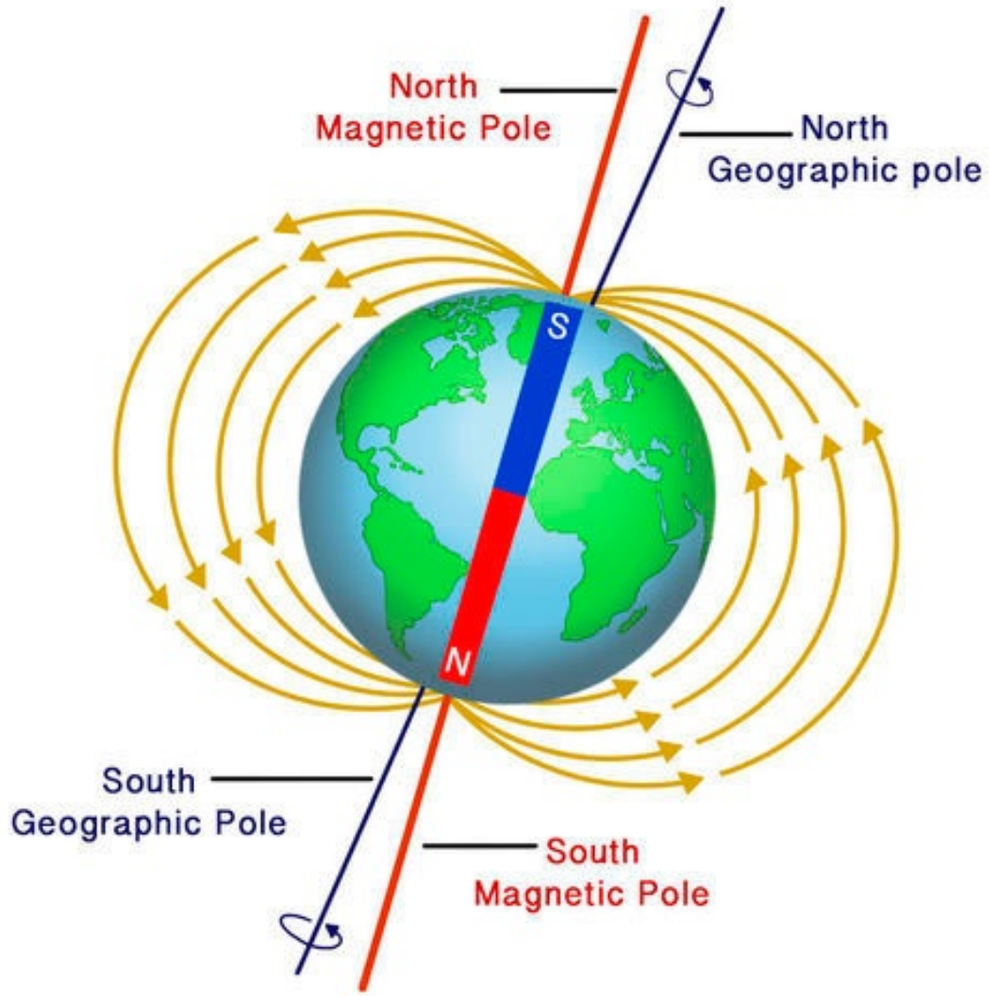


Figure 6.6

Earth's magnetic north pole is 11.5 degrees offset from its geographic north pole on the axis of rotation.

Latitude and Longitude

Any location on Earth's surface -- or on a map -- can be described by latitude and longitude. Latitude and longitude are expressed as degrees that are divided into 60 minutes. Each minute is divided into 60 seconds.

Latitude tells the distance north or south of the equator. Latitude lines start at the equator and circle around the planet. The equator is the line that falls equally between the North and South Poles. The latitude of the equator is 0°. The North Pole is 90°N, with 90 degree lines in the Northern Hemisphere. The South Pole is 90°S, with 90 degree lines in the Southern Hemisphere (**Figure** below). The latitude of Clovis West High School (**Figure** above) is 36.85926°N expressed in degrees and fractions of degrees.

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° longitude and passes through Greenwich, England. The International Date Line is the 180° meridian. The longitude of Clovis West High School is 119.76468°W expressed in degrees and fractions of degrees.

An interactive globe from the Scripps Institution of Oceanography helps with orienting by longitude: http://earthguide.ucsd.edu/earthguide/diagrams/globe/globe.swf .

Since Earth is not flat, 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 and is the same all around Earth. The **topography** of a region is the height or depth of that feature relative to sea level. **Relief** or terrain includes all the major features or landforms of a region. **Figure** below illustrates a topographic relief of California.



Figure 6.7

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

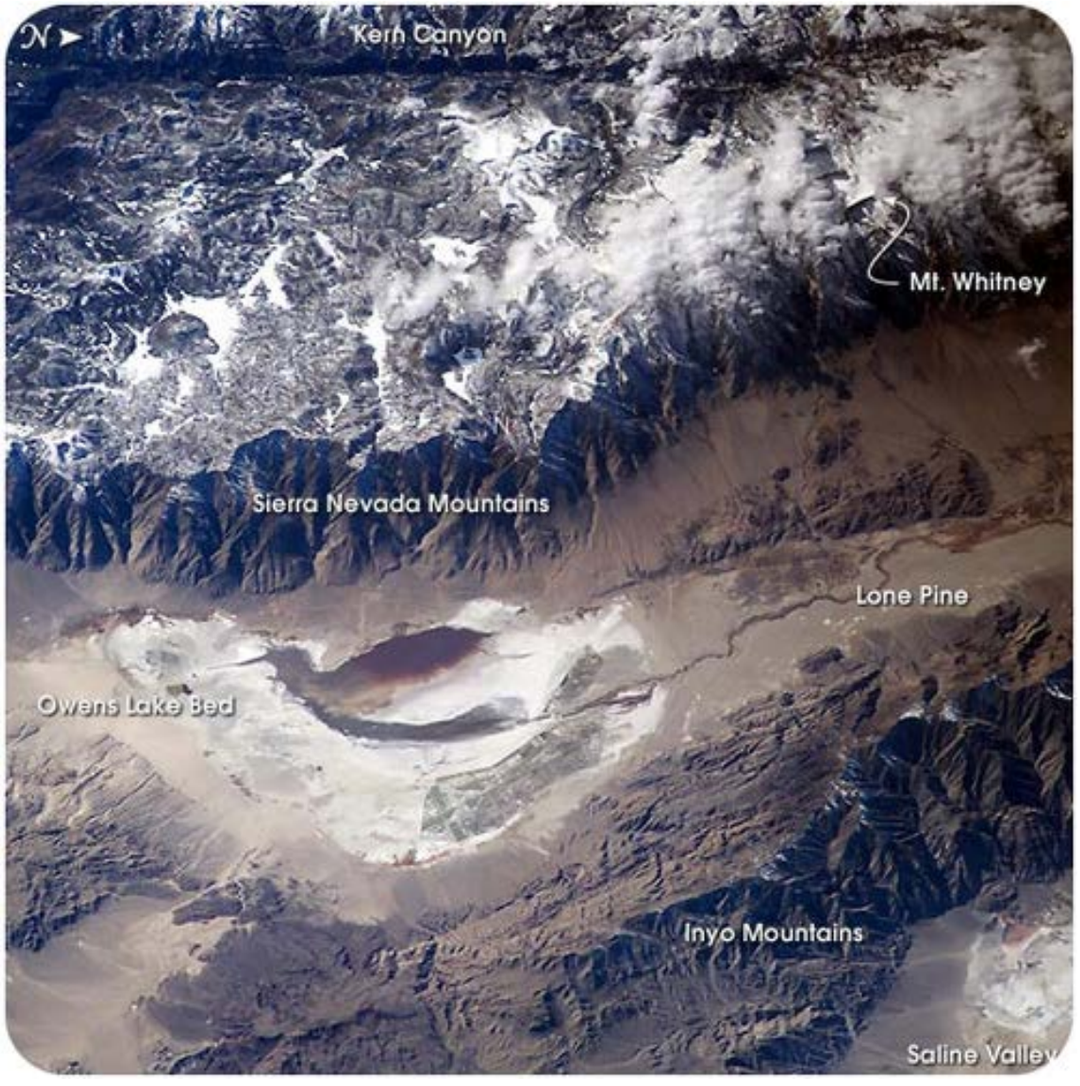


Figure 6.8

Topographic relief in California. Mt. Whitney is on the upper right, the highest point in the contiguous United States at 14,494 feet. Death Valley at -282 feet, the lowest contiguous point in the United States, does not appear in this figure but is SE of the Saline Valley, which it resembles.

Lesson Summary

•Location can be expressed in a variety of ways.
•Direction is useful for describing a moving object or the way to get between two locations.
•A compass needle aligns with magnetic north.
•Latitude indicates position north or south of the equator. Longitude indicates position relative to the Prime Meridian. Elevation is height above or below sea level.

Review Questions

1.What information could you use to describe the location of a feature on the Earth's surface?
2.Give an example of a situation where you might need to describe which direction an object is moving.
3.What type of instrument can you use to tell the direction an object is moving?
4.What is topography?
5.What landforms are highest on the continents?
6.Explain what landforms on the continents are created by erosion by wind and water. How does erosion create a landform?
7.A volcano creates a new landform in Mexico. As the Earth scientist assigned to study this feature, explain how you would describe its position in your report.
8.Think about how you would draw a map to show all the different elevations around the area where you live. How might you create such a map?

Further Reading / Supplemental Links

•A good explanation of latitude and longitude is found at National Atlas: http://www.nationalatlas.gov/articles/mapping/a_latlong.html .

Points to Consider

- How can a two-dimensional object, such as a map, express the features of an area in three dimensions?
- To locate yourself accurately, should you use a compass or a map?
- Why does California have such extreme relief?

Modeling Earth's Surface

Lesson Objectives

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

Vocabulary

- map
- projection

Introduction

Different representations of Earth's surface are valuable for different purposes. Accuracy, scale, portability, and features represented are among the many factors that determine which representation is most useful.

Globe

Earth is best represented by a globe like the one seen in **Figure** below because Earth is a sphere. Sizes and shapes of features are not distorted and distances are true to scale.



Figure 6.9

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

Globes usually have a geographic coordinate system and a scale. The shortest distance between two points is the length of the arc (portion of a circle) that connects them.

Math problem: How would you measure the distance between two points on a globe in miles?

- Here's an idea: Pull a string taut between the two locations and mark both locations. Lay the string on the equator of the globe. Count the number of degrees between the marks, starting with one end at 0. The number of miles per degree at the equator is 69.17; now multiply the number of degrees by that number to get the distance in miles between the two locations.

A location on a globe must be determined using polar coordinates because a globe is curved (**Figure** below).

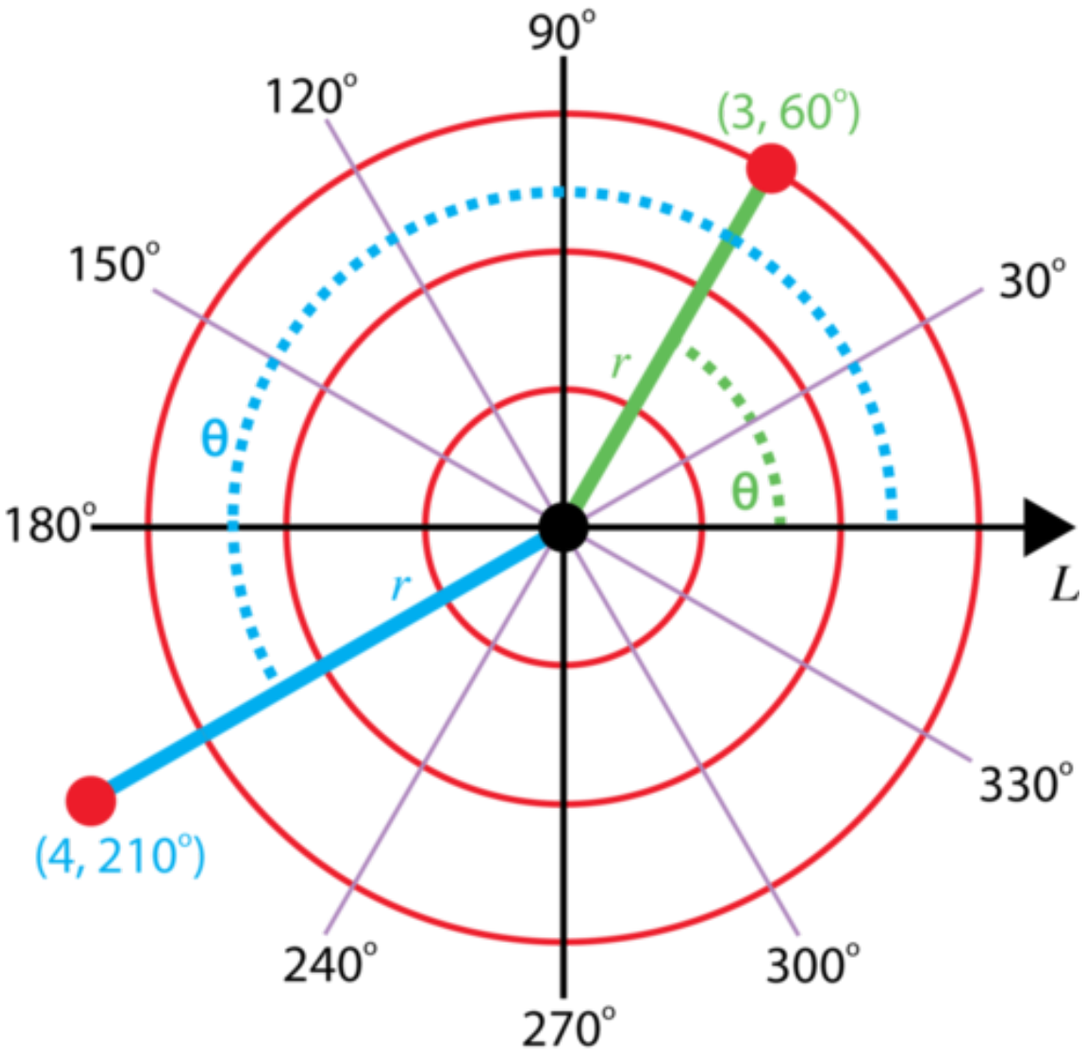


Figure 6.10

The polar coordinate system is useful for curved surfaces.

Globes are difficult to make and carry around, and they cannot be enlarged to show the details of any particular area. As a result, people need maps.

Maps as Models

A **map** is a visual representation of a surface with symbols indicating important features. Different types of maps contain different information. Examples of some maps that are important in Earth science are:

- Relief maps use color to show elevations of larger areas (**Figure** above).
- Radar maps topography (**Figure** above) or weather. National Weather Service Doppler Radar maps are found here: http://radar.weather.gov/ .
- Satellite-view maps show terrains and vegetation, such as forests, deserts, and mountains (**Figure** above).
- Climate maps show average temperatures and rainfall. Climate maps from the National Oceanic and Atmospheric Administration (NOAA) are found here: http://www.esrl.noaa.gov/psd/data/usclimate/states.fast.html .
- Weather maps show storms, air masses, and fronts. Weather maps, also from NOAA, are found here: http://www.nws.noaa.gov/ .
- Topographic maps show elevations using contour lines to reveal landforms (**Figure** below).
- Geologic maps detail the types and locations of rocks found in an area (**Figure** below).

Map Projections

Maps are 2-dimensional (2D) representations of a 3-dimensional (3D) Earth. In a small area, Earth is essentially flat, so a flat map is accurate. But to represent a larger portion of Earth, map makers must use some type of projection to collapse the third dimension onto a flat surface. A **projection** is a way to represent the Earth's

curved surface on flat paper. One example of a projection is shown in the **Figure** below .

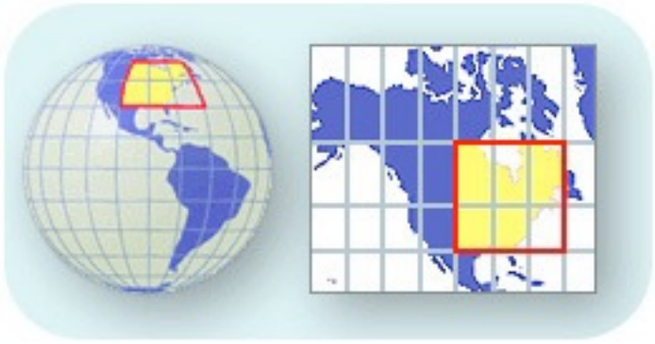


Figure 6.11

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

There are two basic methods for making projections:

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

Let's look at a few commonly used projections.

Mercator Projection

In 1569, Gerardus Mercator (1512-1594) developed the Mercator projection (seen in the **Figure** below). A flat piece of paper curves around the spherical Earth to make a cylinder. The paper touches the sphere at the equator, but the distance between the sphere and the paper increases toward the poles. The features of Earth's surface are projected out onto the cylinder and then unrolled, creating a Mercator projection map.

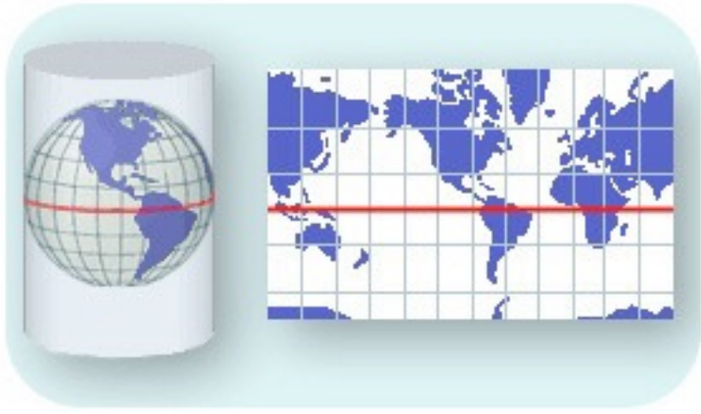


Figure 6.12

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

Where do you think a Mercator map is most accurate? Where is it least accurate? Near the equator the shapes and sizes of features are correct, but features get stretched out near the poles. For example, on a globe, Greenland is fairly small, but in a Mercator map, Greenland is stretched out to look almost as big the United States.

In a Mercator projection, all compass directions are straight lines, but a curved line is the shortest distance between the two points. Many world maps still use Mercator projection today. Early explorers found Mercator maps useful because they visited the equatorial regions more frequently.

A good explanation of the distortion that results from the projection of a sphere onto a flat surface can be seen in Alternative World Maps: http://www.youtube.com/watch?v=cuuluAq4TtU .

Conic Projection

A conic map projection uses a cone shape to better represent regions and best depicts the area where the cone touches the globe. Looking at **Figure** below , what is the advantage of a conic projection over a Mercator projection?

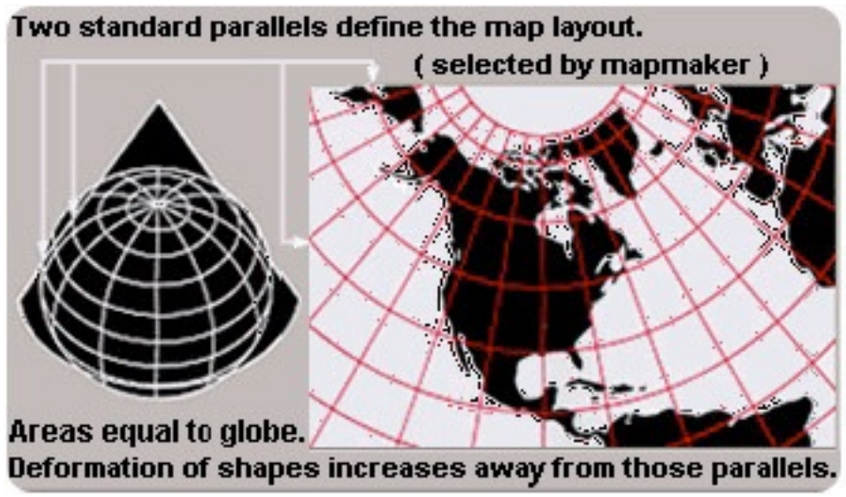


Figure 6.13

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

Gnomonic Projection

A gnomonic map projection is illustrated in **Figure** below . With a gnomonic map projection, paper is placed on the area that you want to map. The projection is good for features near that point. The poles are often mapped this way.

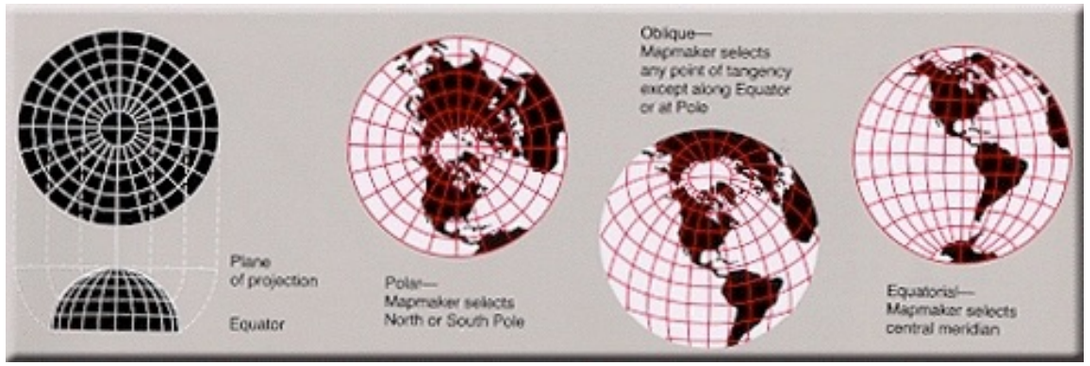


Figure 6.14

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

Robinson Projection

In 1963, Arthur Robinson created an attractive map projection in which latitude lines are projected but meridians are curved, resulting in a map that is an ellipse rather than a rectangle (see **Figure** below for an example). This projection has less distortion near the poles, and features within 45 degrees of the equator are closer to their true dimensions. The distances along latitude lines are true, but the scales along each line of latitude are different. Robinson projections are still commonly used.

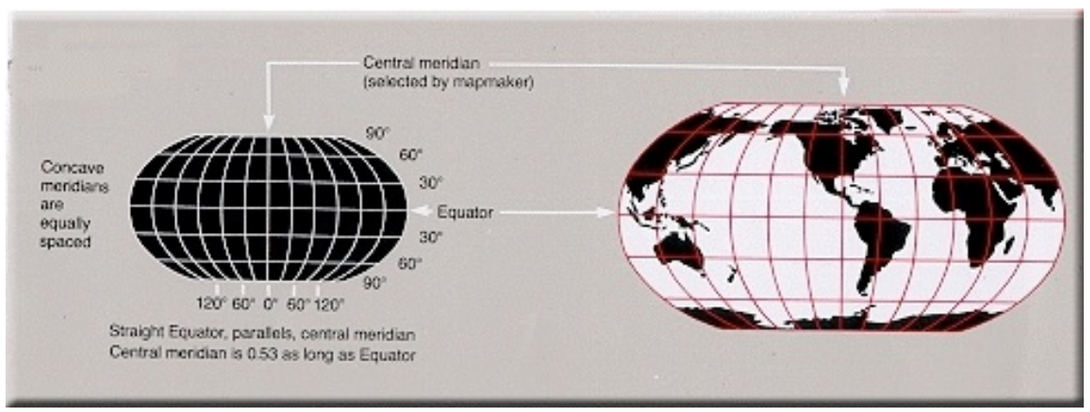


Figure 6.15

A Robinson projection more accurately reflects the size and shape of features near 45 degrees.

Winkel Tripel Projection

The National Geographic Society uses the Winkel Tripel Projection, which uses mathematical formulas to create a map projection that is also distorted at the edges (**Figure** below).

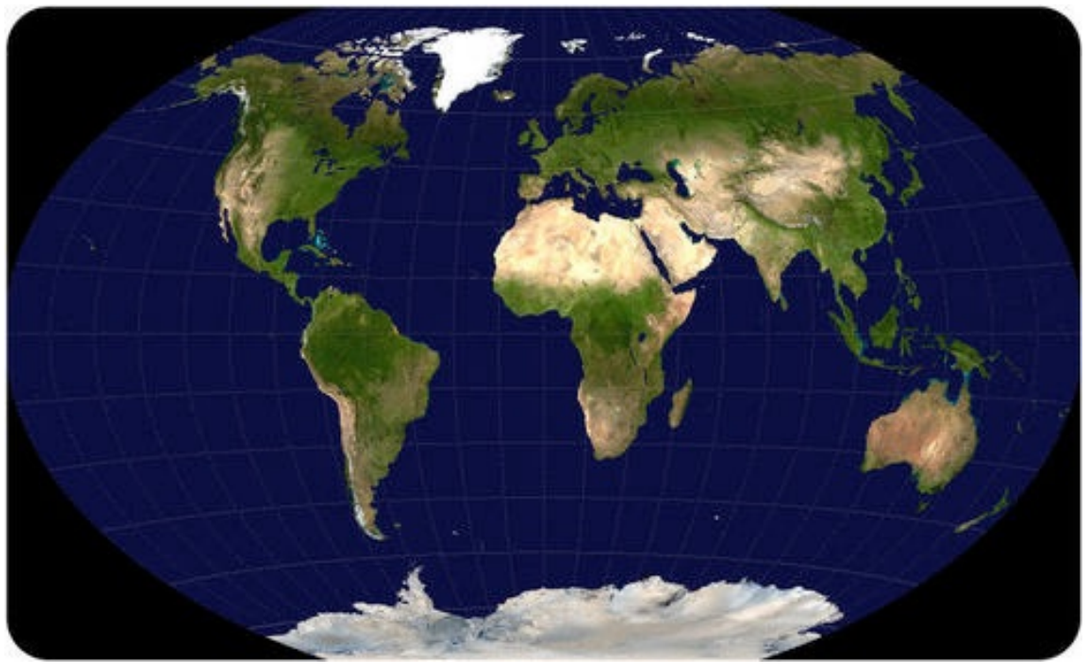


Figure 6.16

The Winkel Tripel Projection of Earth.

Locations on a map are determined using rectangular coordinates (see **Figure** below).

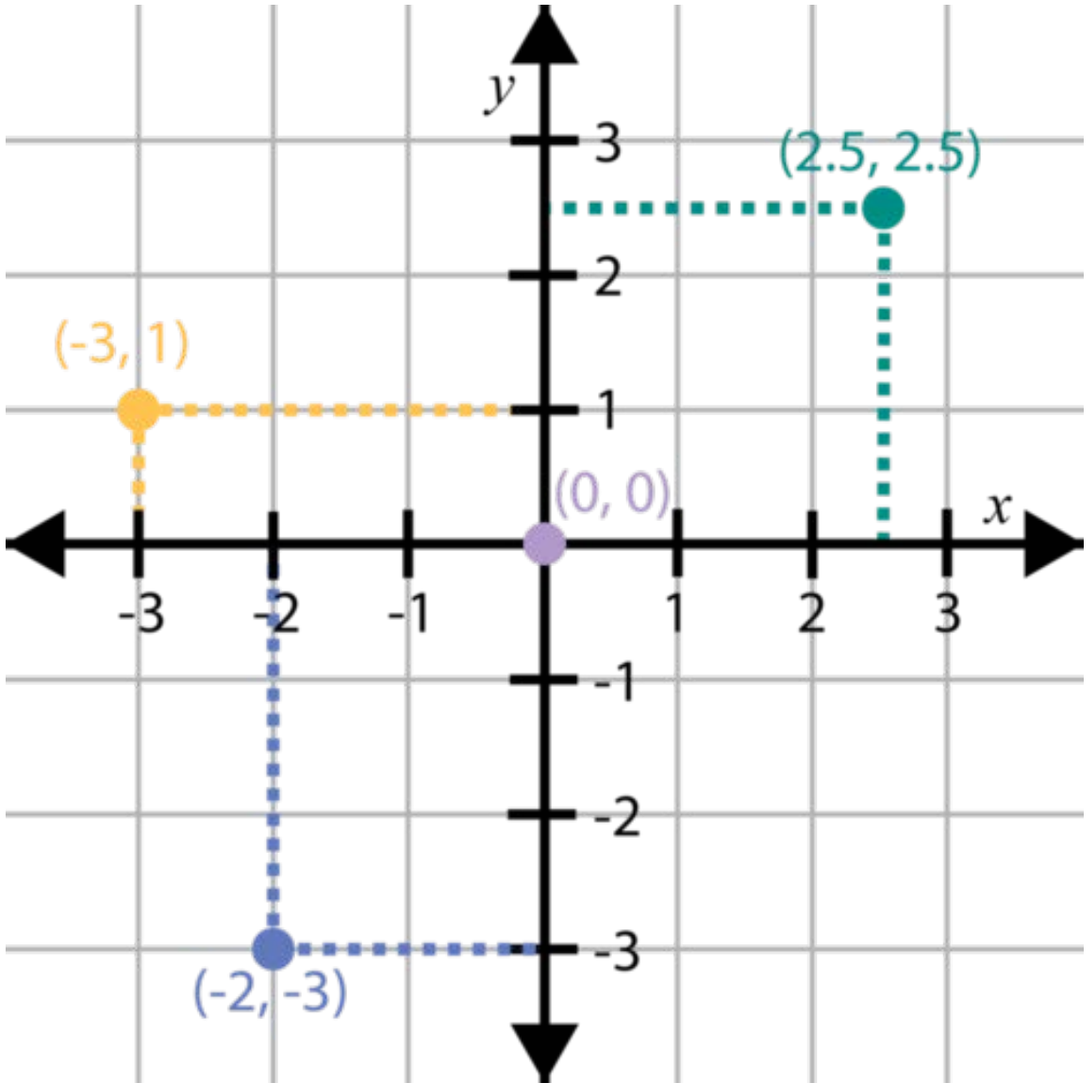


Figure 6.17

Rectangular coordinates are useful for flat surfaces.

Google Earth is a neat site to download to your computer: http://www.google.com/earth/index.html . The maps on this site allow you to zoom in or out, look from above, tilt your image, and a lot more.

Lesson Summary

•Maps and globes are models of the Earth's surface.
•Globes are the most accurate representations because they are spherical like the Earth is, but using a globe as a map has practical disadvantages.
•There are many ways to project the three-dimensional surface of the Earth on to a flat map. Each type of map has some advantages as well as disadvantages.
•Most maps use latitude and longitude to indicate locations.

Review Questions

1.Which of the following gives you the most accurate representations of distances and shapes on the Earth's surface?

a.Mercator projection map
b.Robinson projection map
c.globe

2.Explain the difference between latitude and longitude.
3.In what country are you located if your coordinates are 60 ◦N and 120 ◦W?
4.Which map projection is most useful for navigation, especially near the equator? Explain.
5.In many cases, maps are more useful than a globe. Why?
6.Which of the following map projections gives you the least distortion around the poles?

a.Mercator projection map
b.Robinson projection map
c.conic projection

Further Reading / Supplemental Links

•National Geographic has an introduction to maps: http://www.mywonderfulworld.org/toolsforadventure/usingmaps/index.html and http://www.mywonderfulworld.org/toolsforadventure/usingmaps/explorers.html .
•An atlas for the United States with many types of maps: http://www.nationalatlas.gov/ .
•Location and relief on maps: http://www.fao.org/docrep/003/T0390E/T0390E04.htm .

Points to Consider

•Imagine you are a pilot and must fly from New York to Paris. Use a globe to determine the distance. Now do the same with a map. How are these activities the same and how are they different?
•Would you choose a map that used a Mercator projection if you were going to explore Antarctica? What other type of map could you use?
•Maps use a scale, which means a certain distance on the map equals a larger distance on Earth. Why are maps drawn to scale? What would be some problems you would have with a map that did not use a scale?

Topographic Maps

Lesson Objectives

•Explain how to read and interpret a topographic map.
•Explain how bathymetric maps are used to determine underwater features.
•Describe what a geologic map shows.

Vocabulary

•bathymetric map
•contour interval
•contour line
•geologic map
•topographic map

Introduction

Maps are extremely useful to Earth scientists to represent geographic features found above and below sea level and to show the geology of a region. Rock units and geologic structures are shown on geologic maps.

What is a Topographic Map?

Mapping is a crucial part of Earth science. **Topographic maps** represent the locations of geographical features, such as hills and valleys. Topographic maps use contour lines to show different elevations on a map. A **contour line** is a type of isoline; in this case, a line of equal elevation. If you walk along a contour line you will not go uphill or downhill. Mathematically, a contour line is a curve in two dimensions on which the value of a function f(x, y) is a constant.

Contour Lines and Intervals

Contour lines connect all the points on a map that have the same elevation and therefore reveal the location of hills, mountains, and valleys. While a road map shows where a road goes, a topographic map shows why. For example, the road bends in order to go around a hill or stops at the top of a mountain. On a contour map:

•Each contour line represents a specific elevation and connects all the points that are at the same elevation. Every fifth contour line is bolded and labeled with numerical elevations.
•The contour lines run next to each other and NEVER cross. After all, a single point can only have one elevation.
•Two contour lines next to one another are separated by a constant difference in elevation (such as 20 ft or 100 ft). This difference between contour lines is called the **contour interval** . The map legend gives the contour interval.

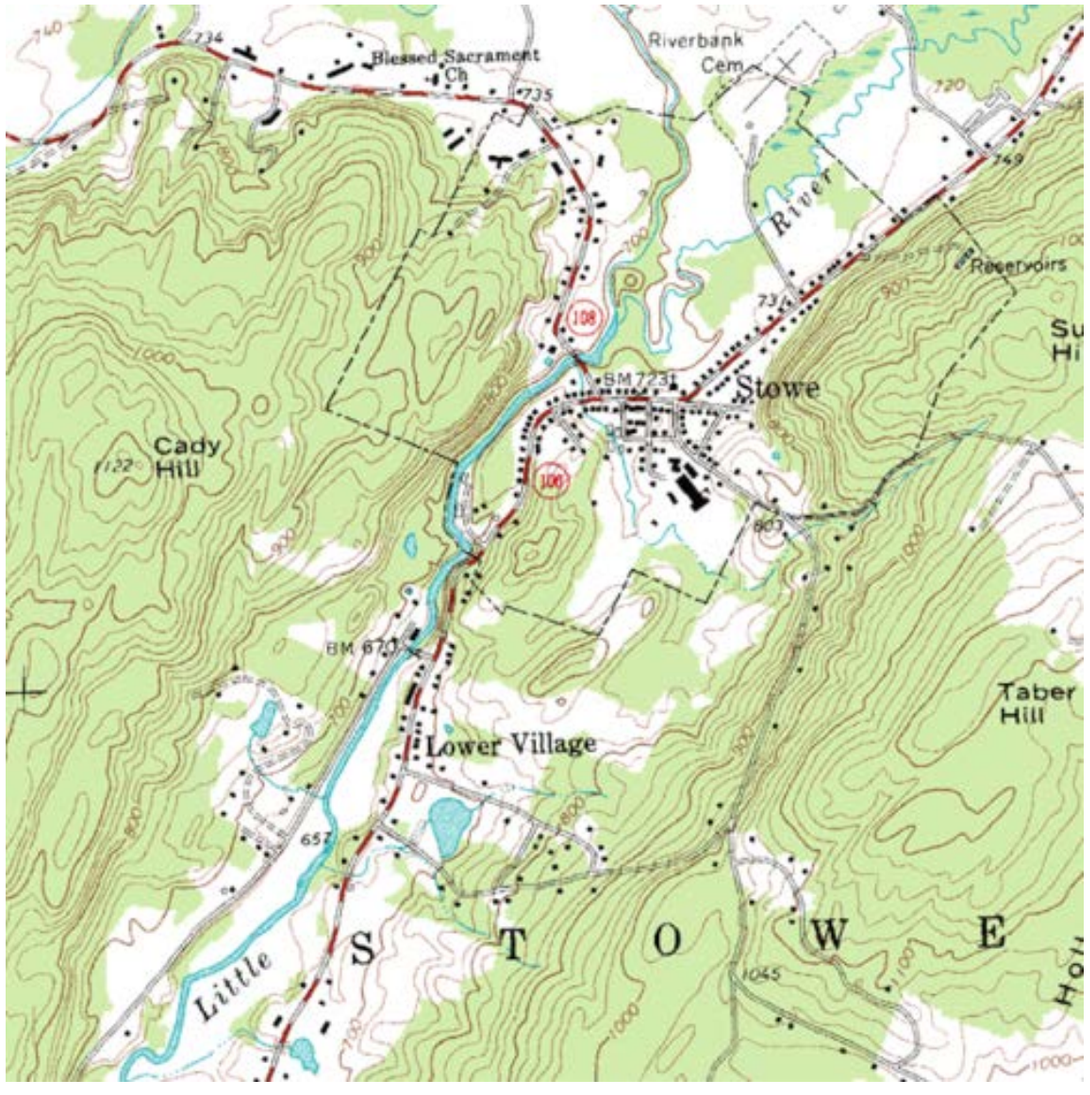


Figure 6.18

A topographic map of Stowe, Vermont.

How would you calculate the contour interval on the map of Stowe, Vermont (see **Figure** above)?

- Calculate the difference in elevation between two bold lines.
- Divide that difference by the number of contour lines between them.

On the Stowe map, the difference between two bold lines is 100 feet and there are five lines between them, so the contour interval is 20 feet (100 ft/5 lines = 20 ft/line).

The Value of a Topographic Map

Swamp Canyon in Bryce Canyon National Park, Utah (shown in **Figure** below) is very rugged, with steep canyon walls and a valley below.



Figure 6.19

View of Swamp Canyon in Bryce Canyon National Park.

The visitor's map of the area in **Figure** below shows important locations. What's missing from this map? This map does not represent the landscape.

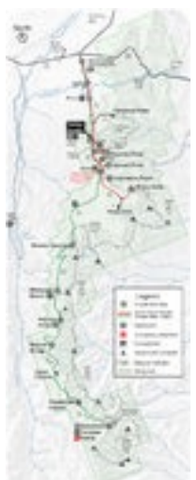


Figure 6.20

Swamp Canyon Loop in Bryce Canyon National Park. The green line indicates the main road, black dotted lines are trails, and there are markers for campsites, a picnic area, and a shuttle bus stop.

With contour lines to indicate elevation, the topographic map in **Figure** below shows the terrain.

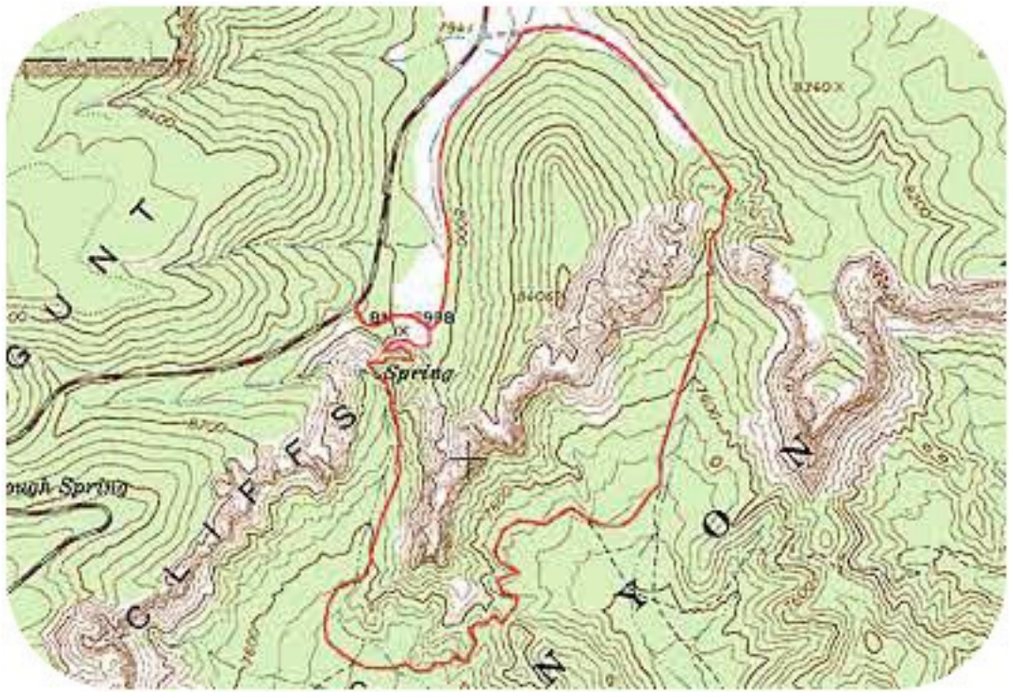


Figure 6.21

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

Interpreting Contour Maps

How does the map of Bryce Canyon reveal the terrain of the region? Several principles are important for reading a topographic map:

1. Contour lines show the 3-dimensional shape of the land (**Figure** below). What does the spacing of contour lines indicate?

- Closely-spaced contour lines indicate a steep slope, because the elevation changes quickly in a small area.
- Contour lines that seem to touch indicate a very steep rise, like a cliff or canyon wall.
- Broadly spaced contour lines indicate a shallow slope.

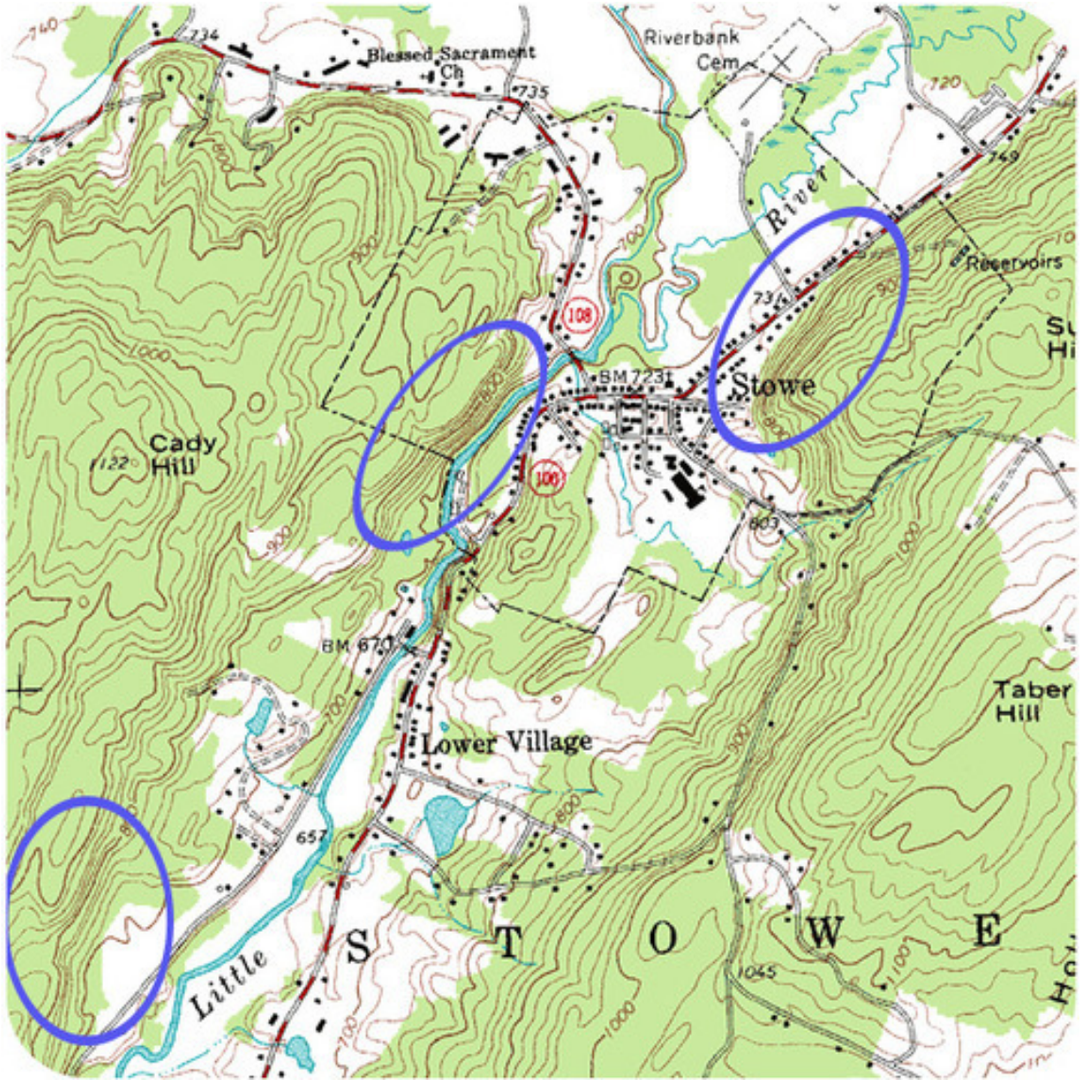


Figure 6.22

A portion of a USGS topographic map of Stowe, Vermont. Just to the right of the city of Stowe is a steep hill with a sharp rise of about 200 ft that becomes less steep toward the right.

2. Concentric circles indicate a hill. When contour lines form closed loops all together in the same area, this is a hill. The smallest loops are the higher elevations and the larger loops are downhill. On the Stowe map, which hill has an elevation of 1122 feet? If you found Cady Hill, on the left side of the map, you are right.

3. Hatched concentric circles indicate a depression, as seen in the **Figure** below . The hatch marks are short, perpendicular lines inside the circle. The innermost hatched circle would represent the deepest part of the depression, while the outer hatched circles represent higher elevations.

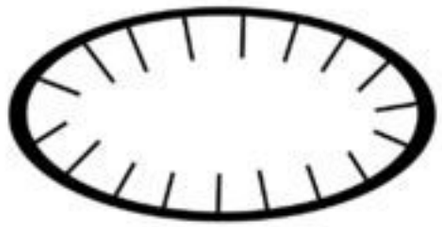


Figure 6.23

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

4. V-shaped expanses of contour lines indicate stream valleys. Where a stream crosses the land, the Vs in the contour lines point uphill. The channel of the stream passes through the point of the V and the open end of the V represents the downstream portion. If the stream contains water, the line will be blue; otherwise, the V patterns indicate the direction water will flow. In the map of Stowe, where does a stream run downhill into a lake?

- Start at the “T” in Stowe. A blue stream goes downhill (northwest) into a lake. Coming out of the T on the other side, you can follow the blue stream uphill (southeast). Where the water flow is light or nonexistent, there is no longer a blue line, but the contour lines point uphill

indicating that the stream channel is still there (see the map of Stowe in **Figure** above).

5. Scales on topographic maps indicate horizontal distance. The horizontal scale can be used to calculate the slope of the land (vertical height/horizontal distance). Common scales used in United States Geological Service (USGS) maps include the following:

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

An animation showing contour lines and the slopes they represent: http://www.youtube.com/watch?v=SkaXsSYKmw8 .

Google Earth Topographic Map shows a 3D image with contour lines superimposed on it to show the relationship between the two **(1h - I&E Stand.)** : http://www.youtube.com/watch?v=c_mxCN3Ez58 (0:43).



Click on the image above for more content

Bathymetric maps

The **bathymetric map** in the **Figure** below 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. Bathymetric maps help oceanographers visualize the landforms at the bottoms of lakes, bays, and the ocean as if the water were removed.

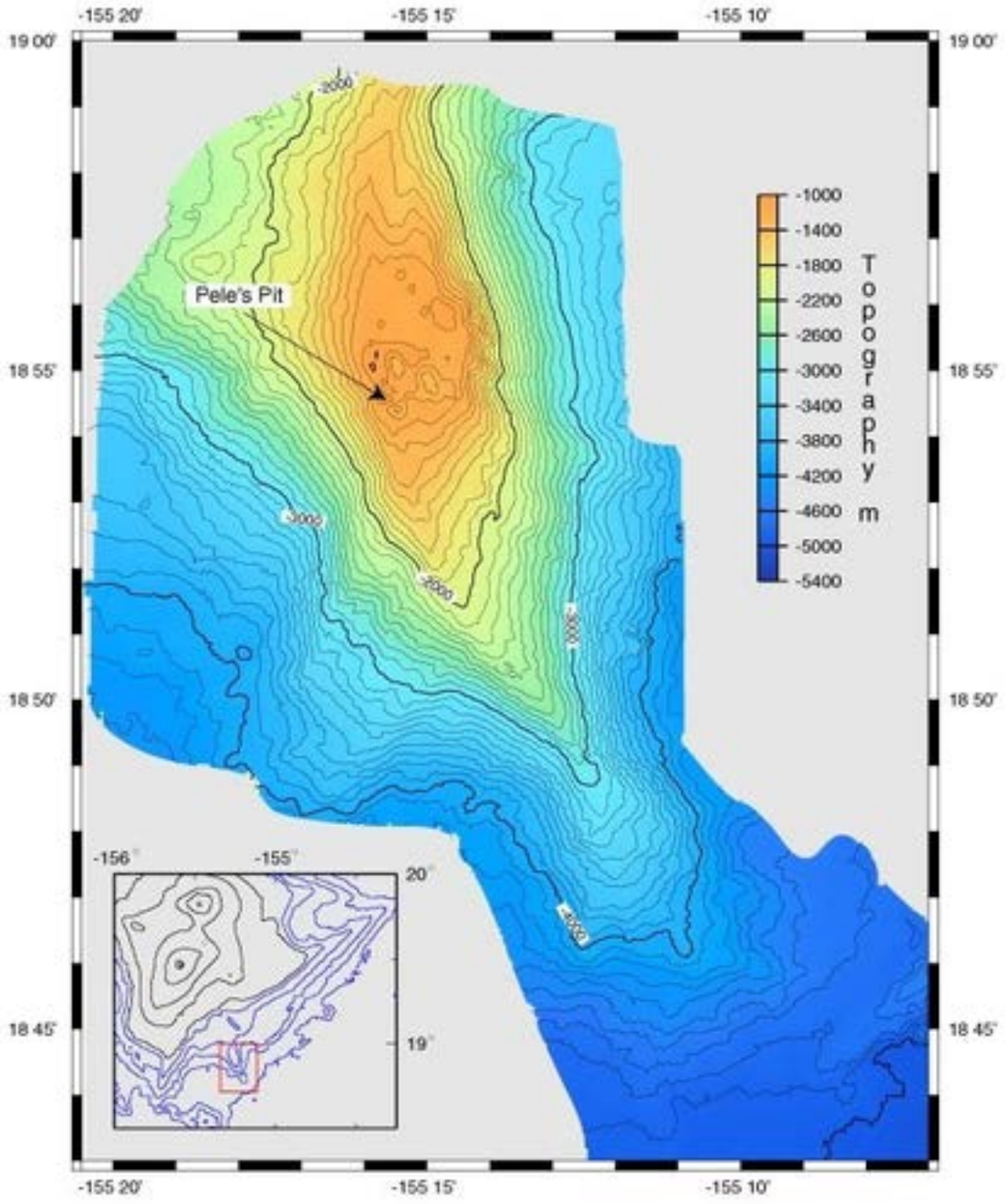


Figure 6.24

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 (see examples in **Figure** below and **Figure** below). Rock units are color-coded and identified in a key. In the map of Yosemite (**Figure** below), volcanic rocks are brown, the Tuolumne Intrusive Suite is peach, and the metamorphosed sedimentary rocks are green. Structural features, such as folds and faults, are also shown on a geologic map. The area around Mt. Dana on the east central side of the map has fault lines.

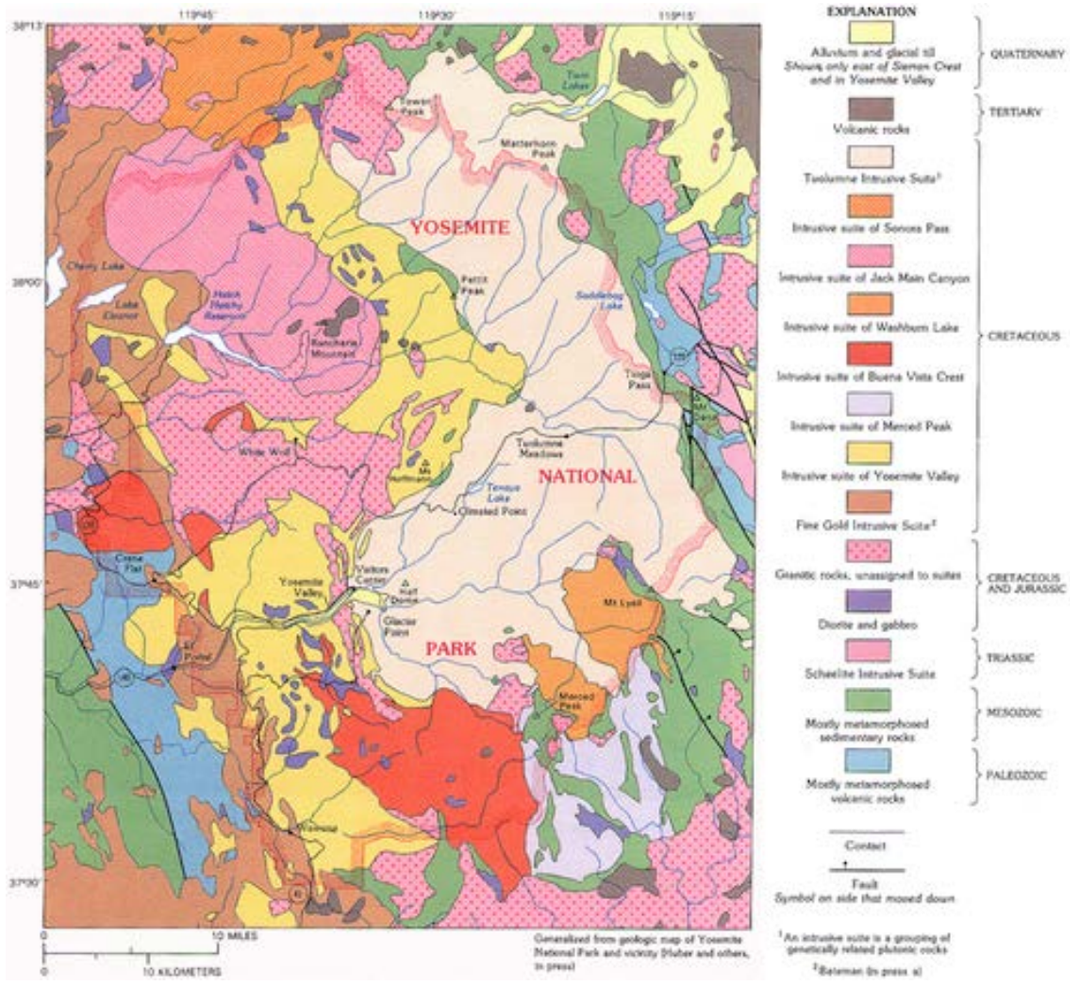


Figure 6.25

Geologic map of Yosemite National Park.

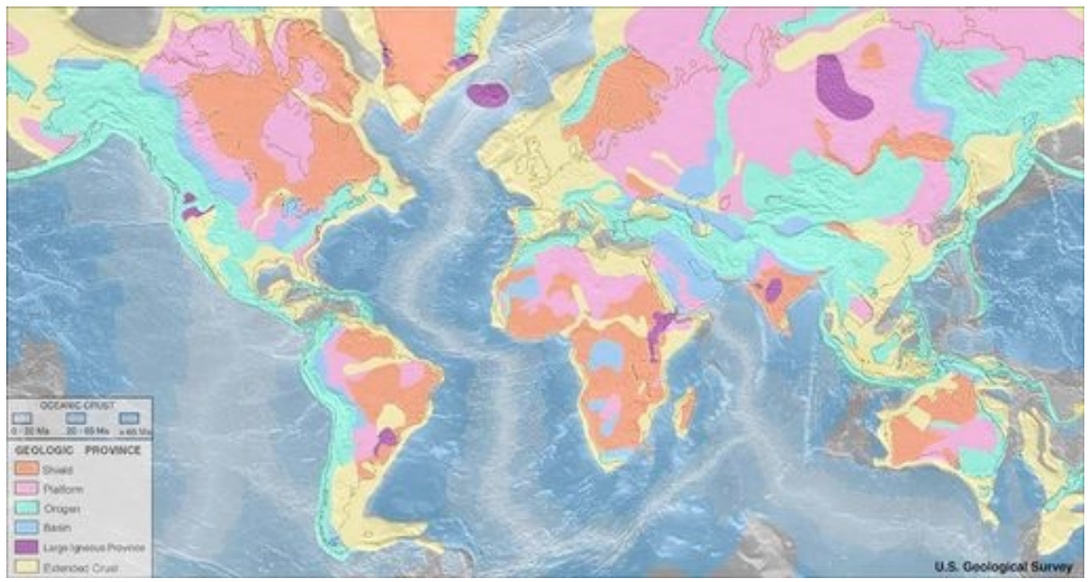
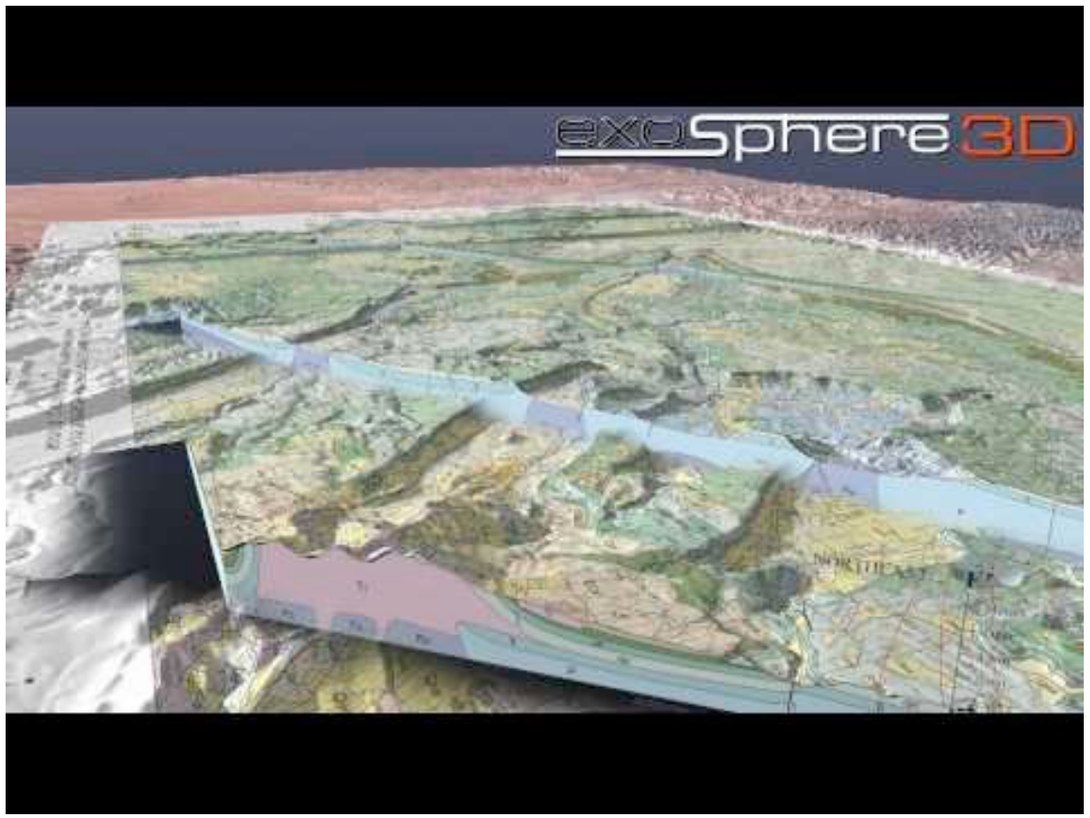


Figure 6.26

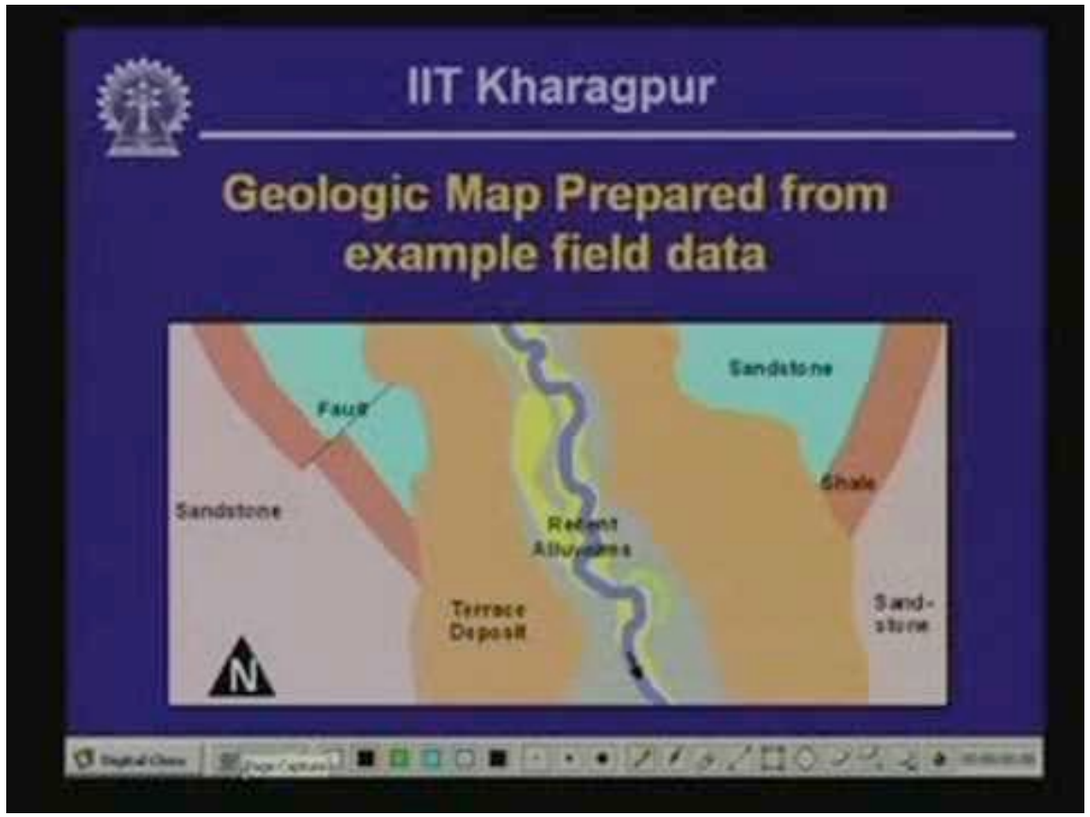
On a large scale geologic map, colors represent geological provinces.

This video shows a 3-dimensional interpretation of a geologic map from the Green River in Utah **(1h - I&E Stand.)** : http://www.youtube.com/watch?v=5CHd6_cIT44 (1:34).



Click on the image above for more content

This hour-long video is a tutorial on how to interpret a geologic map and construct a geological cross-section **(1h - I&E Stand.)** : http://www.youtube.com/watch?v=sTY-ao4RZck (59:56).



Click on the image above for more content

Lesson Summary

•Topographic maps are 2-dimensional representations of the 3-dimensional surface features of an area.
•Topographic maps have contour lines that connect points of identical elevation above sea level.
•Contour lines run next to each other. Adjacent contour lines are separated by a constant difference in elevation, usually noted on the map.
•Topographic maps have a horizontal scale to indicate horizontal distances.
•People use topographic maps to locate surface features in a given area, to find their way through a particular area, and to determine the direction of water flow in a given area.
•Oceanographers use bathymetric maps to depict the features beneath a body of water.
•Geologic maps display rock units and geologic features of a region of any size. A small scale map displays individual rock units; a large scale map shows geologic provinces.

Review Questions

1.On a topographic map, contour lines create a group of concentric, closed loops. Which of the following features could this indicate?
a.a stream channel
b.a hilltop
c.depression
d.a cliff
2.Describe the pattern on a topographic map that would indicate a stream valley. How do you determine the direction of water flow?
3.On a topographic map, five contour lines are very close together in one area. The contour interval is 100 ft. What feature does that indicate? How high is this feature?
4.On a topographic map, describe how you can tell a steep slope from a shallow slope.
5.On a topographic map, a river is shown crossing from Point A in the northwest to Point B in the southeast. Point A is on a contour line of 800 ft and Point B is on a contour line of 900 ft. In which direction does the river flow?
6.On a topographic map, six contour lines span a horizontal map distance of 0.5 inches. The horizontal scale is 1 inch equals 2,000 ft. How far apart are the first and sixth lines?

7.On a geologic map of the Grand Canyon, a rock unit called the Kaibab Limestone takes up the entire surface of the region. Down some steep topographic lines is a very thin rock unit called the Toroweap Formation and down more topographic lines into the canyon from that is another thin unit, the Coconino Sandstone. Describe how these three rock units sit relative to each other. Which is oldest and which is youngest?

Further Reading / Supplemental Links

•A key of topographic map symbols by the USGS is found here: http://erg.usgs.gov/isb/pubs/booklets/symbols/topomapsymbols.pdf .
•How to construct a topographic profile: http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/manuals/instructor_manual/how_to/topographic_profile.html .
•More about reading topographic maps: http://www.globalsecurity.org/military/library/policy/army/fm/3-25-26/ch10.htm ; http://www.map-reading.com/intro.php ; http://egsc.usgs.gov/isb/pubs/booklets/topo/topo.html .

Points to Consider

•How might a civil engineer use a topographic map to build a road, bridge, or tunnel through the area such as that shown in **Figure** above ? What topography would be best for a bridge? Which areas might need a bridge? Where might a tunnel be helpful?
•If you wanted to participate in orienteering, would it be better to have a topographic map or a road map? How would a topographic map help you?
•If you were the captain of a ship, what type of map would you want and why?

Using Satellites and Computers

Lesson Objectives

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

Vocabulary

•Geographic Information System (GIS)
•geostationary orbit
•Global Positioning System (GPS)
•polar orbit
•satellite

Introduction

Modern technology is very useful for Earth scientists. Satellites give researchers a global perspective and can be used to monitor changes. Computers are used for making maps.

Satellite Data

A **satellite** is a small object that orbits a larger object. Satellites orbit Earth to get a large view of the planet's surface and for hauling many different types of instruments to monitor all types of conditions (**Figure** below). Satellite views are important for visualizing global change; for example, the amount of sea ice that is present in the Arctic from winter to winter.



Figure 6.27

Satellites monitor and track hurricanes, reducing property damage and saving lives. This image shows Hurricane Rita on September 23, 2005 as it approaches Texas and Louisiana.

Satellites travel in different orbits:

- In a **geostationary orbit** (illustrated in **Figure** below), the satellite orbits at a distance of 36,000 km. Since it takes 24 hours to complete one orbit, which is the same amount of time it takes Earth to complete one rotation, the satellite hangs in the sky over the same spot. What is the value of a satellite in this type of orbit? From this orbit, weather satellites can observe changing weather conditions and communications satellites can relay signals.

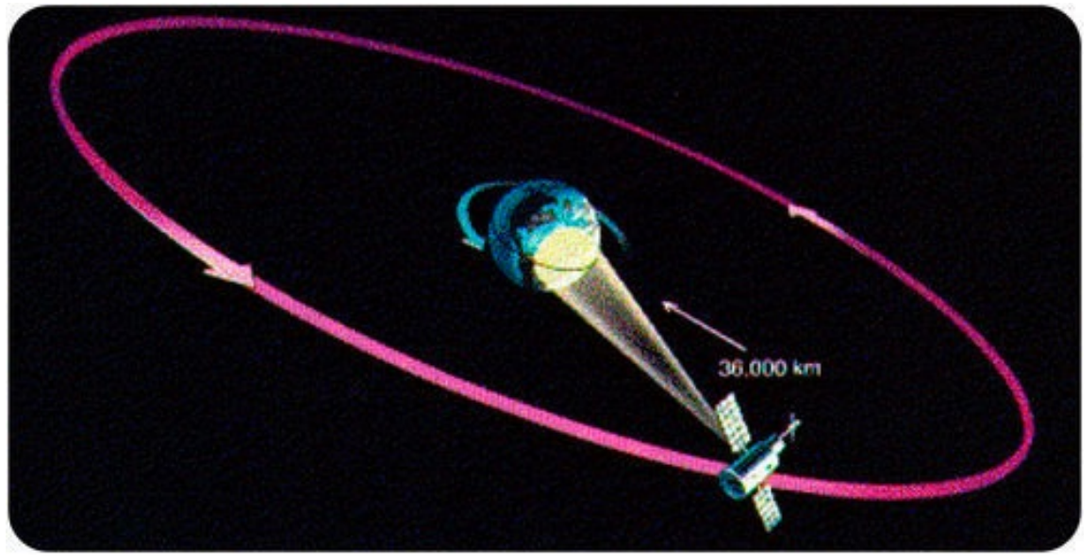


Figure 6.28

Satellite in a geostationary orbit.

- In a **polar orbit** , seen in **Figure** below , the satellite orbits at a distance of several hundred kilometers. It makes one complete orbit around the Earth from the North Pole to the South Pole about every 90 minutes. Earth rotates only slightly underneath the satellite, so the satellite can see the entire surface of the Earth in less than a day. What would be the value of this type of orbit? Weather satellites can get a picture of how the weather is changing globally. Some satellites that observe the lands and oceans use a polar orbit.

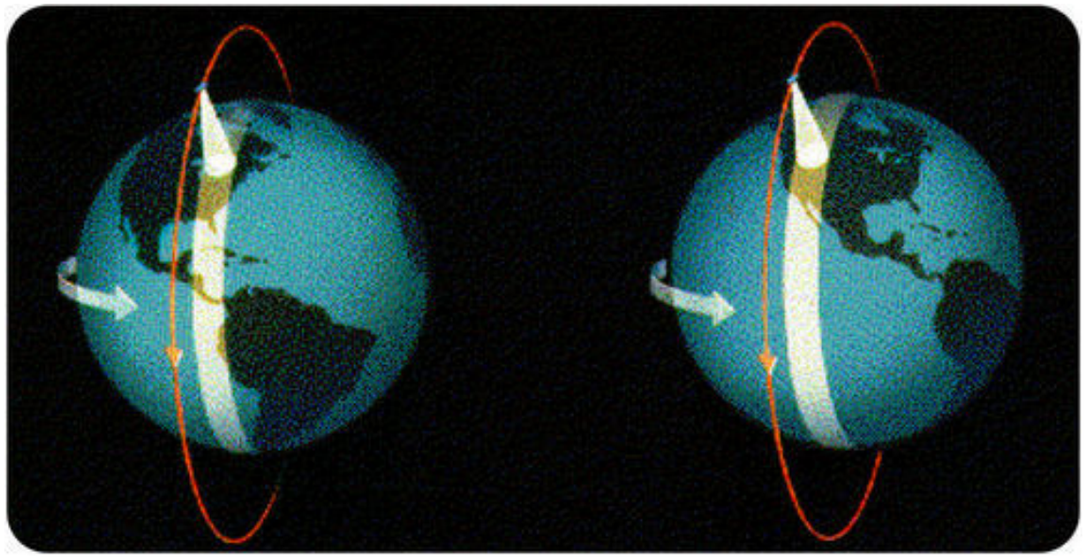


Figure 6.29

Satellite in a polar orbit.

The National Aeronautics and Space Administration (NASA) has launched a fleet of satellites to study Earth. The satellites are operated by several government agencies, including NASA, the National Oceanographic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS).

Using different types of scientific instruments, satellites measure many things, including the temperatures of the land and oceans, amounts of gases such as water vapor and carbon dioxide in the atmosphere, the ability of the surface to reflect various colors of light, which indicates plant life, and even the height of the ocean's surface.

You can have lots of fun with satellite maps by playing around with Google maps: http://maps.google.com/ . Try searching for these interesting features: Goosenecks State Park, Utah; Mt. Whitney, Lone Pine, California; Empire State Building, New York; or your home. Note that you can zoom in and out to see features in more detail or to see how they fit into the area.

Global Positioning System

Satellites help people locate their position on Earth's surface. By 1993, the United States military had launched 24 satellites to help soldiers locate their positions on battlefields. This system of satellites was called the **Global Positioning System (GPS)** . Later, the United States government allowed the public to use this system. GPS receivers, like the one pictured in image A of **Figure** below , are now common.

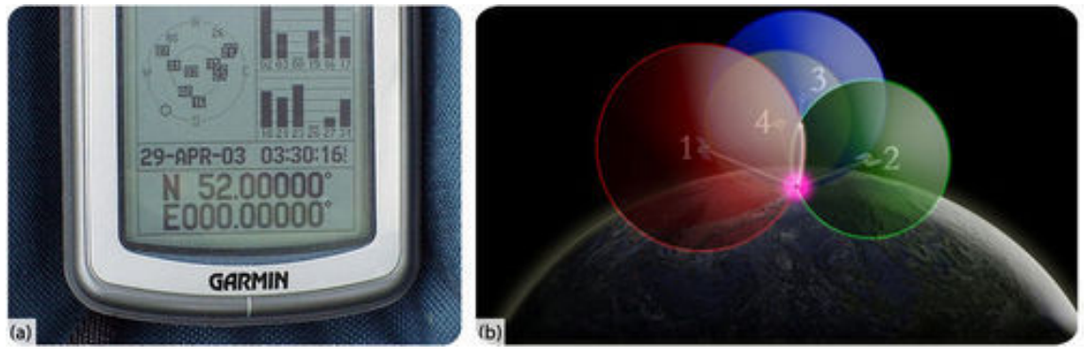


Figure 6.30

(a) This GPS receiver is located at 52 degrees N and 0 degrees E, on the Prime Meridian. (b) The receiver takes signals from 4 GPS satellites to calculate your location precisely.

The GPS receiver detects radio signals from at least four nearby GPS satellites. There are precise clocks on each satellite and in the receiver. The receiver measures the time for radio signals from the satellite to reach it and then calculates the distance between the receiver and the satellite using the time and the speed of radio signals. The receiver triangulates by calculating distances from

each of the four satellites. It then determines the location of the GPS receiver, as illustrated in image B of **Figure** above .

Computer-Generated Maps

Computers have improved how maps are made and have increased the amount of information that can be displayed. Map makers use satellite images and computers to draw maps. Computers break apart the fine details of a satellite image, store the pieces of information, and put them back together in a 2D or 3D image (**Figure** below).

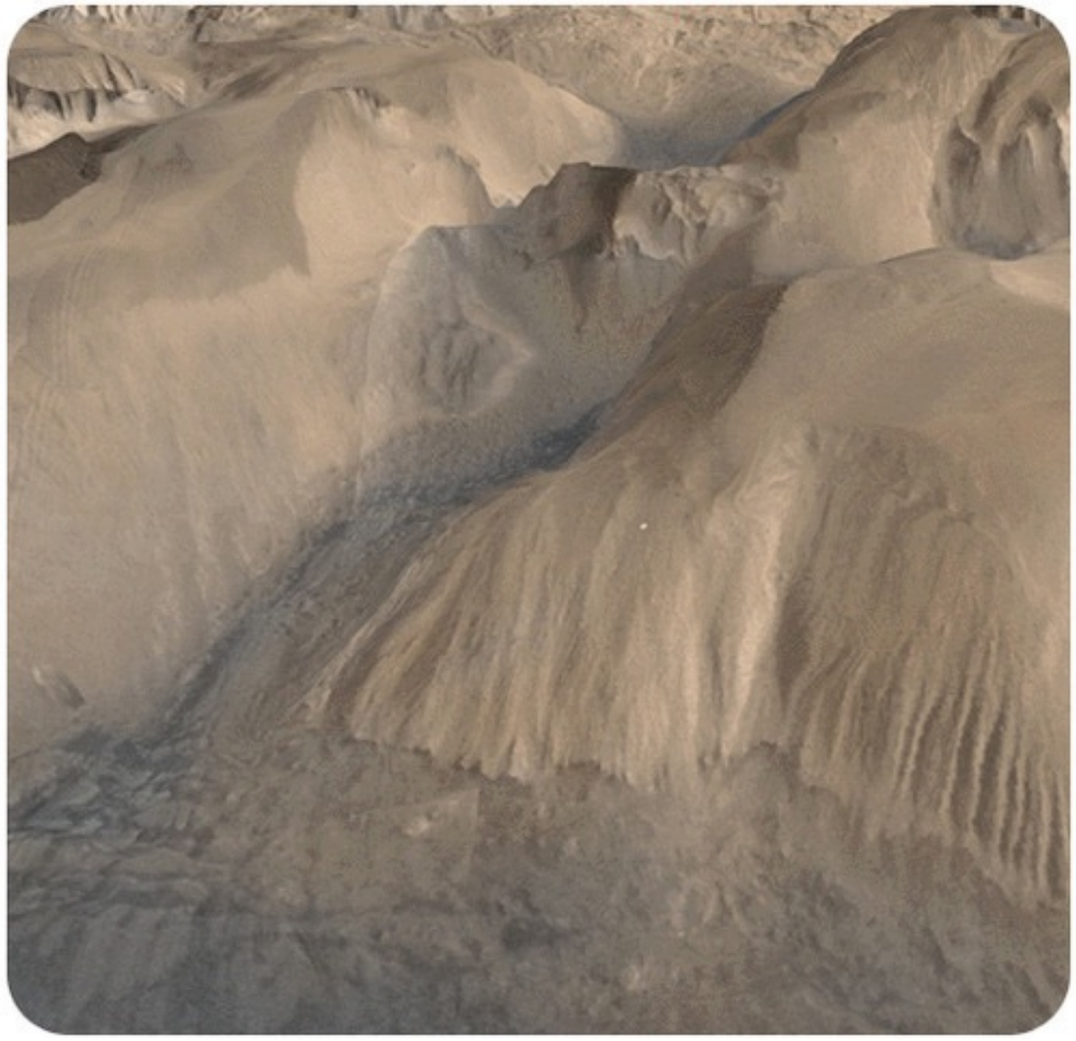


Figure 6.31

Scientists used computers and satellite images from Mars to create a 3D image of Valles Marineris.

Geographic Information Systems (GIS) use exact geographic locations from GPS receivers along with any type of spatial information to create maps and images (**Figure** below). The information might be of people living in an area, types of plants or soil, locations of groundwater, or levels of rainfall. Geologists use GIS to make maps of natural resource distributions.

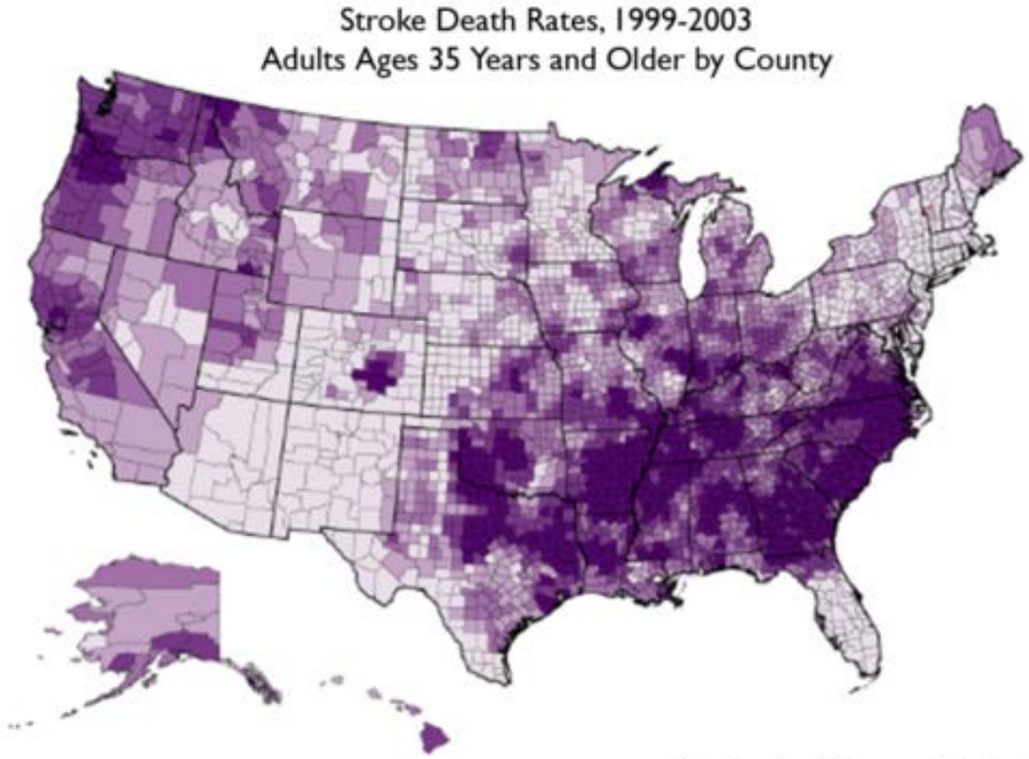


Figure 6.32

A GIS map of stroke death rates in the United States. Health rates may be affected by geographic region.

Lesson Summary

•Satellites give a larger view of the Earth's surface and make many types of measurements that are of interest to Earth scientists.
•A group of specialized satellites called Global Positioning Satellites help people to pinpoint their location.
•Location information, satellite views, and other information are linked together in Geographical Information Systems (GIS).
•GIS are powerful tools that Earth scientists and others can use to study Earth and its resources.

Review Questions

1.Which type of satellite can be used to pinpoint your location on Earth?
   a.weather satellite
   b.communications satellite
   c.global positioning satellite
   d.climate satellite
2.Explain the difference between geostationary orbits and polar orbits.
3.Describe how GPS satellites can find a location in which there is a transmitter on Earth.
4.What is a Geographical Information System (GIS)?
5.To map the entire Earth's surface from orbit, which type of orbit would you use? Explain why this would be your best choice.
6.Explain how weather satellites can track a tropical storm from its beginnings.

Further Reading / Supplemental Links

•"Isaac's Storm": http://www.randomhouse.com/features/isaacsstorm/ .
•About Geographic Information Systems: http://erg.usgs.gov/isb/pubs/gis_poster/ .
•Wonderful satellite images of Earth are found at: http://earthobservatory.nasa.gov/ .
•How NOAA uses satellites: http://www.noaa.gov/satellites.html .

Points to Consider

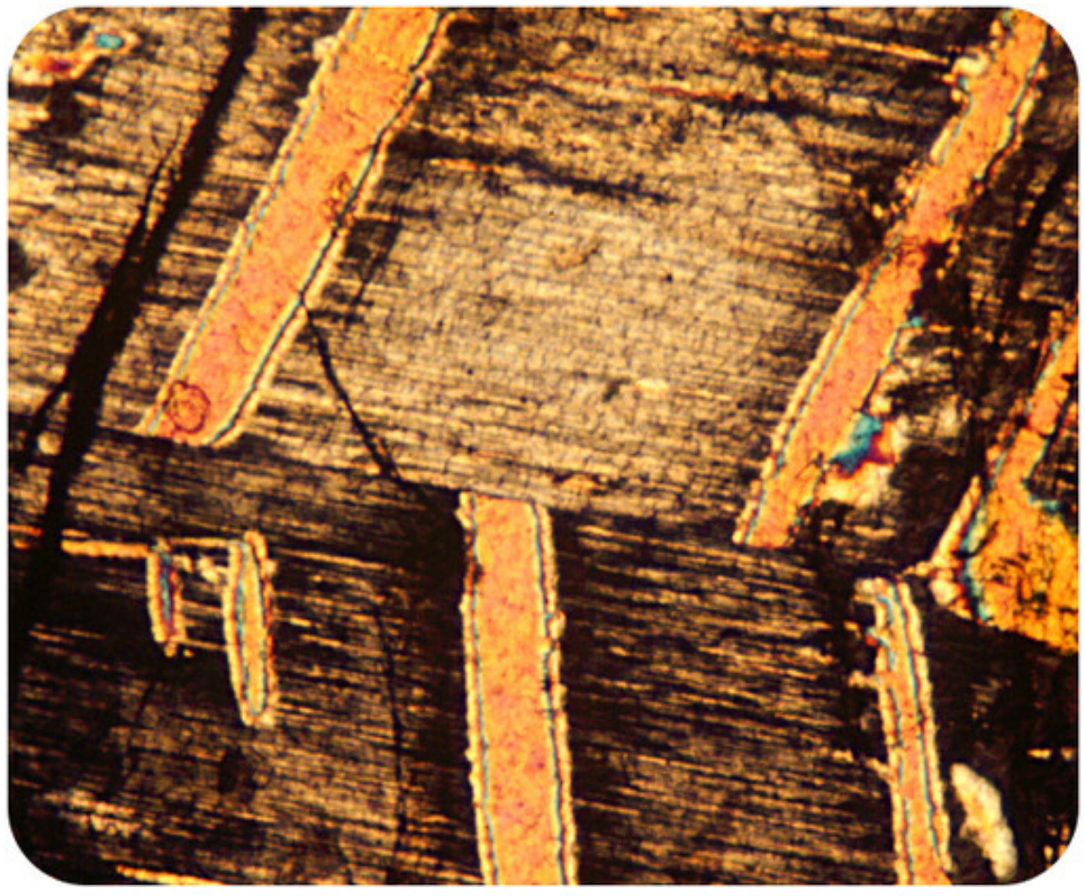
•Imagine tracking a hurricane across the Atlantic Ocean. What information would you need to follow its path? What satellite images might be most useful? Research how the National Weather Service tracks and monitors hurricanes.
•What information and type of map would be most useful for understanding the distribution of natural resources for a particular state?
•What are some ways that people use Global Positioning Systems? What problems are easier to solve using GPS?

References

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2.Courtesy of NASA/JPL/NGA Shuttle Radar Topography team. http://earthobservatory.nasa.gov/IOTD/view.php?id=6316 . Public Domain
3.Courtesy of WHF Smith and DT Sandwell/National Oceanic and Atmospheric Administration. http://www.ngdc.noaa.gov/mgg/fliers/97mgg03.html . Public Domain
4.Laura Guerin. This example demonstrates how triangulation can be used to indicate your location . CC BY-NC 3.0
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27.Courtesy of Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC. Satellite image tracking Hurricane Rita approaching Texas and Louisiana . Public Domain
28.Courtesy of NOAA's National Weather Service. http://pajk.arh.noaa.gov/sat.php . Public Domain
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31.Courtesy of US Geological Survey Astrogeology Science Center. http://astrogeology.usgs.gov/Projects/VallesMarineris/Surveyor/ccandor7.html . Public Domain
32.Courtesy of the Centers for Disease Control and Prevention. http://www.cdc.gov/gis/mg_heartdisease_stroke.htm . Public Domain

Ch. 7: Earth's Minerals



This is a picture of a mineral taken through a microscope. You may find it hard to believe that this is a mineral, but it is! This piece of orthopyroxene was cut very thin, mounted on a slide, and viewed in a polarizing light microscope. The image contains features you wouldn't be able to see by just looking at that piece of orthopyroxene with the unaided eye. A trained mineralogist can see that the orthopyroxene crystal formed first, then partly dissolved, and that augite crystals formed around the original crystals. Minerals are valuable resources for just about every aspect of our lives. When and where different minerals form are also important clues in telling the history of Earth.

User:Omphacite/Wikimedia Commons. commons.wikimedia.org/wiki/File:PyroxeneExsol_0.5mmm.jpg. Public Domain.

Matter Matters

Matter Matters

Lesson Objectives

- Review basic chemistry concepts: atoms, elements, ions, and molecules.
- Understand the types of chemical bonding and how they result in molecules.

Vocabulary

- atom
- atomic mass
- chemical bond
- covalent bond
- electron
- element
- hydrogen bond
- ion
- ionic bond
- isotope
- molecular mass
- molecule
- neutron
- nucleus
- polar molecule
- proton
- quark

Introduction

Minerals are made up of different chemical elements bound together. Understanding mineral chemistry aids in understanding how minerals form and why they have certain properties.

Atoms and Isotopes

A chemical **element** is a substance that cannot be made into a simpler form by ordinary chemical means. The chemical element is comprised of the **atom** . An atom has all the properties of that element. These are the parts of an atom:

- At the center of an atom is a **nucleus** made up of subatomic particles called protons and neutrons.
  - **Protons** have a positive electrical charge. The number of protons in the nucleus determines what element the atom is (**Figure** below).
  - **Neutrons** are about the size of protons but have no charge.
- Tiny **electrons** , each having a negative electrical charge, orbit the nucleus at varying energy levels in a region known as the electron cloud.

An introduction to the atom is seen on this Khan Academy video: https://www.khanacademy.org/science/chemistry/introduction-to-the-atom/v/introduction-to-the-atom

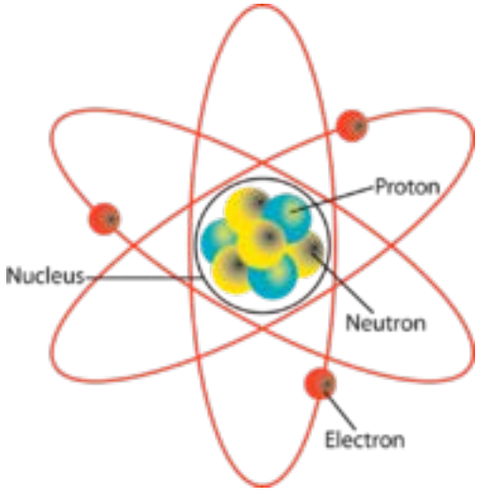


Figure 7.1

Major parts of an atom, although the electrons are more accurately represented in a cloud. What chemical element is this? (Hint: 3 protons, 3 electrons)

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 its nucleus. 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. How many protons and neutrons make up carbon-12? Carbon-13? Carbon-14?

For a funny view of the chemical elements, check out this Tom Lehrer ELEMENT song: http://www.youtube.com/watch?v=GFIvXVMbII0 .

Is the atom the absolute smallest part of an element? Watch this video and read the text below to find the answer.



Figure 7.2

For thousands of years, scientists thought atoms were the smallest building blocks of matter (in fact the word atom comes from the Greek atomos, meaning indivisible). Only in the past century have physicists realized that atoms are composed of still smaller particles: protons, electrons, and neutrons. And for most of that time, they thought that these subatomic particles were the fundamental units of matter.

In the 1960s, however, experiments began to show that protons and neutrons display internal structure and thus must be made of still smaller particles: quarks. These particles come in six "flavors," called up, down, strange, charmed, top, and bottom. A proton consists of two up quarks and one down quark, while a neutron is made of two downs and one up. Combinations of quarks yield still more particles, although most are unstable and decay quickly to protons or neutrons. The very early universe was likely a dense soup of quarks and antiquarks.

Ions and Molecules

Atoms are stable when they have a full outermost electron valence shell. 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.

Electron orbitals are described in this Khan Academy video: http://www.khanacademy.org/video/orbitals .

When atoms chemically bond, they form compounds. The smallest unit of a compound with all the properties of that compound is a **molecule** . When two or more atoms share electrons to form a chemical bond, they form a molecule. The **molecular mass** is the sum of the masses of all the atoms in the molecule.

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 **chemical bonding** . There are three main types of chemical bonds:

- **Ionic bond:** Electrons are transferred between atoms. An atom of a metal will give one or more electrons to a non-metallic atom.
- **Covalent bond:** An atom shares one or more electrons with another atom. The sharing of electrons is not always evenly distributed within a molecule. If one atom has the electrons more often than another atom in the molecule, the molecule has a positive and a negative side. It is a **polar molecule** because it acts a little bit as if it had poles, similar to a magnet (**Figure** below).
  - A great explanation of ionic and covalent bonding is found in this animation: http://www.youtube.com/watch?v=QqjcCvzWwww .
- **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.

A video about chemical bonding, also from Khan Academy:https://www.khanacademy.org/science/chemistry/periodic-table-trends-bonding/v/ionic--covalent--and-metallic-bonds

Hydrogen and oxygen share electrons to form water, which is a covalently bonded, polar molecule.

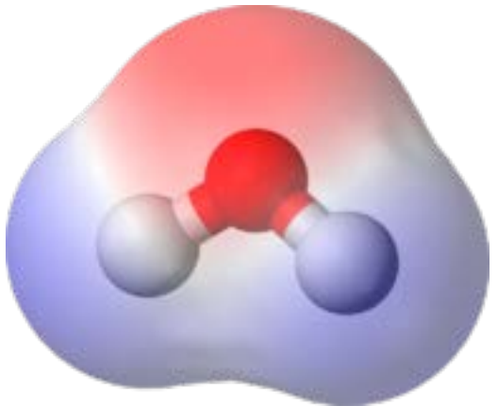


Figure 7.3

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.

Lesson Summary

•An element is a substance that cannot be made into a simpler form by ordinary chemical means. It is made of atoms.
•An atom's nucleus contains positively charged protons and neutrally charged neutrons.
•The nucleus is orbited by negatively charged electrons found in the electron cloud.
•An ion is an atom that has gained or lost one or more electrons.
•Molecules form when electrons are transferred, creating ionic bonds, or when electrons are shared, forming covalent bonds.

Review Questions

1.How is an atom different from an ion? How is an atom different from an element?
2.Describe the subatomic particles you learned about in this lesson.
3.How is a molecule different from an element? Can a molecule be an element?
4.Think of the smallest unit of water, a molecule of H_2O. Which of the vocabulary words in this lesson describe the hydrogen? Which describe the oxygen? Which terms describe the whole H_2O unit?
5.In which type of bonding are electrons shared? In which are they given or taken? Which type of bond is stronger?

Further Reading and Supplemental Links

•Basic chemistry in a fun, easy website: http://www.chem4kids.com/index.html .
•Science Daily has chemistry news: http://www.sciencedaily.com/news/matter_energy/chemistry/ .

Points to Consider

•The noble gases all have a full outermost electron level. How do they bind to other molecules?
•Why don't electrons fly off into space? Is electrical force the same as the gravitational force that keeps planets orbiting the Sun?
•Water has a lot of unusual properties: It forms droplets, lightweight insects can land on it, it is less dense in solid form (ice) than in liquid form. Can you link these properties to hydrogen bonding?

Minerals and Mineral Groups

Minerals and Mineral Groups

Lesson Objectives

- Describe the characteristics that all minerals share.
- Identify the groups in which minerals are classified and their characteristics.

Vocabulary

- carbonate
- chemical compound
- crystal
- feldspar
- habit
- inorganic
- mineral
- native mineral
- quartz
- rock-forming minerals
- silicates

Introduction

Earth's crust and oceans are a source of a wide variety of useful and essential minerals. Most people are familiar with the common uses of many basic metals, including aluminum in beverage cans, copper in electrical wiring, and gold and silver in jewelry. But some people are not aware that pencil lead contains the greasy-feeling mineral graphite and that bath powders and many cosmetics contain the mineral talc. Moreover, many do not know that drill bits impregnanted with diamonds are employed by dentists to drill through tooth enamel, or that the common mineral quartz is the source of silicon for computer chips. In fact, practically every manufactured product contains materials obtained from minerals.

What is a Mineral?

Minerals are everywhere! **Figure** below shows some common household items and the minerals used to make them. The salt you sprinkle on food is the mineral halite. Silver in jewelry is also a mineral. Baseball bats and bicycle frames both contain minerals. Although glass is not a mineral, it is produced from the mineral quartz. Scientists have identified more than 4,000 minerals in Earth's crust. A few are common, but many are uncommon.



Figure 7.4

Silver and halite are minerals; the mineral quartz is used to make glass.

Minerals are categorized based on their chemical composition. Owing to similarities in composition, minerals within a same group may have similar characteristics.

Geologists have a very specific definition for minerals. A material is characterized as a mineral if it meets all of the following traits. A mineral is defined as any naturally occurring inorganic solid that posses an orderly crystalline structure and can be represented by a chemical formula. Minerals can be identified by their characteristic physical properties such as crystalline structure, hardness, density, flammability, and color.

1. Naturally occurring

Minerals are made by natural processes, those that occur in or on Earth (geologic processes). A diamond created deep in Earth's crust is a mineral. Is a diamond created in a laboratory by placing carbon under high pressures a mineral? *No*. Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.

2. Orderly Crystalline Structure

Minerals are crystalline solids. A **crystal** is a solid in which the atoms are arranged in a regular, repeating pattern (**Figure** below). This orderly packing of atoms is reflected in the regularly shaped objects called crystals. The pattern of atoms in different samples of the same mineral is the same. Is glass a mineral? Without a crystalline structure, even natural glass is not a mineral.

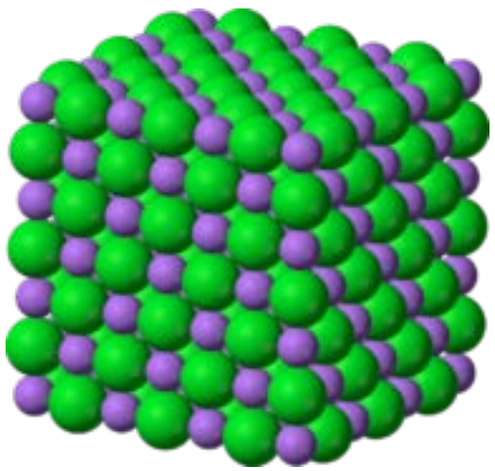


Figure 7.5

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.

3. Solid Substance

Only crystalline substances that are solid at temperatures encountered at Earth's surface are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not. The exception is mercury, which is found in its liquid form in nature.

4. Inorganic Substances

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 classified as a sedimentary rock but is not a mineral. Ordinary table salt (halite), is found naturally in the ground and is considered a mineral. Sugar is a crystalline solid like salt but which comes from sugarcane or sugar beets and is a common example of such an organic compound. Therefore sugar is not considered a mineral.

5. 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. Halite, pictured in the **Figure** above , is NaCl (sodium chloride). Quartz is always made of two oxygen atoms bonded to a silicon atom, SiO_2 .

A hard mineral containing covalently bonded carbon is diamond, but a softer mineral that also contains calcium and oxygen along with carbon is calcite (**Figure** below).

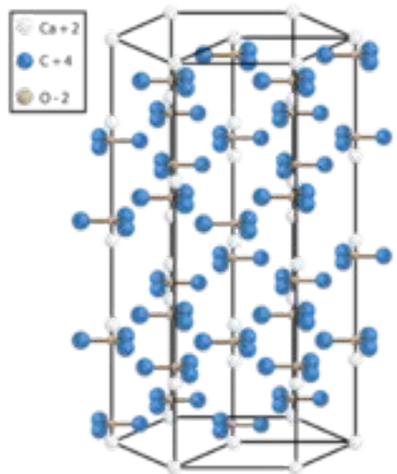


Figure 7.6

The structure of calcite shows the relationship of calcium (Ca), carbon (C), and oxygen (O).

Some minerals have a range of chemical composition. Olivine always has silicon and oxygen as well as iron or magnesium or both, $(Mg, Fe)_2SiO_4$.

Properties of Minerals

Minerals have definite crystalline structures and chemical compositions that give them unique sets of physical and chemical properties shared by all samples of that mineral. Because a mineral's internal structure and chemical composition are difficult to determine without the aid of sophisticated tests and equipment,

the more easily recognized physical properties are frequently used in identification.

Physical Properties

The physical properties of minerals include:

- •Color: the color of the mineral.
- •Streak: the color of the mineral's powder.
- •Luster: the way light reflects off the mineral's surface.
- •Specific gravity: how heavy the mineral is relative to the same volume of water.
- •Cleavage: the mineral's tendency to break along flat surfaces.
- •Fracture: the pattern in which a mineral breaks.
- •Hardness: what minerals it can scratch and what minerals can scratch it.
- •Habit (Crystal Shape): refers to the common or characteristic shape of a crystal or aggregate of crystals.

How physical properties are used to identify minerals is described in the lesson on *Mineral Formation* .

Mineral Groups

Over 4,000 minerals have been named, and several new ones are identified each year. Fortunately, for students who are beginning to study minerals, no more than a few dozen are abundant! Collectively, these few make up most of the rocks of Earth's crust and, as such, are often referred to as the **rock-forming minerals.**

It is worth noting again that only 8 elements make up the vast majority of the rock-forming minerals and represent more than 98% (by weight) of the continetal crust. These elements, in order of abundance from most to least, are oxygen (O), silicon (Si), aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg).

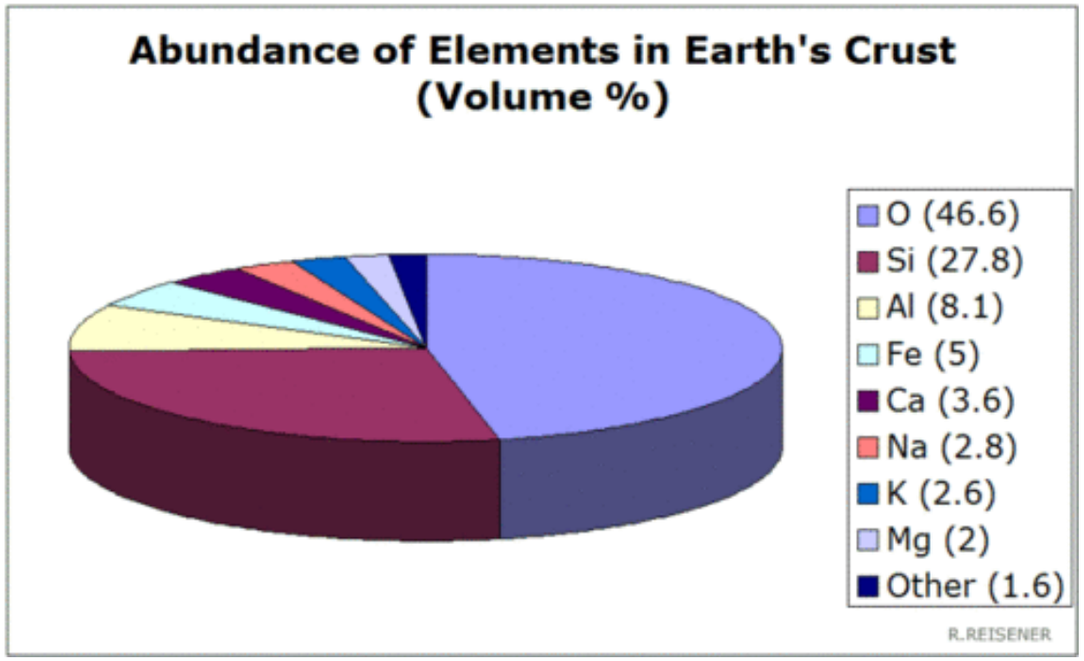


Figure 7.7

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

1. Silicate Minerals

Silicon and Oxygen are by far the most common elements in Earth's crust. They combine to form the basic "building block" for the most common minerl group, the silicates. The roughly 1,000 silicate minerals make up over 90% of Earth's crust. 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** below . To create the wide variety of silicate minerals, this pyramid-shaped structure is often bound to other elements, such as calcium, iron, and magnesium.

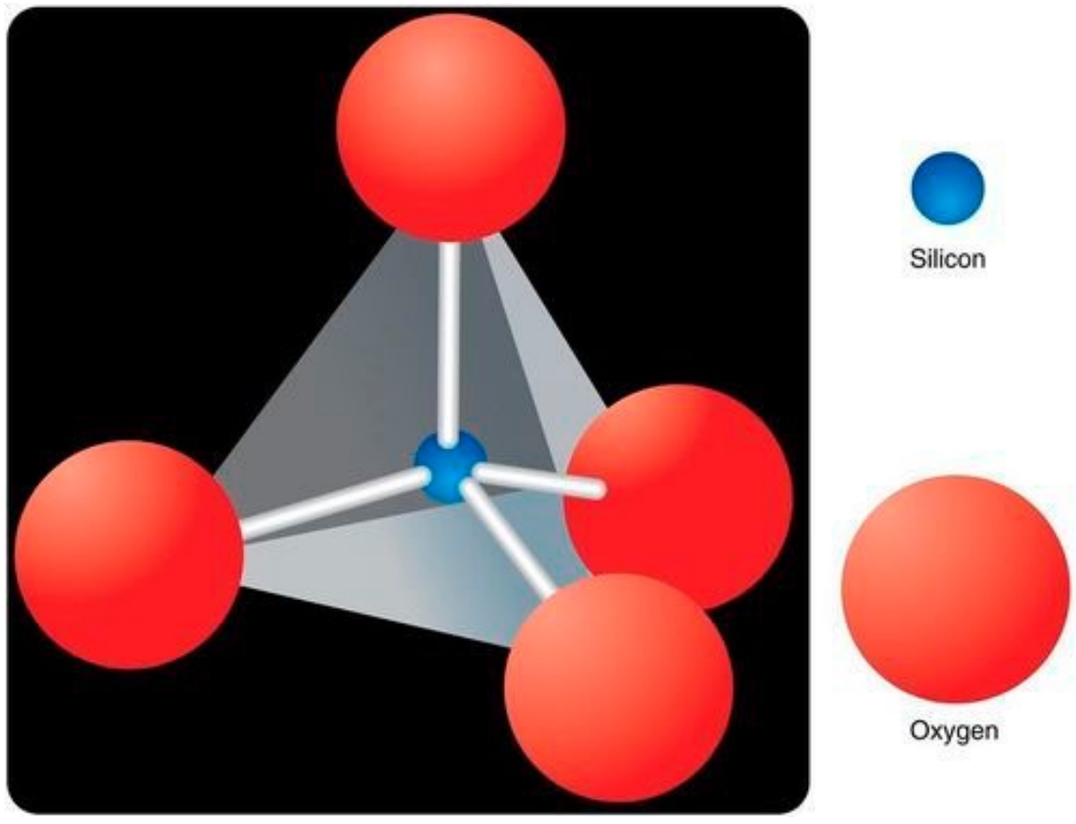


Figure 7.8

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** below). 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.



Muscovite has platy cleavage due to the sheet-like structure of the silica tetrahedra.

The silica tetrahedra in tourmaline are in rings to create elongated prisms.

Figure 7.9

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



Figure 7.10

Common Silicate Minerals. Note that the complexity of the silicate structure increases from top to bottom.

Feldspars are by far the most plentiful group of silicates, comprising over 50% of Earth's crust. How does the molecular structure of feldspar differ from that of quartz? In feldspar, aluminum atoms replace some of the silicon atoms in the silica tetrahedra. This replacement creates a net electrical charge in these tetrahedra, which is balanced by the addition of other metals, such as potassium, sodium, or calcium. On the basis of the types of additional elements, feldspars are classified into two major groups--the potassium feldspars and the sodium-calcium feldspars.

The most common potassium feldspar is orthoclase. Typically, orthoclase is light-colored-pink or salmon. The sodium-calcium feldspars are called plagioclase feldspars. They range in color from white to gray. Feldspars are important rock-forming minerals as well as important economically. Minerals in this family are used in the manufacture of such everyday products as glass and ceramics.



Click on the image above to view the table

Quartz, the second most abundant mineral in the continental crust, is the only common mineral made completely of silicon and oxygen. Pure quartz is colorless or white; colored varieties include rose quartz, amethyst, and smoky quartz. Quartz is the hardest common mineral and is a 7 on the Mohs scale of hardness. Quartz is found in granite and is a significant component of many types of

rocks. Quartzite consists entirely of quartz. Most sands consist mainly of grains of quartz.



Figure 7.11

Pure quartz

2. 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, silver, sulfur, and diamond are examples of native elements.

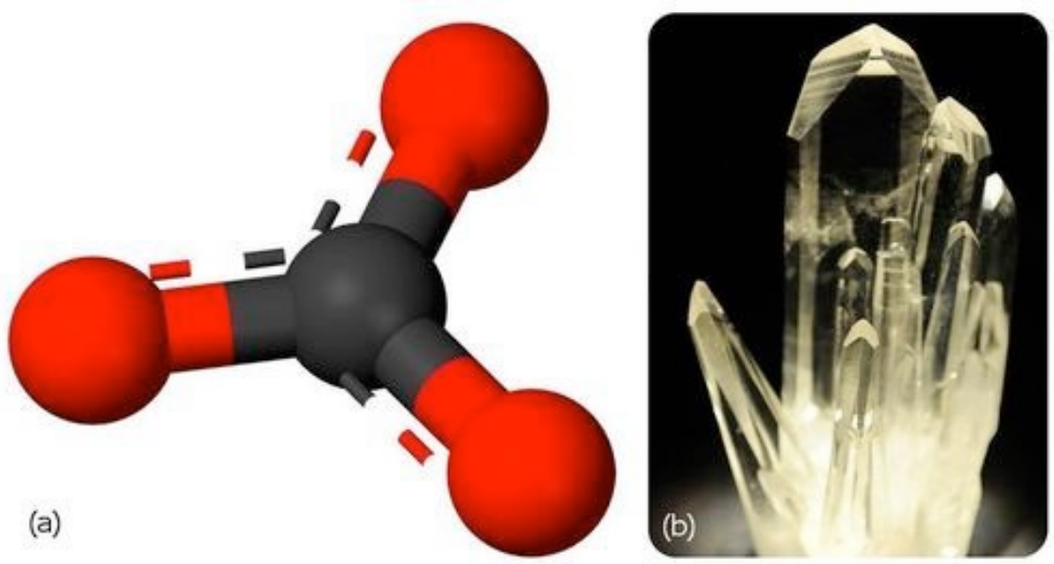


Figure 7.12

Sulfur is an example of a native element

3. Carbonates

The basic carbonate structure is one carbon atom bonded to three oxygen atoms. Carbonates are much simpler structurally than the silicates. Carbonates include other elements, such as calcium, iron, and copper. Calcite ($CaCO_3$) is the most common carbonate mineral (**Figure** below). Calcite is the major constituent in two well-known rocks: limestone and marble.



The carbonate ion is one carbon atom bonded to three oxygen atoms.

Calcite crystals.

Figure 7.13

Calcite is the most common carbonate mineral.

Azurite and malachite, shown in the **Figure** below , are carbonates that contain copper instead of calcium.

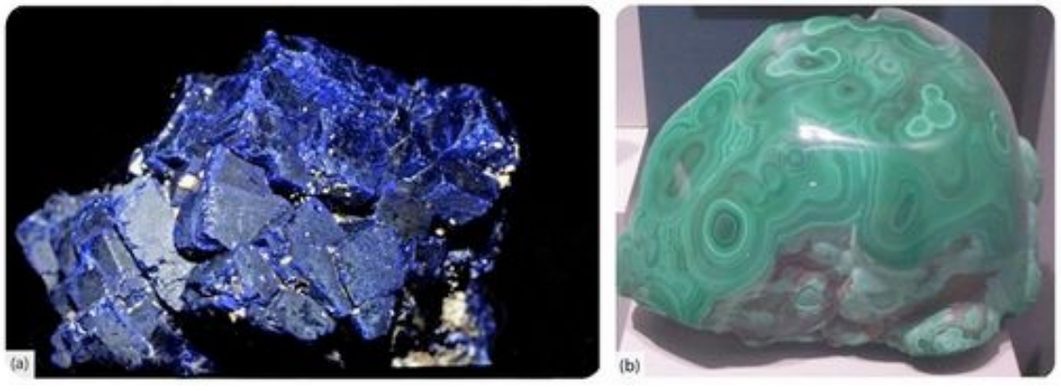


Figure 7.14

Two carbonate minerals: (a) deep blue azurite and (b) opaque green malachite.

4. Halides

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



Figure 7.15

Fluorite is a halide containing calcium and fluorine.

5. Oxides

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

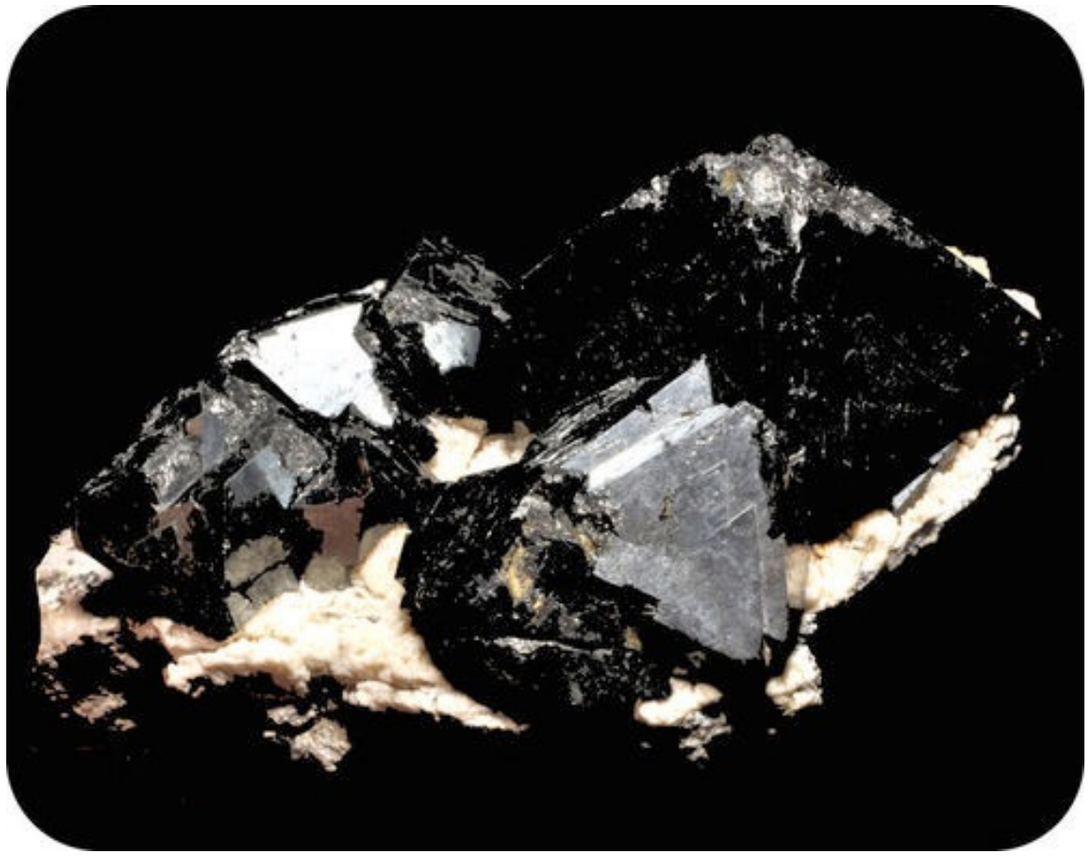


Figure 7.16

Magnetite is the most magnetic mineral. Magnetite attracts or repels other magnets.

6. Phosphates

Phosphate minerals are similar in atomic structure to the silicate minerals. In the phosphates, phosphorus, arsenic, or vanadium bond to oxygen to form a tetrahedra. There are many different minerals in the phosphate group, but most are rare (**Figure** below).



Figure 7.17

Turquoise is a phosphate mineral containing copper, aluminum, and phosphorus.

7. Sulfates

Sulfate minerals contain sulfur atoms bonded to oxygen atoms. Like halides, they form where salt water evaporates. The sulfate group contains many different minerals, but only a few are common.

Gypsum is a common sulfate with a variety of appearances (**Figure** below). Some gigantic 11-meter gypsum crystals have been found. That is about as long as a school bus!



Figure 7.18

Although the orange crystals on the left looks nothing like the white sands on the right, both the crystals and sands are gypsum.

8. Sulfides

Sulfides are formed when metallic elements combine with sulfur. Unlike sulfates, sulfides do not contain oxygen. Pyrite, or iron sulfide, is a common sulfide mineral known as *fool's gold* . People may mistake pyrite for gold because the two minerals are shiny, metallic, and yellow in color.

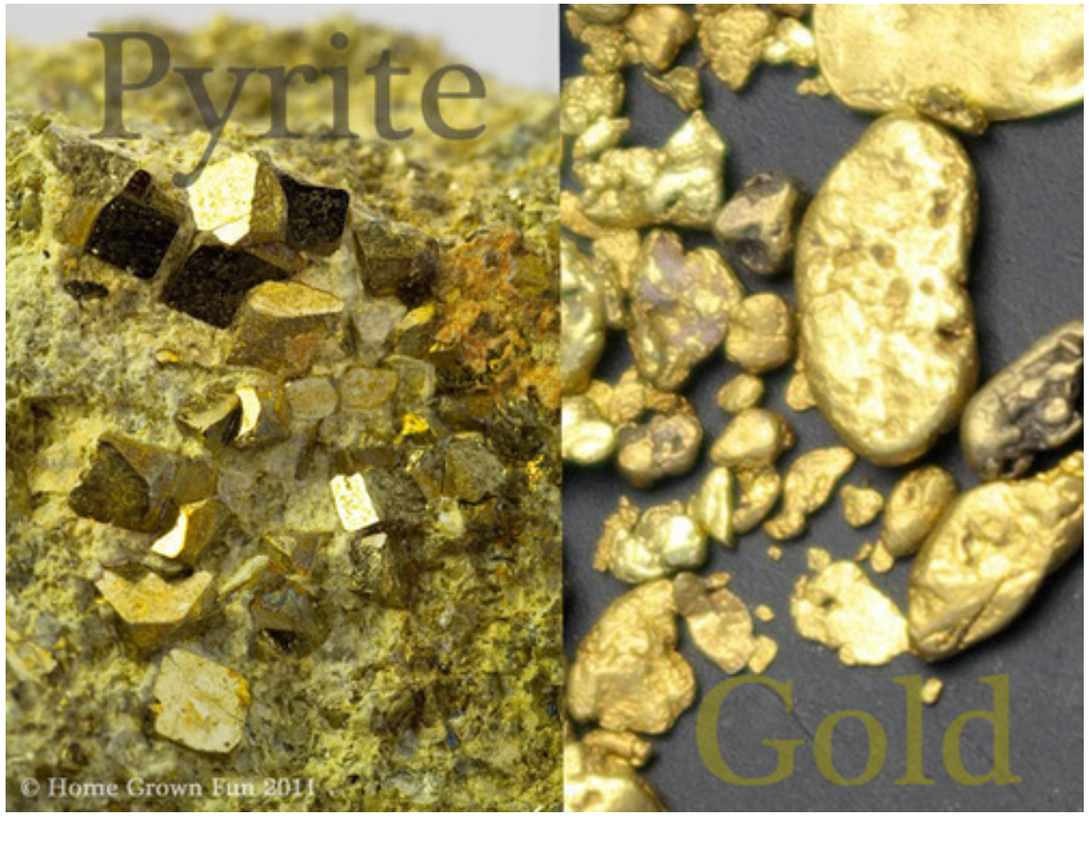


Figure 7.19

Lesson Summary

•For a substance to be a mineral, it must be a naturally occurring, inorganic, crystalline solid that has a characteristic chemical composition and crystal structure.
•The atoms in minerals are arranged in regular, repeating patterns that can be used to identify that mineral.
•Minerals are divided into groups based on their chemical composition.
•The chemical feature of each groups is: native elements – only one element; silicates – silica tetrahedron; phosphates – phosphate tetrahedron; carbonates – one carbon atom with three oxygen atoms; halides – a halogen bonded with a

metallic atom; oxides – a metal combined with oxygen; sulfates – sulfur and oxygen; sulfides – metal with sulfur, no oxygen.

Review Questions

1.What is a crystal?
2.Which elements do all silicate minerals contain?
3.Obsidian is a glass that forms when lava cools so quickly that the atoms do not have a chance to arrange themselves in crystals. Is obsidian a crystal? Explain your reasoning.
4.What are the eight major mineral groups?
5.What is the same about all minerals in the silicate group? What is different about them?
6.One sample has a chemical composition with a ratio of two iron atoms to three oxygen atoms. Another sample has a chemical composition with a ratio of three iron atoms to four oxygen atoms. They contain the same elements: Are they the same mineral?
7.How does the native elements mineral group differ from all of the other mineral groups?
8.On a trip to the natural history museum you find two minerals that are similar in color. You can see from their chemical formulas that one mineral contains the elements zinc, carbon, and oxygen. The other mineral contains the elements zinc, silicon, oxygen, and hydrogen. Your friend tells you that the minerals are in the same mineral group. Do you agree? Explain your reasoning.

Further Reading / Supplemental Links

•Dana Classification of Minerals: http://webmineral.com/danaclass.shtml .

•A Lot of Different Minerals: http://hyperphysics.phy-astr.gsu.edu/hbase/geophys/mineral.html#c1 .

Points to Consider

•Why is obsidian, a natural glass that forms from cooling lava, not a mineral?
•Why are diamonds made in a laboratory not minerals?
•Is coal, formed mostly from decayed plants, a mineral? Is it a rock?
•Artists used to grind up the mineral azurite to make colorful pigments for paints. Is the powdered azurite still crystalline?

Section 3

Mineral Identification

Mineral Identification

Lesson Objectives

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

Vocabulary

- brittle
- cleavage
- density
- elastic
- fracture
- hardness
- luster
- malleable
- mineralogist
- minero logy
- specific gravity
- streak
- tenacity

Introduction

Minerology is the study of minerlas. Minerals can be identified by their physical characteristics. The physical properties of minerals are related to their chemical composition and bonding. Some characteristics, such as a mineral's hardness, are more useful for mineral identification. Color is readily observable and certainly obvious, but it is usually less reliable than other physical properties.

How are Minerals Identified?

This video helps to create a visual in identifying a mineral.

Mineralogists are scientists who study minerals. One of the things mineralogists must do is identify and categorize minerals. While a mineralogist might use a high-powered microscope to identify some minerals, most are recognizable using physical properties.

Check out the mineral in **Figure** below . 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.



Figure 7.20

This mineral has shiny, gold, cubic crystals with striations, so it is pyrite.

Optical Properties: Luster, Color, Streak and Habit

Diamonds are popular gemstones because the way they reflect light makes them very sparkly. Turquoise is prized for its striking greenish-blue color. Notice that specific terms are being used to describe the appearance of minerals.

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** below.

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

Can you match the minerals in **Figure** below with the correct luster from **Table** above?



Figure 7.22

(a) Diamond has an adamantine luster. (b) Quartz is not sparkly and has a vitreous, or glassy, luster. (b) Sulfur reflects less light than quartz, so it has a resinous luster.

Color

Color is rarely very useful for identifying a mineral. Different minerals may be the same color. Real gold, as seen in **Figure** below , is very similar in color to the pyrite in **Figure** above .



Figure 7.23

This mineral is shiny, very soft, heavy, and gold in color, and is actually gold.

The same mineral may also be found in different colors. **Figure** below shows one sample of quartz that is colorless and another quartz that is purple. A tiny amount of iron makes the quartz purple. Many minerals are colored by chemical impurities.



Figure 7.24

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. Streak is a more reliable property than color because streak does not vary. Minerals that are the same color may have a different colored streak.

Streak can also help distinguish between minerals with metallic luster and those with nonmetallic luster. Metallic minerals generally have a dense, dark streak, whereas minerals with nonmetallic luster typically have a light-colored streak. It should be noted that m any minerals, such as the quartz in the **Figure** above , do not have streak. Although the color of a mineral may vary from sample to sample, its streak is usually consistent in color.

To check streak, scrape the mineral across an unglazed porcelain plate (**Figure** below). Yellow-gold pyrite has a blackish streak, another indicator that pyrite is not gold, which has a golden yellow streak.



Figure 7.25

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

Habit or Crystal Shape

Minerologists use the term **crystal shape** or **habit** to refer to the common or characteristic shape of a crystal or aggregate of crystals. A few minerals exhibit somewhat regular polygons that are helpful in their identification. For example, magnetite crystals sometimes occur as octahedrons, garnets often form dodecahedrons, and halite and fluorite crystals tend to grow as cubes or near cubes. While most minerals have only one common habit, a few have two or more charactgeristic crystal shapes such as pyrite.

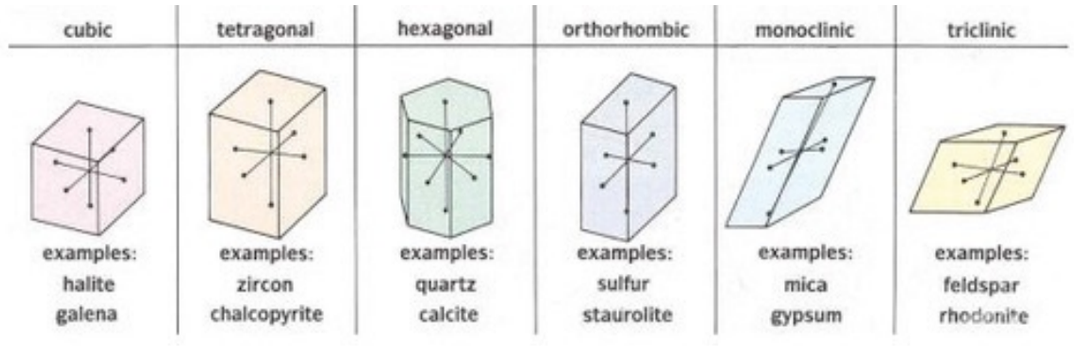


Figure 7.26

Common Crystal Habits

Mineral Strength

How easily minerals break or deform under stress is determined by type and strength of chemical bonds that hold the crystals

together. Mineralogists use terms including tenacity, hardness, cleavage, and fracture to describe mineral strength and how minerals break when stress is applied.

Tenacity

The term **tenacity** describes a mineral's toughness, or its resistance to breaking or deforming. Minerals that are ionically bonded, such as fluorite and halite, tend to be brittle and shatter into small pieces when struck. By contrast, minerals with metallic bonds, such as native copper, are malleable, or easily hammered into different shapes. Micas, are elastic and will bend and snap back into their original shape after the stress is released.

Hardness

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



Click on the image above to view the table

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.

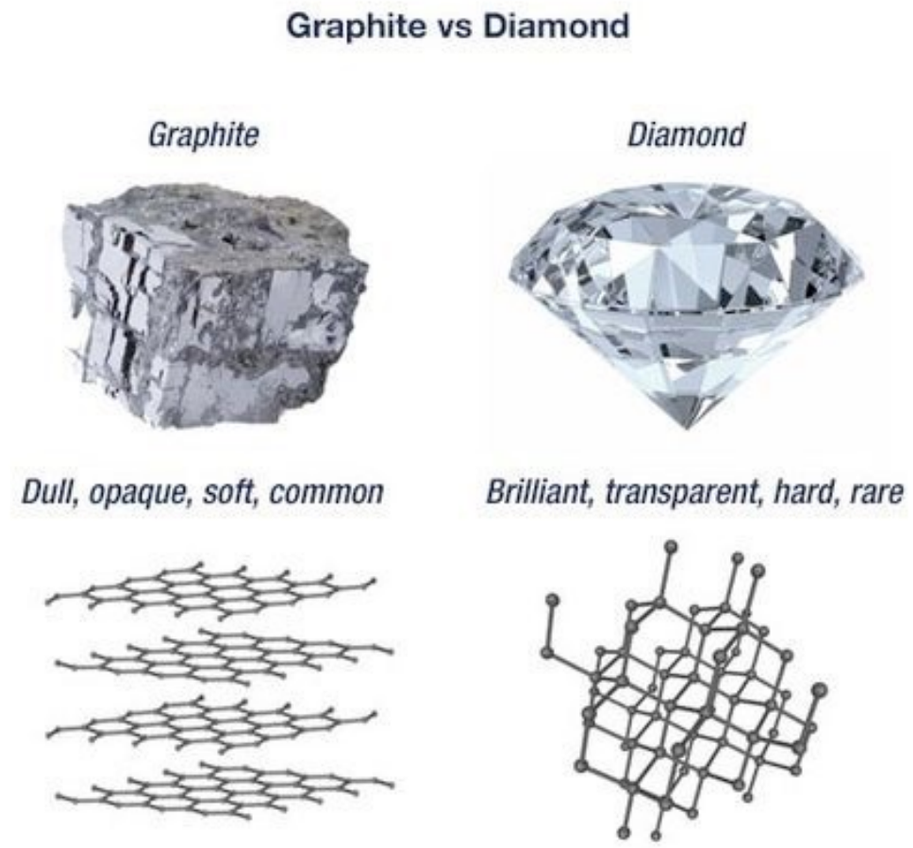


Figure 7.27

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.



Click on the image above to view the table

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 breaks between layers of sodium and chlorine to form cubes with smooth surfaces (**Figure** below).

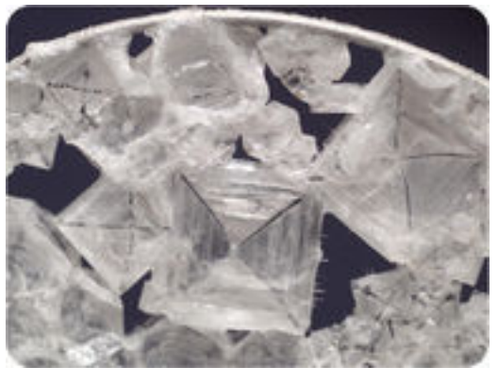


Figure 7.28

A close-up view of sodium chloride in a water bubble aboard the International Space Station.

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



Figure 7.29

Sheets of mica.

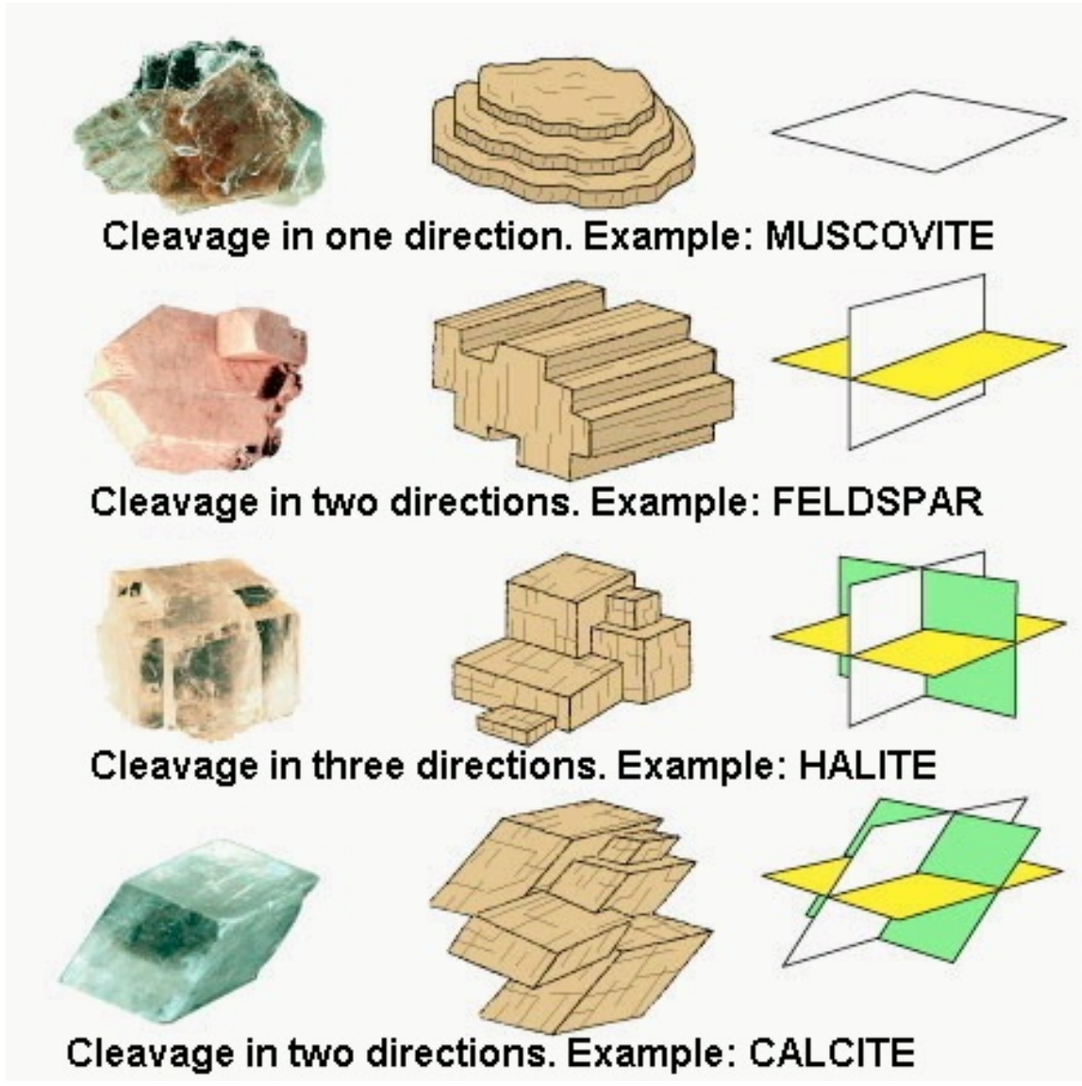
Minerals can cleave into polygons. Fluorite forms octahedrons (**Figure** below).



Figure 7.30

This rough diamond shows its octahedral cleavage.

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



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** below). 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.

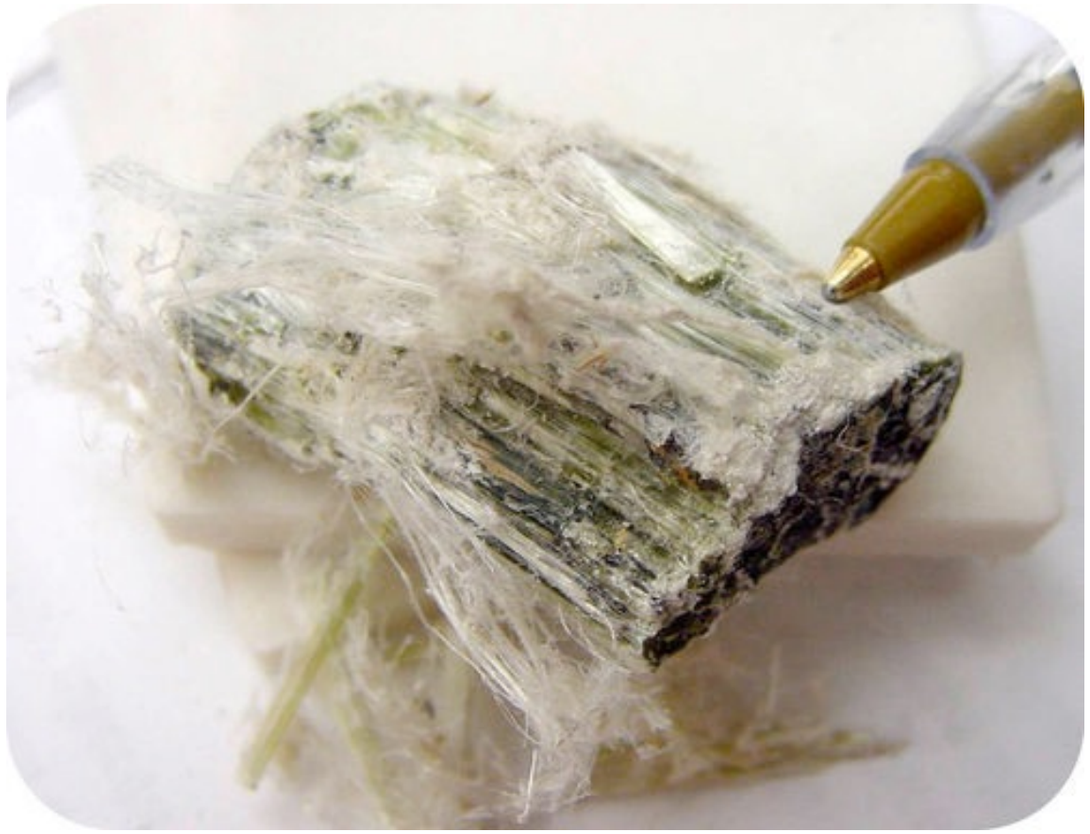


Figure 7.31

Chrysotile has splintery fracture.

Other Identifying Characteristics

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

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

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

Lesson Summary

•Minerals have distinctive properties that can be used to help identify them.
•Color and luster describe the mineral's outer appearance. Streak is the color of the powder.
•A mineral has a characteristic density.
•Mohs Hardness Scale is used to compare the hardness of minerals.
•Cleavage or the characteristic way a mineral breaks depends on the crystal structure of the mineral.
•Some minerals have special properties that can be used to help identify them.

Review Questions

1.Which properties of a mineral describe the way it breaks apart?
2.A mineral looks dry and chalky. What sort of luster does it have?
3.What causes a mineral to have the properties that it has?
4.Apatite scratches the surface of an unknown mineral. Which mineral would you use next to test the mineral's hardness — fluorite or feldspar? Explain your reasoning.
5.Why is streak more reliable than color when identifying a mineral?
6.Mineral A has a density of 5 g/cm ^{3} . Mineral B is twice as dense as Mineral A. What is the density of Mineral B?
7.Why do some minerals cleave along certain planes?

Further Reading / Supplemental Links

•Physical Characteristics of Minerals: http://www.galleries.com/Mineral_Properties
•Brief introduction to minerals: https://www.youtube.com/watch?v=8a7p1NFn64s

Points to Consider

•If a mineral is magnetic, do you know for certain what mineral it is?
•Some minerals are colored because they contain chemical impurities. How did the impurities get into the mineral?
•What two properties of a mineral sample would you have to measure to calculate its density?
•How much do minerals reflect the environment in which they formed?

Section 4

Mineral Formation

Mineral Formation

Lesson Objectives

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

Vocabulary

- lava
- magma
- rock
- vein

Introduction

Minerals form under an enormous range of geologic conditions. There are probably more ways to form minerals than there are types of minerals themselves. Minerals can form from volcanic gases, sediment formation, oxidation, crystallization from magma, or deposition from a saline fluid, to list a few. Some of these methods of mineral formation will be discussed below.

Formation from Hot Material

A **rock** is a collection of minerals. 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 ◦C. Magma cools slowly inside Earth, which gives mineral crystals time to grow large enough to be seen clearly (**Figure** below).

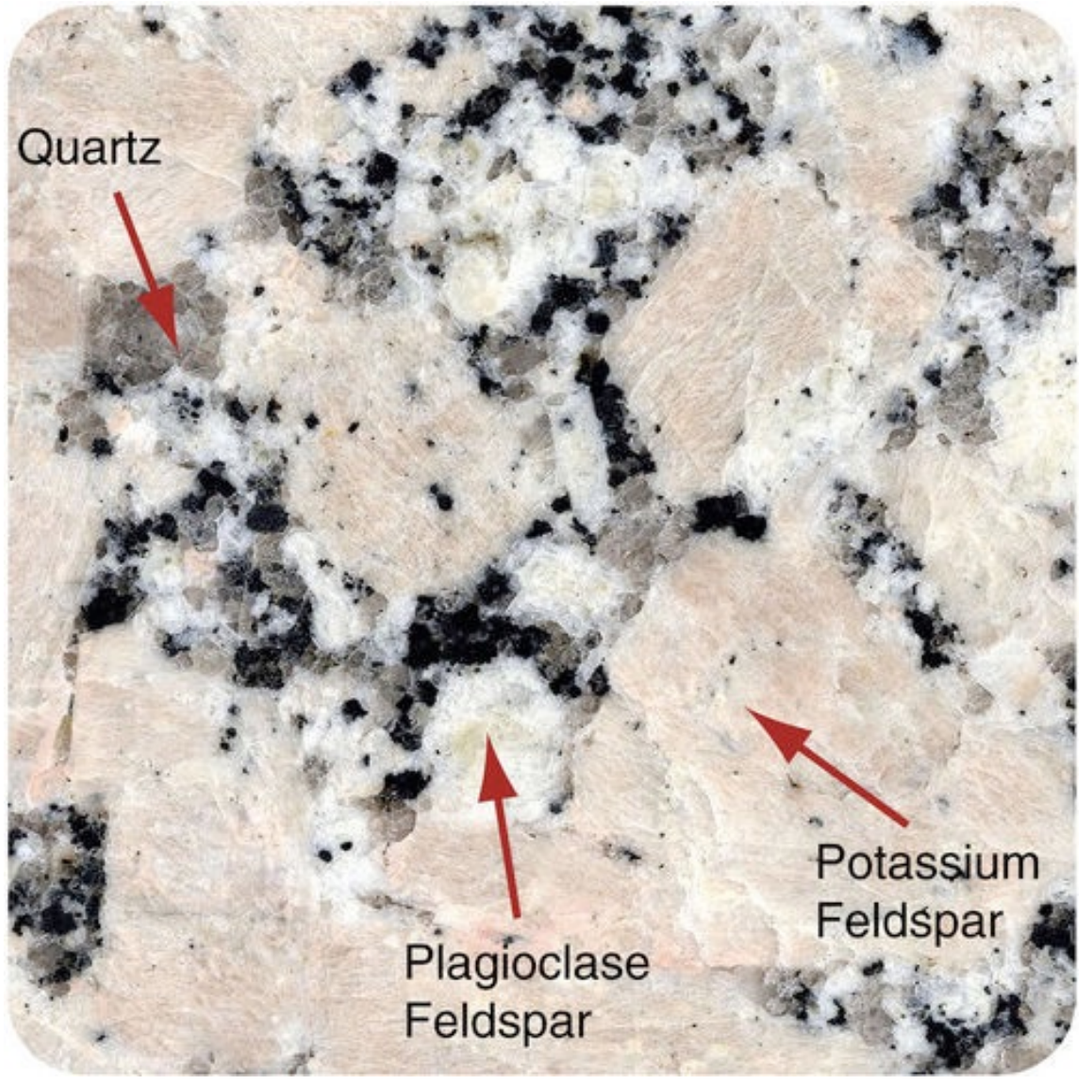


Figure 7.32

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 when it is below the surface. In a cooling lava, mineral crystals do not have time to form and are very small. The chemical composition will be the same as if the magma cooled slowly.

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 chapter “Rocks.”

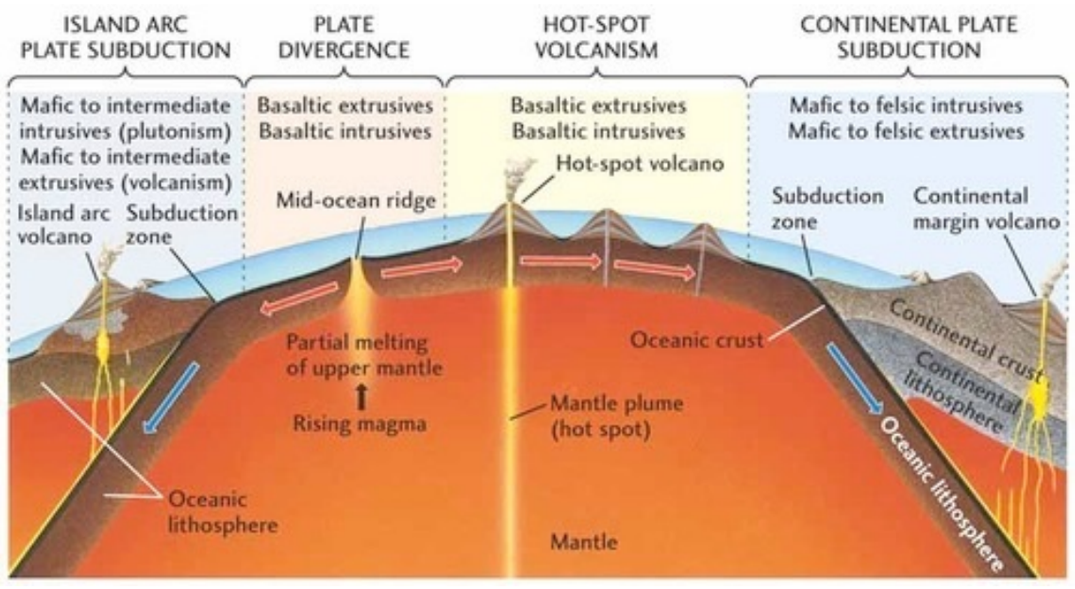


Figure 7.33

Magma and Lava

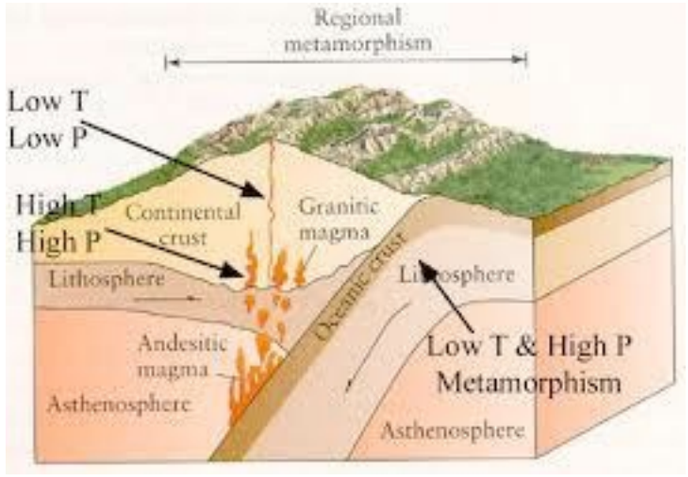


Figure 7.34

Pressure and Temperature

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** below .

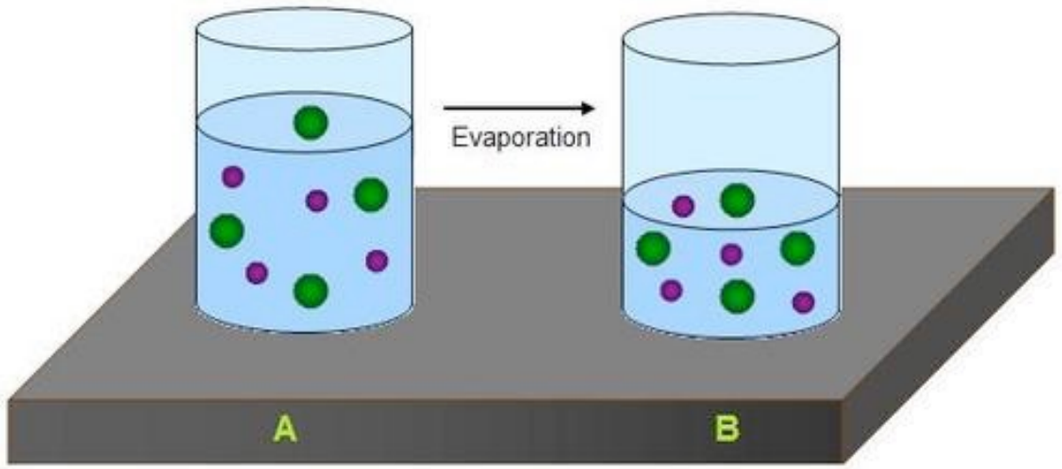


Figure 7.35

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** below) or The Great Salt Lake in Utah, contain many mineral precipitates.



Figure 7.36

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.

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** below).



Figure 7.37

Quartz veins formed in this rock.

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



Figure 7.38

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

Lesson Summary

- Mineral crystals that form when magma cools slowly are larger than crystals that form when lava cools rapidly.
- Minerals form when rocks are heated enough that atoms of different elements can move around and join into different molecules.
- Minerals are deposited from salty water solutions on Earth's surface and underground.

Review Questions

1.What is the difference between magma and lava?
2.Under what circumstances do large crystals form from a cooling magma?
3.Under what circumstances do small crystals form from a cooling magma?
4.What happens to the mineral particles in salt water when the water evaporates?
5.Explain how mineral veins form.

Further Reading / Supplemental Links

•Gems and Where They're Found: http://socrates.berkeley.edu/~eps2/wisc/Lect3.html .
•How to Grow Your Own Crystals: http://www.sdnhm.org/kids/minerals/grow-crystal.html .

Points to Consider

•Is a mineral a static thing or does it change? If it changes, on what time frame?
•When most minerals form, they combine with other minerals to form rocks. How can these minerals be used?
•The same mineral can be formed by different processes. How can the way a mineral forms affect how the mineral is used?

Section 5

Mining and Mineral Use

Mining and Mineral Use

Lesson Objectives

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

Vocabulary

- gemstone
- ore
- ore deposit
- placer
- reclamation

Introduction

Some minerals are very useful. An **ore** is a rock that contains minerals with useful elements. Aluminum in bauxite ore (**Figure** below) 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.



Figure 7.39

Aluminum is made from the aluminum-bearing minerals in bauxite.

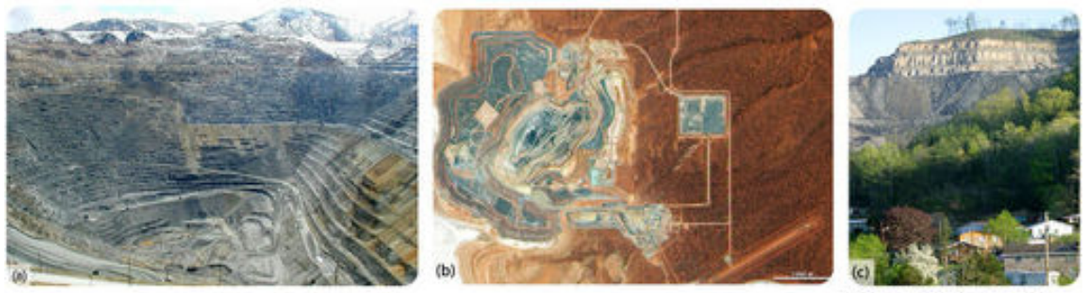
Finding and Mining Minerals

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.

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** below , 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.



Bingham Canyon Open Pit Copper Mine

An aerial view of an open pit gold mine in Australia

With mountaintop removal, everything lying above an ore deposit is just removed. This controversial mining technique is common in coal mining regions, such as Kentucky above.

Figure 7.40

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, 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.

Ore Extraction

The ore's journey to becoming a useable material is only just beginning when the ore leaves the mine (**Figure** below). 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.



Figure 7.41

The de Young Museum in San Francisco is covered in copper panels. Copper is mined and extracted from copper ores.

To extract the metal from the ore, the rock is melted at a temperature greater than 900°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.

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** below).



Figure 7.42

Acid drainage from a surface coal mine in Missouri.

U.S. law has changed so that in recent decades 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 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.

Valuable Minerals

Some minerals are valuable because they are beautiful. Jade has been used for thousands of years in China. Diamonds sparkle on many engagement rings. Minerals like jade, turquoise, diamonds, and emeralds are gemstones. A **gemstone** , or gem, is a material that is cut and polished for jewelry. Many gemstones, including many in **Figure** below , are minerals.



Figure 7.43

Gemstones come in many colors.

Gemstones are usually rare and do not break or scratch easily. Most are cut along cleavage faces and then polished so that light bounces back off the cleavage planes (**Figure** below). Light does not pass through gemstones that are opaque, such as turquoise.





Figure 7.44

Uncut (left) and cut (right) ruby. The cut and polished ruby sparkles.

Gemstones are not just used in jewelry. Diamonds are used to cut and polish other materials, such as glass and metals, because they are so hard. The mineral corundum, of which ruby and sapphire are varieties, is used in products such as sandpaper.

Minerals are used in much less obvious places. The mineral gypsum is used for the sheetrock in homes. Window glass is made from sand, which is mostly quartz. Halite is mined for rock salt. Copper is used in electrical wiring, and bauxite is the source for the aluminum used in soda cans.

Lesson Summary

- Geologists use many methods to find mineral deposits that will be profitable to mine.
- Ore deposits can be mined by surface or underground mining methods.
- Mining provides important resources but has environmental costs.
- By U.S. law, currently mined land must undergo reclamation. This is not true for old mines.
- Metal ores must be melted to make metals.
- Many gems are cut and polished to increase their beauty.
- Minerals are used in a variety of ways.

Review Questions

1. What category of mining would be used to extract ore that is close to the surface? Why?
2. Describe some surface mining methods.

3.What are some disadvantages of underground mining?
4.What are some ways an area can undergo reclamation after being mined?
5.What steps are taken to extract a pure metal from an ore?
6.What makes a gemstone valuable?

Further Reading / Supplemental Links

•Aluminum and Bauxite: http://www.mii.org/Minerals/photoal.html .

Points to Consider

•Are all mineral deposits ores?
•Why might an open pit mine be turned into an underground mine?
•How well does reclaimed land resemble the land before mining began?
•Diamonds are not necessarily the rarest gem so why do people value them more than most other gems?
•Under what circumstances might a mineral deposit be an ore one day and not the next?

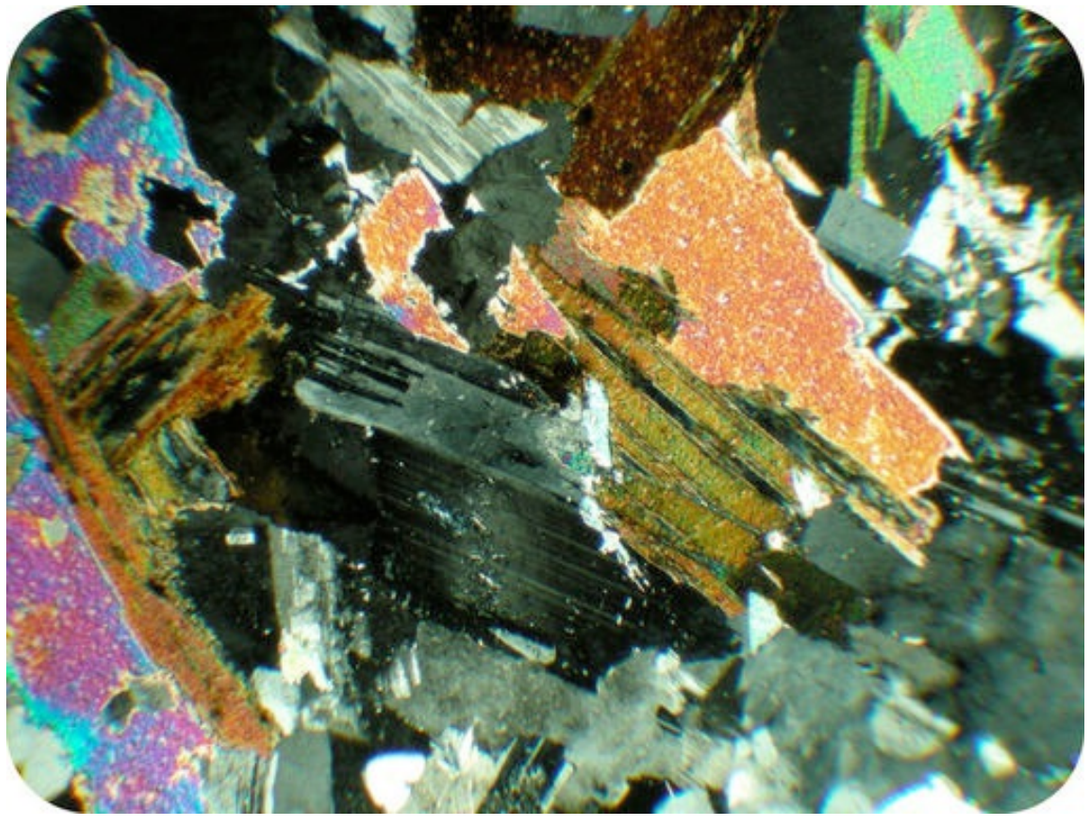
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Ch. 8: Rocks



This image is of an igneous rock, specifically an igneous intrusive rock called granite The rock was sliced very thin, mounted on a slide and viewed in a polarizing light microscope. In a photomicrograph, different minerals have different colors and shapes. The gray and black striped crystals are plagioclase, the blobby gray ones are quartz and the colored segmented ones are mica. Geologists like to use photomicrographs because the minerals are more identifiable. The textures are also easier to recognize, which gives the scientists clues about the rock's formation. All this makes a rock easier to identify.

Thomas Bresson. commons.wikimedia.org/wiki/File:Thomas_Bresson_-_Granite_vu_au_microscope_%28by%29.jpg. CC BY 2.0.

Section 1

Types of Rocks

Types of Rocks

Lesson Objectives

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

Vocabulary

- crystallization
- erosion
- igneous rock
- metamorphic rock
- metamorphism
- outcrop
- precipitate
- rock cycle
- sediment
- sedimentary rock
- sedimentation
- weathering

Introduction

There are three types of rocks: igneous, sedimentary and metamorphic. Each of these types is part of the rock cycle. Through changes in conditions one rock type can become another rock type. Or it can become a different rock of the same type.

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** below).



Figure 8.1

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

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** below).



Figure 8.2

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

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** below the same rock type? Do they have the same minerals? The same texture?

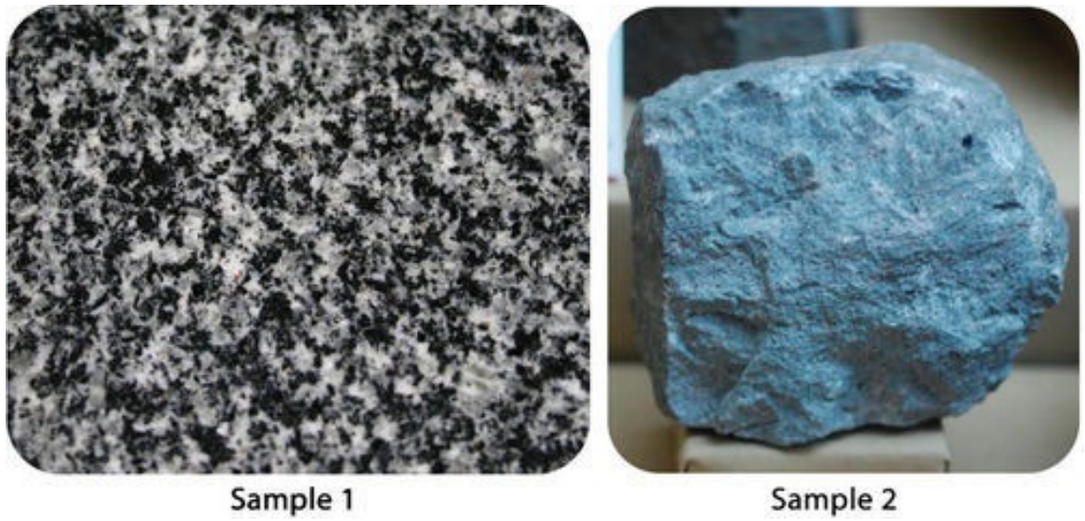


Figure 8.3

Rock samples.

Sample	Minerals	Texture	Formation	Rock type
Sample 1	plagioclase, quartz, hornblende, pyroxene	Crystals, visible to naked eye	Magma cooled slowly	Diorite
Sample 2	plagioclase, hornblende, pyroxene	Crystals are tiny or microscopic	Magma erupted and cooled quickly	Andesite

As seen in **Table** above , 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 very tiny or invisible grains. 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.

Three Main Categories of Rocks

Rocks are classified into three major groups according to how they form. Rocks can be studied in hand samples that can be moved from their original location. Rocks can also be studied in **outcrop** , exposed rock formations that are attached to the ground, at the location where they are found.

Igneous Rocks

Igneous rocks form from cooling magma. Magma that erupts onto Earth's surface is lava, as seen in **Figure** below . The chemical composition of the magma and the rate at which it cools determine what rock forms as the minerals cool and crystallize.



Figure 8.4

This flowing lava is molten rock that will harden into an igneous rock.

Sedimentary Rocks

Sedimentary rocks form by the compaction and cementing together of **sediments** , broken pieces of rock-like gravel, sand, silt, or clay (**Figure** below). 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.



Figure 8.5

This sedimentary rock is made of sand that is cemented together to form a sandstone.

Metamorphic Rocks

Metamorphic rocks form when the minerals in an existing rock are changed by heat or pressure within the Earth. See **Figure** below for an example of a metamorphic rock.



Figure 8.6

Quartzite is a metamorphic rock formed when quartz sandstone is exposed to heat and pressure within the Earth.

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 .

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

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

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



Click on the image above for more content

The Rock Cycle

Rocks change as a result of natural processes that are taking place all the time. Most changes happen very slowly; many take place below the Earth's surface, so we may not even notice the changes. Although we may not see the changes, the physical and chemical properties of rocks are constantly changing in a natural, never-ending cycle called the **rock cycle** .

The concept of the rock cycle was first developed by James Hutton, an eighteenth century scientist often called the "Father of Geology" (shown in **Figure** below). Hutton recognized that geologic processes have "no [sign] of a beginning, and no prospect of an end." The processes involved in the rock cycle often take place over millions of years. So on the scale of a human lifetime, rocks appear to be "rock solid" and unchanging, but in the longer term, change is always taking place.

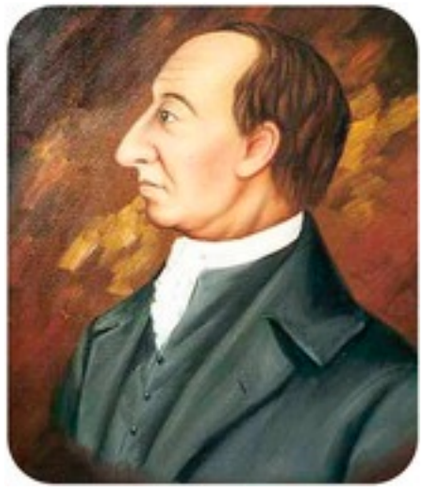


Figure 8.7

James Hutton is considered the Father of Geology.

In the rock cycle, illustrated in **Figure** below , the three main rock types – igneous, sedimentary, and metamorphic - are shown. Arrows connecting the three rock types show the processes that change one rock type into another. The cycle has no beginning and no end. 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.



Figure 8.8

The Rock Cycle.

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.

Lesson Summary

•Rocks are collections of minerals of various sizes and types.
•The three main rock types are igneous, sedimentary, and metamorphic.
•Crystallization, erosion and sedimentation, and metamorphism transform one rock type into another or change sediments into rock.
•The rock cycle describes the transformations of one type of rock to another.

Review Questions

1.Describe the difference between a rock and a mineral.
2.Why can the minerals in a rock be a clue about how the rock formed?
3.What are the three main types of rocks and how does each form?
4.Describe how an igneous rock changes into a metamorphic rock.
5.Describe how an igneous rock changes into a sedimentary rock.
6.Explain how sediments form.
7.In which rock type do you think fossils, which are the remains of past living organisms, are most often found?

Further Reading / Supplemental Links

•An interactive, illustrated rock cycle diagram is seen here: http://www.learner.org/interactives/rockcycle/diagram.html.

Points to Consider

•If Earth's interior were no longer hot but all other processes on Earth continued unchanged, what would happen to the different rock types in the rock cycle?

•Stone tools were important to early humans. Are rocks still important to humans today?

Section 2

Igneous Rocks

Igneous Rocks

Lesson Objectives

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

Vocabulary

- Bowen's Reaction Series
- extrusive
- felsic
- fractional crystallization
- intermediate
- intrusive
- mafic
- partial melting
- pluton
- porphyritic
- ultramafic
- vesicular
- volcanic rock

Introduction

Igneous rocks form from the cooling and hardening of molten magma in many different environments. These rocks are identified by their composition and texture. More than 700 different types of igneous rocks are known.

Magma Composition

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 that melted. Magmas also contain gases. The main elements are the same as the elements found in the crust. **Table** below 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.

Element	Symbol	Percent
Oxygen	O	46.6%
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%**

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 the "Plate Tectonics" chapter.

As a rock heats up, the minerals that melt at the lowest temperatures will 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.

Bowen's Reaction Series indicates the temperatures at which minerals melt or crystallize (**Figure** below). 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.

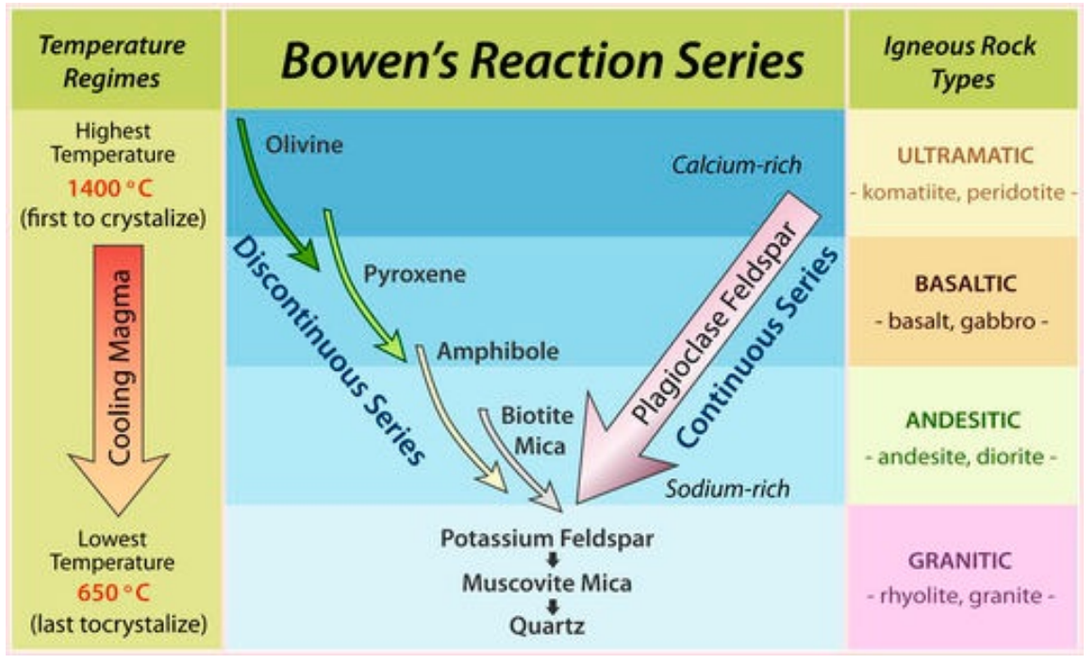


Figure 8.9

Bowen's Reaction Series.

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.

Intrusive and Extrusive 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** below for an example).

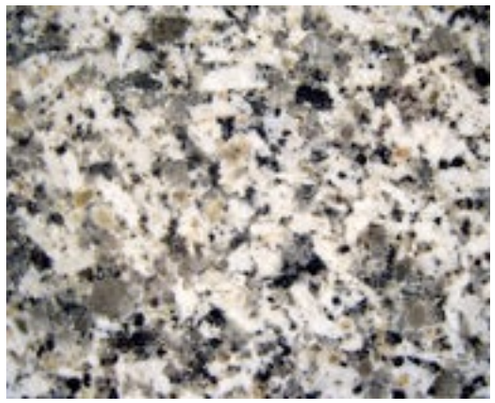


Figure 8.10

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

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** below shows a landscape in California's Sierra Nevada made of granite that has been raised to create mountains.



Figure 8.11

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

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** below).



Figure 8.12

Extrusive igneous rocks form after lava cools above the surface.

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** below).



Figure 8.13

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

Some volcanic rocks have a mixed texture. A rock such as an andesite may have 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** below 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.

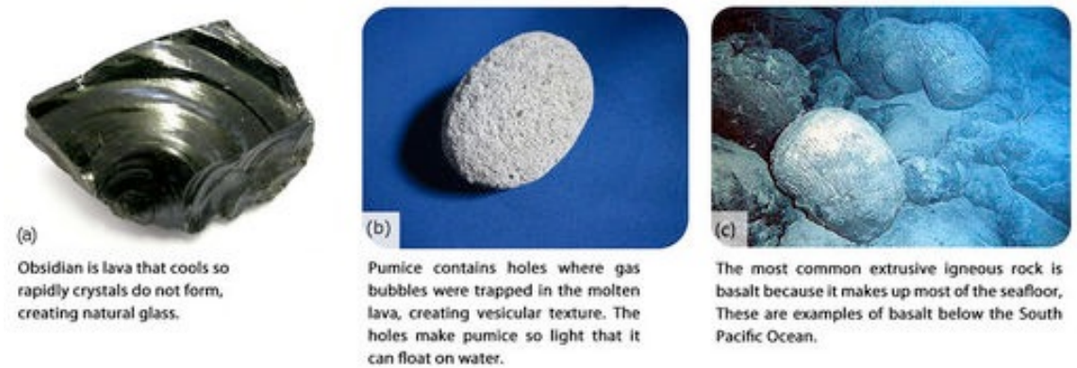


Figure 8.14

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

Igneous Rock Classification

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

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

Type	Amount of Silica	Extrusive	Intrusive
Ultramafic	<45%	Komatiite	Peridotite
Mafic	45-52%	Basalt	Gabbro

Some of the rocks in the **Table** above were pictured earlier in this chapter. 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 following photos in **Figure** below :

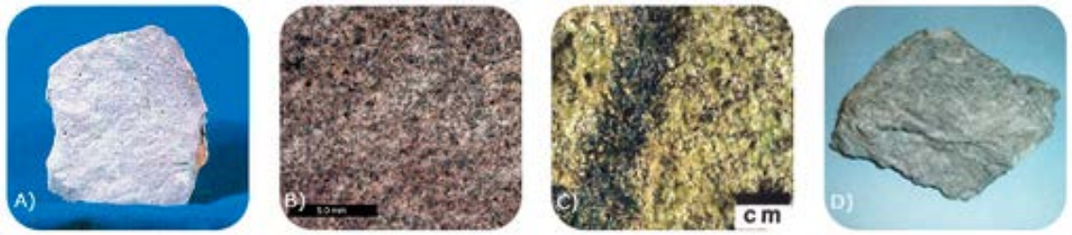


Figure 8.15

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

Uses of Igneous Rocks

Igneous rocks have a wide variety of uses. One important use is as stone for buildings and statues. Granite is used for both of these purposes and is popular for kitchen countertops (**Figure** below).



Figure 8.16

Granite is an igneous rock used commonly in statues and building materials.

Pumice, shown in **Figure** above , is commonly used as an abrasive. Pumice is used to smooth skin or scrape up grime around the house. When pumice is placed into giant washing machines with newly manufactured jeans and tumbled, the result is “stone-washed” jeans. Ground up pumice stone is sometimes added to toothpaste to act as an abrasive material to scrub teeth.

Peridotite is sometimes mined for peridot, a type of olivine that is used in jewelry. Diorite was used extensively by ancient civilizations for vases and other decorative artwork and is still used for art today (**Figure** below).



Figure 8.17

This diorite statue was made in approximately 2120 BC.

Lesson Summary

•Igneous rocks form either when they cool very slowly deep within the Earth (intrusive) or when magma cools rapidly at the Earth's surface (extrusive).
•Rock may melt to create magma if temperature increases, pressure decreases, or water is added. Different minerals melt at different temperatures.
•Igneous rocks are classified on their composition and grain size, which indicates whether they are intrusive or extrusive.

Review Questions

1.What is the visible difference between an intrusive and an extrusive igneous rock?
2.How does the difference in the way intrusive and extrusive rocks form lead to the differences in how the rocks appear?
3.What causes solid rocks to melt?
4.How are partial melting and fractional crystallization the same and different from each other?
5.How are igneous rocks classified?
6.Describe two ways granite is different from basalt.
7.List three common uses of igneous rocks.
8.Occasionally, igneous rocks contain both large crystals and tiny mineral crystals. Propose a way that both sizes of crystals might have formed in the rock.
9.How do you imagine an igneous rock will cool on the seafloor, and what will be the size of its crystals?

Further Reading / Supplemental Links

•A way to learn about the three rock types and some of the rocks within each type: http://geology.com/rocks/

Points to Consider

•Are igneous rocks forming right now?
•Why don’t all igneous rocks with the same composition have the same name?
•Could an igneous rock cool at two different rates? What would the crystals in such a rock look like?

Sedimentary Rocks

Sedimentary Rocks

Lesson Objectives

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

Vocabulary

- biochemical sedimentary rocks
- bioclastic
- cementation
- chemical sedimentary rocks
- clastic
- compaction
- lithification
- organic

Introduction



Figure 8.18

The White House of the USA is made of a sedimentary rock called sandstone.

The White House (shown in the **Figure** above) is the official home and workplace of the President of the United States of America. Why do you think the White House is white? If you answered, “Because it is made of white rock,” you would be only partially correct. Construction for the White House began in 1792. Its outside walls are made of the sedimentary rock sandstone. This sandstone is very porous and is easily penetrated by rainwater. Water damage was common in the early days of construction for the building. To stop the water damage, workers covered the sandstone in a mixture of salt, rice, and glue, which help to give the White House its distinctive white color.

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. Physical 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** below). Much more information about weathering can be found in the "Weathering and Formation of Soil" chapter. Erosion is described in detail in the "Erosion and Deposition" chapter.



Figure 8.19

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

Streams carry huge amounts of sediment (**Figure** below). 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 8.20

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. Avalanches 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.

Sedimentary Rock Formation

Accumulated sediments harden into rock by **lithification** , as illustrated in the **Figure** below . 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** below).



Figure 8.21

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

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 “Earth's Minerals” chapter, dissolved ions in fluids precipitate out of the fluid and settle out, just like the halite in **Figure** below .



Figure 8.22

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** below).



Figure 8.23

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

Table below shows some common types of sedimentary rocks.



Click on the image above to view the table

Uses of Sedimentary Rocks

Sedimentary rocks are used as building stones, although they are not as hard as igneous or metamorphic rocks. Sedimentary rocks are used in construction. Sand and gravel are used to make concrete; they are also used in asphalt. Many economically valuable resources come from sedimentary rocks. Iron ore and aluminum are two examples.

Lesson Summary

- Weathering and erosion produce sediments. Sediments are transported by water, wind, ice, or gravity.
- After sediments are deposited, they undergo compaction and/or cementation to become sedimentary rocks.
- Biochemical sedimentary rocks form when living creatures using ions in water to create shells, bones, or soft tissue die and fall to the bottom as sediments.

Review Questions

1. What are three categories of things that might be part of the sediments in sedimentary rock?
2. If you see a sedimentary rock outcrop with layers of red sandstone on top of layers of tan sandstone, what do you know about the ages of the two layers?
3. Why do sedimentary rocks sometimes have layers of different colors?
4. Describe the two processes necessary for sediments to lithify into sedimentary rock.

5.How are bioclastic rocks different from clastic rocks? Give an example of a bioclastic rock.
6.What type of sedimentary rock is coal?
7.In what environment do you think chemical sedimentary rocks are most likely to form?

Further Reading / Supplemental Links

•A way to learn about the three rock types and some of the rocks within each type: http://geology.com/rocks/

Points to Consider

•Is a rock always made of minerals? Do the requirements for something to be a mineral need to be met for something to be a rock?
•Which type of rocks do you think yield the most information about Earth's past?
•Could a younger layer of sedimentary rock ever be found under an older layer? How do you think this could happen?
•Could a sedimentary rock form only by compaction from intense pressure?

Metamorphic Rocks

Metamorphic Rocks

Lesson Objectives

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

Vocabulary

- contact metamorphism
- foliation
- regional metamorphism

Introduction

In the large outcrop of metamorphic rocks in **Figure** below , the rocks' platy appearance is a result of the process metamorphism. Metamorphism is the addition of heat and/or pressure to existing rocks, which causes them to change physically and/or chemically so that they become a new rock. Metamorphic rocks may change so much that they may not resemble the original rock.



Figure 8.24

The platy layers in this large outcrop of metamorphic rock show the effects of pressure on rocks during metamorphism.

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** below .

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



Figure 8.25

A foliated metamorphic rock.

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 because of the magma's extreme heat.

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



Click on the image above to view the table

Uses of Metamorphic Rocks

Quartzite and marble are commonly used for building materials and artwork. Marble is beautiful for statues and decorative items such as vases (see an example in **Figure** below). Ground up marble is also a component of toothpaste, plastics, and paper.



Figure 8.26

Marble is used for decorative items and in art.

Quartzite is very hard and is often crushed and used in building railroad tracks (see **Figure** below). Schist and slate are sometimes used as building and landscape materials. Graphite, the "lead" in pencils, is a mineral commonly found in metamorphic rocks.



Figure 8.27

Crushed quartzite is sometimes placed under railroad tracks because it is very hard and durable.

Lesson Summary

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

Review Questions

1.Why do minerals change composition as they undergo metamorphism?
2.Describe the process by which minerals in a rock rearrange to become different minerals when exposed to heat or pressure.
3.Describe the conditions that lead to foliated versus non-foliated metamorphic rocks.
4.List and describe the two main types of metamorphism.
5.What can geologists look at in a metamorphic rock to understand that rock's history?
6.Suppose a phyllite sample was metamorphosed again. How might it look different after this second round of metamorphism?

Further Reading / Supplemental Links

•Film: The Living Rock: Earth's Continental Crust http://media.wr.usgs.gov/movies/index.html?id=living_rock .

Points to Consider

•What type of rock forms if an existing rock heats up so much that it melts completely and then forms a different rock?
•What clues can a rock give about its history if it was so altered by metamorphism that it is unrecognizable?

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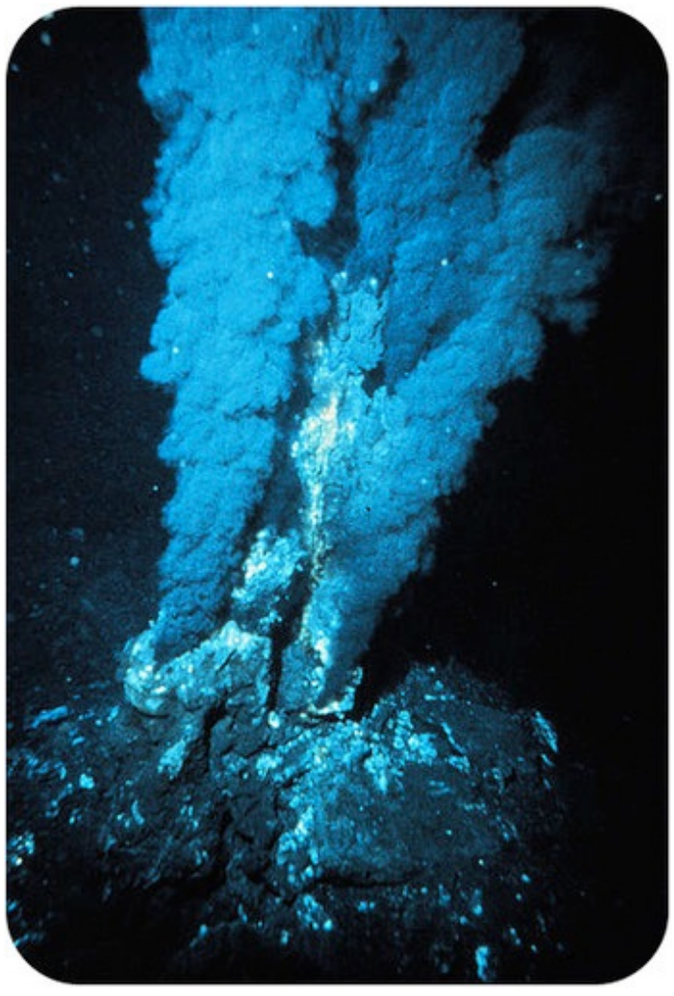
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Ch. 9: Plate Tectonics



Like just about everything in Earth Science, this strange feature is related to plate tectonics. It's really just a hot geyser like the ones found at Yellowstone National Park, except this geyser is found under 10,000 feet of seawater. These features, called hydrothermal vents, are found where lava eruptions hit seawater in regions where new ocean crust is being created. The hot water coming from the vent explodes from the release of pressure. Once in the cold seawater, sulfide minerals precipitate out, creating the "smoke" in the photo. As the sulfide minerals fall, they create the chimney-like structure in the photo.

Many hydrothermal vents are home to unusual life forms.

Courtesy of P. Rona/NOAA. commons.wikimedia.org/wiki/File:Blacksmoker_in_Atlantic_Ocean.jpg. Public Domain.

Section 1

Inside Earth

Inside Earth

Lesson Objectives

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

Vocabulary

- asthenosphere
- conduction
- continental crust
- continental drift
- convection
- convection cell
- convergent boundary
- core
- crust
- divergent boundary
- lithosphere
- lithospheric plate
- mantle
- meteorite
- oceanic crust
- pangaea
- plate tectonics
- primary waves
- rift valley
- S-waves
- seafloor spreading
- seismic waves
- supercontinent
- transform fault boundary

Introduction

Before you can learn about plate tectonics, you need to review the layers that are found inside Earth. These layers are divided by composition into core, mantle, and crust or by mechanical properties into lithosphere and asthenosphere. Scientists use information from earthquakes and computer modeling to learn about Earth's interior.

Exploring Earth's Interior

How do scientists know what is inside the Earth? We don't have direct evidence! Rocks yield some clues, but they only reveal information about the outer crust. In rare instances, a mineral, such as a diamond, comes to the surface from deeper down in the crust or the mantle. To learn about Earth's interior, scientists use energy to "see" the different layers of the Earth, just like doctors can use an MRI, CT scan, or x-ray to see inside our bodies.

Seismic Waves

One ingenious way scientists learn about Earth's interior is by looking at how energy travels from the point of an earthquake. These are **seismic waves** (**Figure** below). Seismic waves travel outward in all directions from the focus, point of rock displacement at an earthquake. These waves are picked up by seismographs around the world. Two types of seismic waves are most useful for learning about Earth's interior.

•**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 ◦ to 140 ◦ from the earthquakes focus.

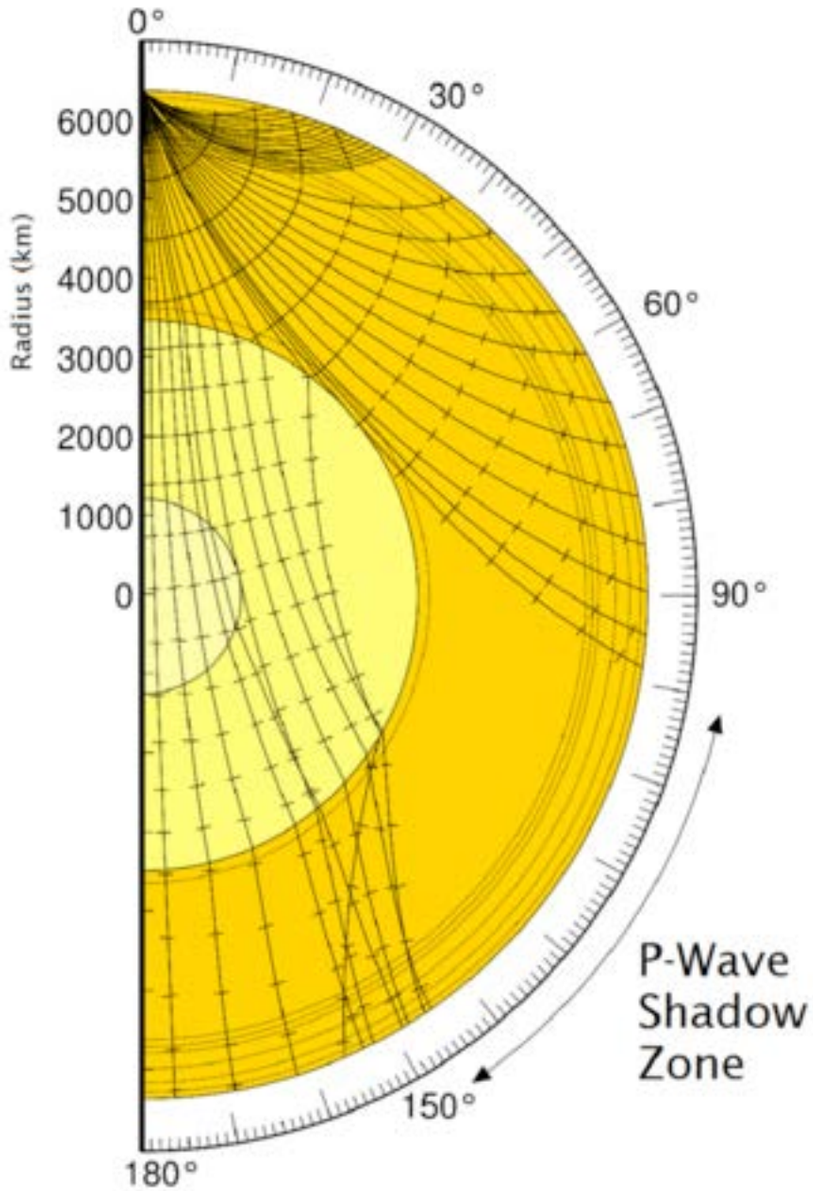


Figure 9.1

How P-waves travel through Earth's interior.

•**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 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.

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

•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 the outer core is liquid.

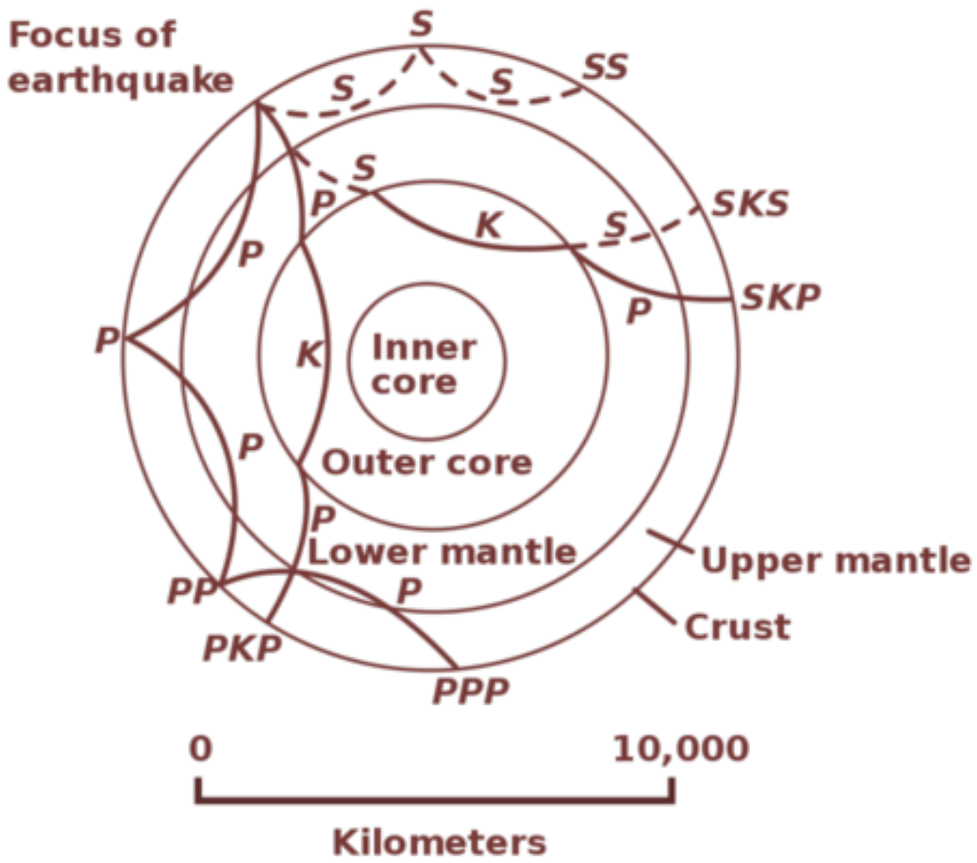


Figure 9.2

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

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

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. We know that the inner core is made of solid Iron and Nickel and the outer core is liquid Iron and Nickel.
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** below).



Figure 9.3

This meteorite contains silica minerals and iron-nickel. The material is like the boundary between Earth's core and mantle. The meteorite is 4.2 billion years old.

The Earth's Layers

The layers scientists recognize are pictured below (**Figure** below).

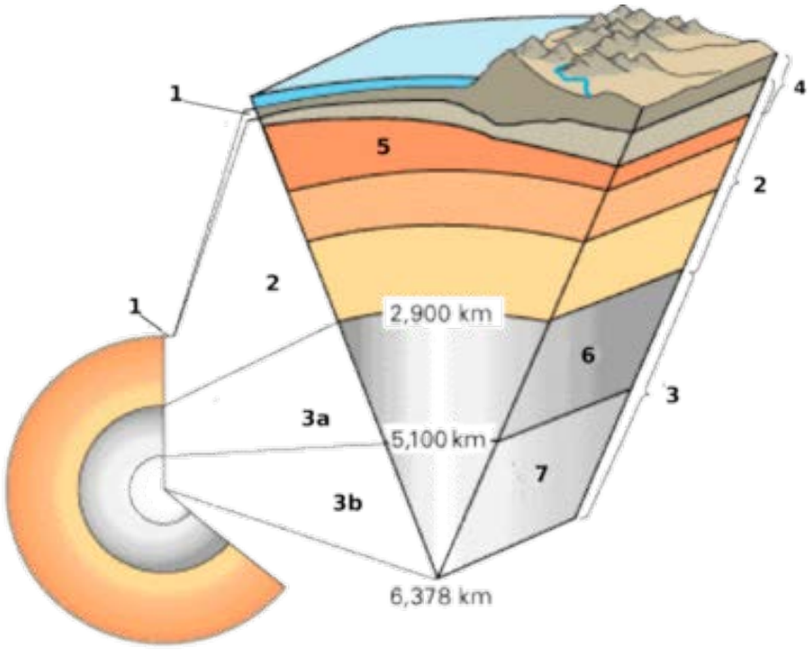


Figure 9.4

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.

Core, mantle, and crust are divisions based on composition:

1. The **crust** is less than 1% of Earth by mass. The **oceanic crust** is mafic, while **continental crust** is often more felsic rock.
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.

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 that behaves as a brittle, rigid solid.
2. The asthenosphere is partially molten upper mantle material that 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 .

Crust and Lithosphere

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. If you consider a hard boiled egg, the shell of the egg would be similar to the crust, the albumin, or egg white, would be the mantle , and the yolk would complete the core. There are two very different types of crust, each with its own distinctive physical and chemical properties, which are summarized in **Table** below .

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 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** below).



Figure 9.5

Gabbro from ocean crust. The gabbro is deformed because of intense faulting at the eruption site.

Sediments, primarily muds and the shells of tiny sea creatures, coat the seafloor. Sediment is thickest near the shore where it comes off the continents in rivers and on wind currents.

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** below). 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.



Figure 9.6

This granite from Missouri is more than 1 billion years old.

The **lithosphere** is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. Look at **Figure** above . Can you find where the crust and the lithosphere are located? How are they 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.

Mantle

The two most important things about the mantle are: (1) it is made of solid rock, and (2) it is hot. 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** below). Peridotite is rarely found at Earth's surface.



Figure 9.7

Peridotite is formed of crystals of olivine (green) and pyroxene (black).

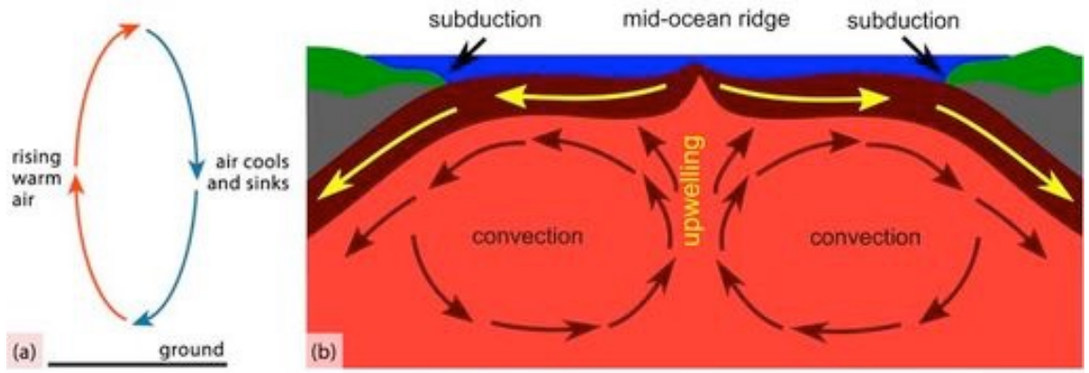
The uppermost mantle is classified as lithosphere based on the rigid composition which is similar to the composition of the overlying crust. Directly below the rigid lithosphere is the asthenosphere, a ductile, or semisolid, layer that allows the overlying lithosphere to "flow" and move about. Consider a pizza pie for a second. The hot cheese is ductile because it is neither liquid or solid and toppings link pepperoni or meatball are solid and float on the cheese. We will see in the flowing sections that Earth's plates are like toppings on the ductile asthenosphere.

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:

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** below).



In a convection cell, warm material rises and cool material sinks. In mantle convection, the heat source is the core.

Diagram of convection within Earth's mantle.

Figure 9.8

Convections

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** below).



Figure 9.9

An iron meteorite is the closest thing to the Earth’s core that we can hold in our hands.

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.

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.

Lesson Summary

•Earth is made of three layers: the crust, mantle, and core.
•The brittle crust and uppermost mantle are together called the lithosphere.
•Beneath the lithosphere, the mantle is solid rock that can flow, or behave plastically.
•The hot core warms the base of the mantle, which causes mantle convection.

Review Questions

1.What are the two main ways that scientists learn about Earth's interior and what do these two things indicate?
2.What is the difference between crust and lithosphere? Include in your answer both where they are located and what their properties are.
3.How do the differences between oceanic and continental crust lead to the presence of ocean basins and continents?
4.What types of rock make up the oceanic crust and how do they form?
5.What types of rock make up the continental crust?
6.How do scientists know about the liquid outer core? How do scientists know that the outer core is liquid?
7.Describe the properties of each of these parts of the Earth’s interior: lithosphere, mantle, and core. What are they made of? How hot are they? What are their physical properties?
8.When you put your hand above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction? Based on your answers, which type of heat transfer moves heat more easily and efficiently?

Points to Consider

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

Continental Drift

Continental Drift

Lesson Objectives

- Explain the continental drift hypothesis.
- Describe the evidence Wegener used to support his continental drift idea.
- Describe later evidence for continental drift.

Vocabulary

- apparent polar wander
- continental drift
- magnetic field
- magnetic polarity
- magnetite
- magnetometer

Introduction

The continental drift hypothesis was developed in the early part of the 20 th century, mostly by Alfred Wegener. Wegener said that continents rafted about on Earth's surface and that they were once joined together as a single supercontinent he called Pangaea. Wegener published *Origins of Continents and Oceans* in 1915 which challenged precedent that oceans and continents were fixed locations. Wegener's hypothesis was immediately rejected by scientists who refused to believe that the continents could move. Sadly Wegener die in 1930 while leading a expedition is Greenland and was never able to find a creditable mechanism for plate motion.



Figure 9.10

The Continental Drift Idea

Find a map of the continents and cut each one out. Better yet, use a map where the edges of the continents show the continental shelf. That's the true size and shape of a continent. Can you fit the pieces together? The easiest link is between the eastern Americas and western Africa and Europe, but the rest can fit together too (**Figure** below).



Figure 9.11

The continents fit together like pieces of a puzzle. This is how they looked 250 million years ago.

Alfred Wegener proposed that the continents were once united into a single supercontinent named Pangaea, meaning *all earth* in ancient Greek. He suggested that Pangaea broke up long ago and that the continents then moved to their current positions. He called his hypothesis **continental drift.**

Evidence for Continental Drift

Besides the way the continents fit together, Wegener and his supporters collected a great deal of evidence for the continental drift hypothesis.

•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** below). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.



Figure 9.12

The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

•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** below). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. He suggested that the organisms would 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.

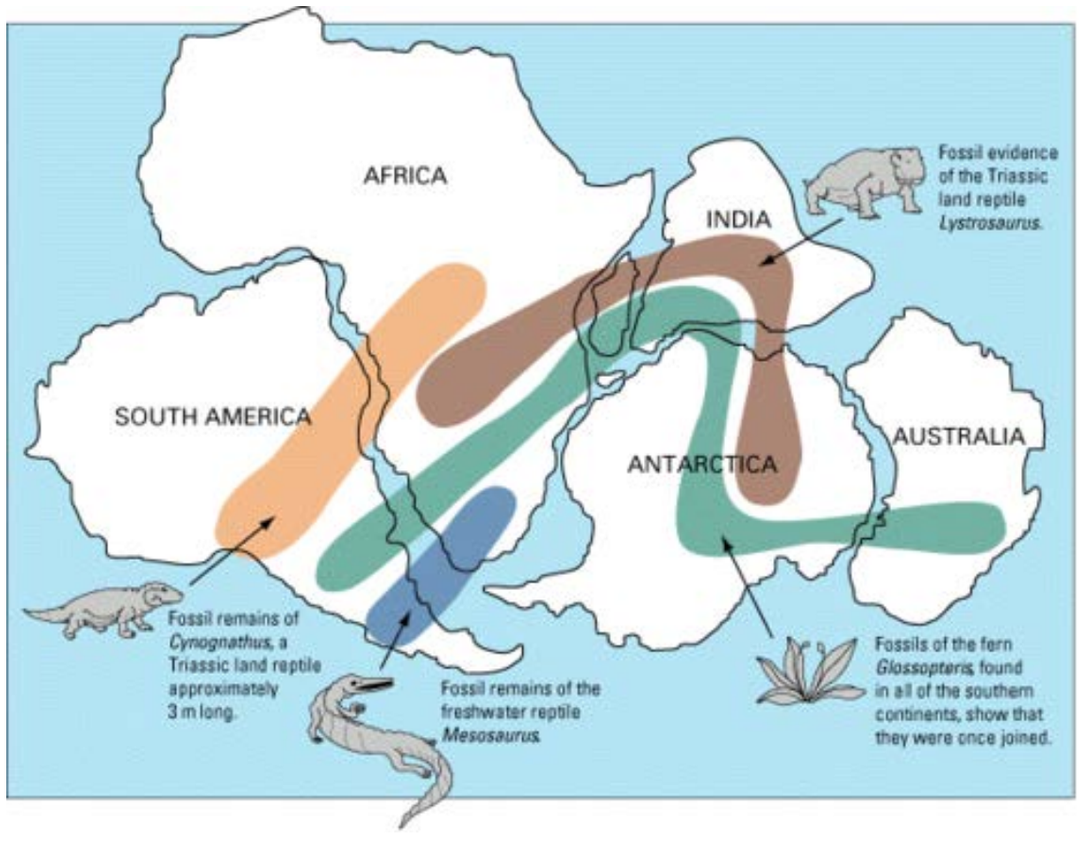


Figure 9.13

Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

•Grooves (striations) in bedrock 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 had 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: Breakup of Pangaea.

An animation showing how the continents split up can be found here: http://www.exploratorium.edu/origins/antarctica/ideas/gondwana2.html .

Although Wegener's evidence was sound, most geologists at the time rejected his hypothesis of continental drift. Why do you think they did not accept continental drift?

Scientists argued that there was no way to explain how solid continents could plow through solid oceanic crust. However, beginning in the 1950s, a wealth of new evidence emerged to revive the debate about Wegener's provocative ideas and their implications. In particular, four major scientific developments spurred the formulation of the plate-tectonics theory: (1) demonstration of the ruggedness and youth of the ocean floor; (2) confirmation of repeated reversals of the Earth magnetic field in the geologic past; (3) emergence of the seafloor-spreading hypothesis and associated recycling of oceanic crust; and (4)

precise documentation that the world's earthquake and volcanic activity is concentrated along oceanic trenches and submarine mountain ranges.

Seafloor Mapping

About two thirds of the Earth's surface lies beneath the oceans. Before the 19th century most people thought that the ocean floor was relatively flat and featureless. However, since the 16th century explorers have found that the open ocean can differ considerably in depth. "Modern" measurements in the 19th century included deep-sea line soundings (*bathymetric* surveys) and later echo-sounding devices which began to measure ocean depth. The result was the discovery of submarine mountain chain in the central Atlantic called the *Mid-Atlantic Ridge*. The data collected during these deep-sea explorations was used by Maria Tharp and Bruce Heezen to create the first seafloor map of the Earth.



Figure 9.14

Map of the Ocean Floor In 1959, Marie Tharp and colleague Bruce Heezen completed their first map of the North Atlantic.

Magnetic Polarity Evidence

Puzzling new evidence came in the 1950s from studies on the Earth's magnetic history (**Figure** below). Scientists used **magnetometers** , devices capable of measuring the magnetic field intensity, to look at the magnetic properties of rocks in many locations.

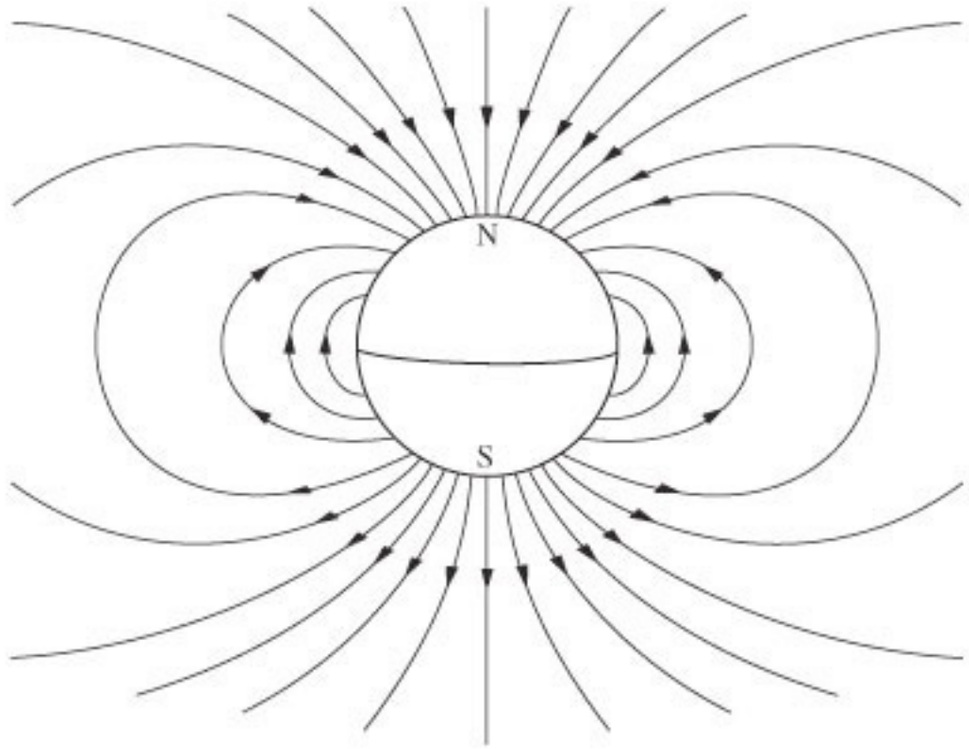


Figure 9.15

Earth’s magnetic field is like a magnet with its north pole near the geographic North Pole and the south pole near the geographic South Pole.

Magnetite crystals are like tiny magnets that point to the north magnetic pole as they crystallize from magma. The crystals record

both the direction and strength of the **magnetic field** at the time. The direction is known as the field's **magnetic polarity.**

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** below) 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 rock that are of different ages do not point to the same locations or to the current magnetic north pole.

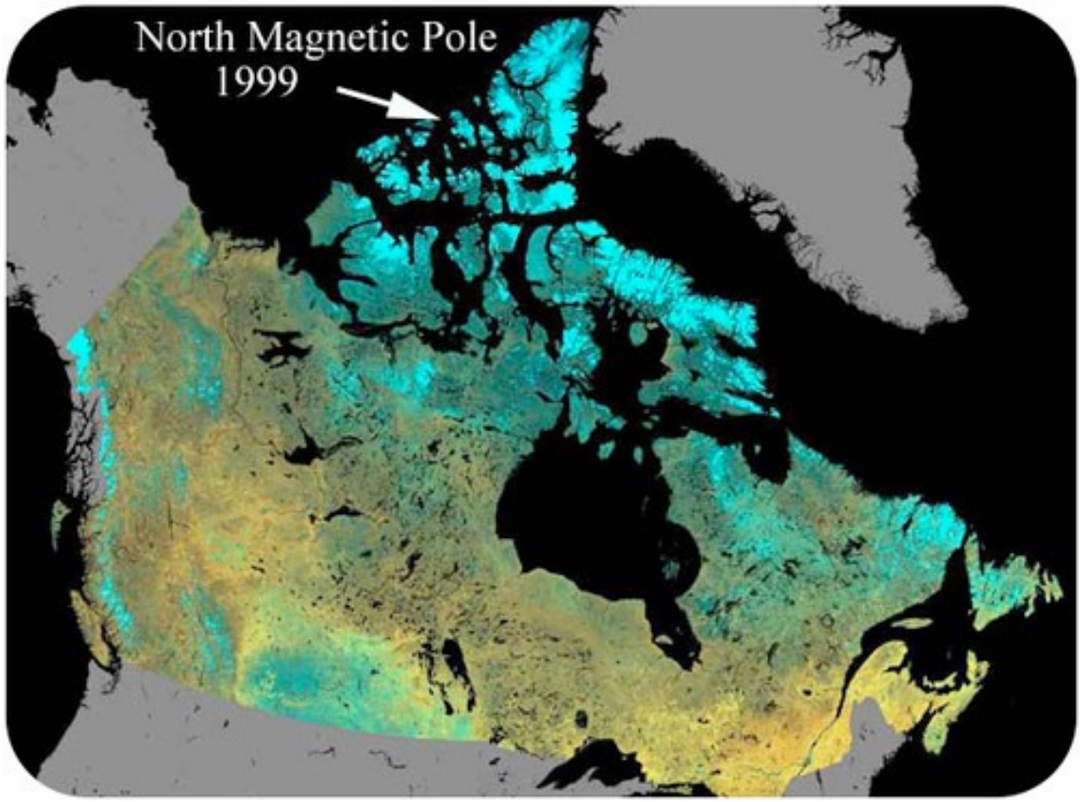


Figure 9.16

Earth's current north magnetic pole is in northern Canada.

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 through time (**Figure** below).

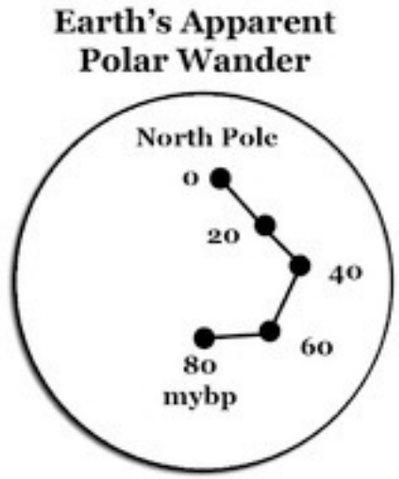


Figure 9.17

The location of the north magnetic north pole 80 million years before present (mybp), then 60, 40, 20, and now.

There are three possible explanations for this:

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

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 the same-aged magnetite in North America.
- 250 million years ago, the north poles were also different for the two continents.

The scientists looked 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, the only reasonable explanation is that the north magnetic pole has remained fixed but that the continents have moved.

To test this, 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** below). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander.**

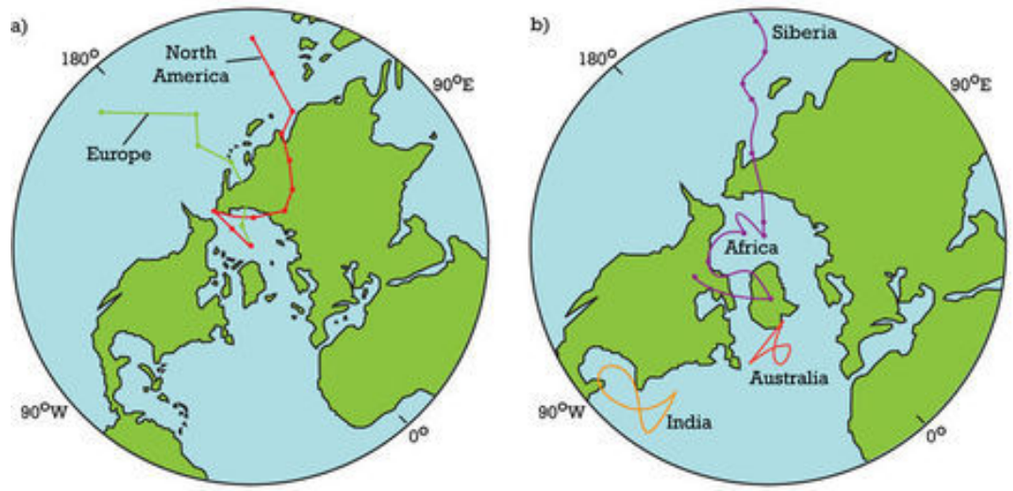


Figure 9.18

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.

Lesson Summary

- In the early part of the 20th century, scientists began to put together evidence that the continents could move around on Earth's surface.
- The evidence for continental drift included the fit of the continents; the distribution of ancient fossils, rocks, and mountain ranges; and the locations of ancient climatic zones.
- Although the evidence for continental drift was extremely strong, scientists rejected the idea because no mechanism

for how solid continents could move around on the solid earth was developed.
•The discovery of apparent polar wander renewed scientists interest in continental drift.

Review Questions

1.Why can paper cutouts of the continents including the continental margins be pieced together to form a single whole?
2.How can the locations where ancient fossils are found be used as evidence for continental drift?
3.To show that mountain ranges on opposite sides of the Atlantic formed as two parts of the same range and were once joined, what would you look for?
4.What are the three possible explanations for apparent polar wander? Considering all the evidence, which explanation is the only one likely to be true and why?
5.With so much evidence to support continental drift, how could scientists reject the idea?
6.Look at a world map. Besides the coast of west Africa and eastern South America, what are some other regions of the world that look as they could be closely fit together?

Points to Consider

•Why is continental drift referred to as a hypothesis (or idea) and not a theory?
•What did Wegener's idea need for it to be accepted?
•What other explanations did scientists come up with to explain the evidence Wegener had for continental drift?

Section 3

Seafloor Spreading

Seafloor Spreading

Lesson Objectives

- Describe the main features of the seafloor.
- Explain what seafloor magnetism tells scientists about the seafloor.
- Describe the process of seafloor spreading.

Vocabulary

- abyssal plains
- echo sounder
- seafloor spreading
- trench

Introduction

World War II gave scientists the tools to find the mechanism for continental drift that had eluded Wegener. Maps and other data gathered during the war allowed scientists to develop the seafloor spreading hypothesis. This hypothesis traces oceanic crust from its origin at a mid-ocean ridge to its destruction at a deep sea trench and is the mechanism for continental drift.

Seafloor Bathymetry

During World War II, battleships and submarines carried **echo sounders** to locate enemy submarines (**Figure** below). 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. During the war, most of the sound waves ricocheted off the ocean bottom.

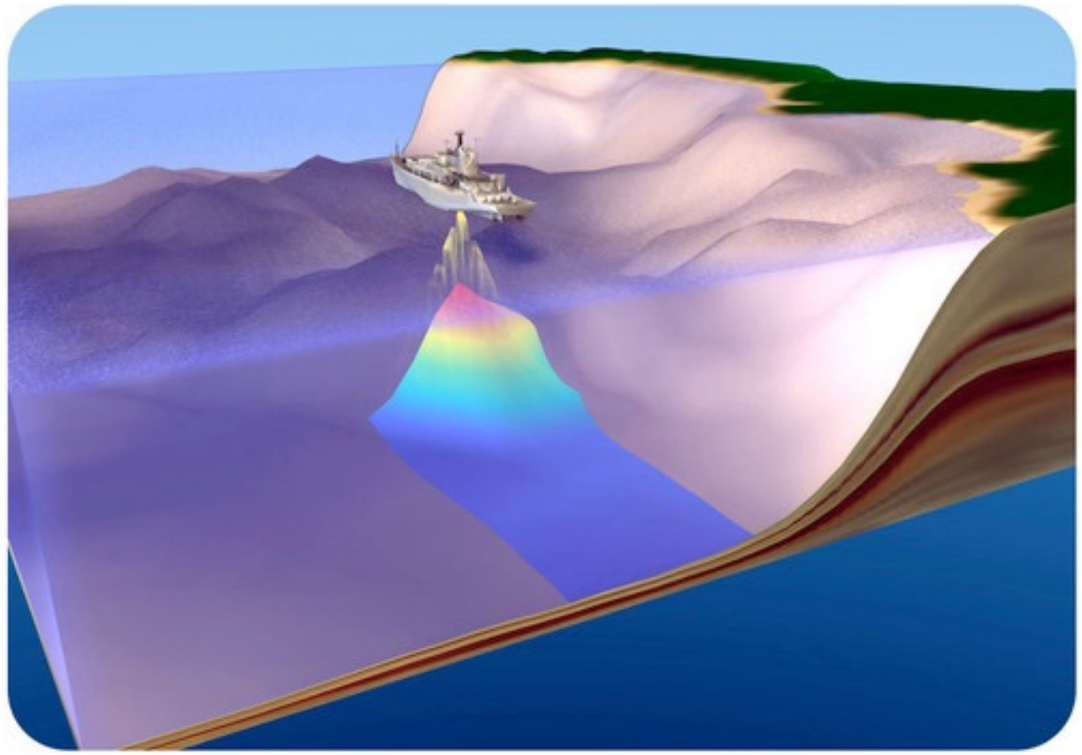


Figure 9.19

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.

This animation shows how sound waves are used to create pictures of the sea floor and ocean crust: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sonar.html .

After the war, scientists pieced together the ocean depths to produce bathymetric maps, which reveal the features of the ocean floor as if the water were taken away. Even scientist were amazed that the seafloor was not completely flat (**Figure** below).

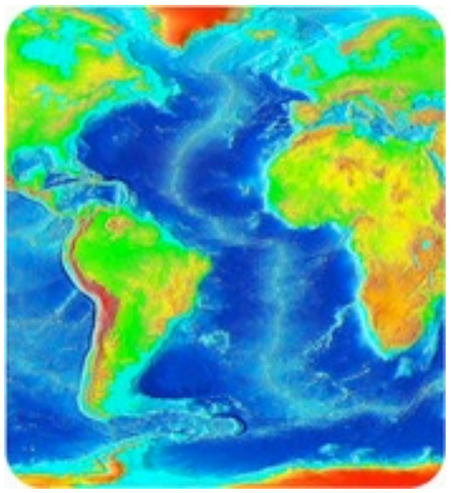


Figure 9.20

A modern map of the southeastern Pacific and Atlantic Oceans.

The major features of the ocean basins and their colors on the map in **Figure** above include:

- mid-ocean ridges: rise up high above the deep seafloor as a long chain of mountains; e.g. the light blue gash in middle of Atlantic Ocean.
- deep sea **trenches:** 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:** flat areas, although many are dotted with volcanic mountains; e.g. consistent blue off of southeastern South America.

When they first observed these bathymetric maps, scientists wondered what had formed these features.

Seafloor Magnetism

Sometimes -- no one really knows why -- the magnetic poles switch positions. North becomes south and south becomes north.

- Normal polarity: north and south poles are aligned as they are now.
- Reversed polarity: north and south poles are in the opposite position.

During WWII, magnetometers attached to ships to search for submarines located an astonishing feature: 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** below).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** below).

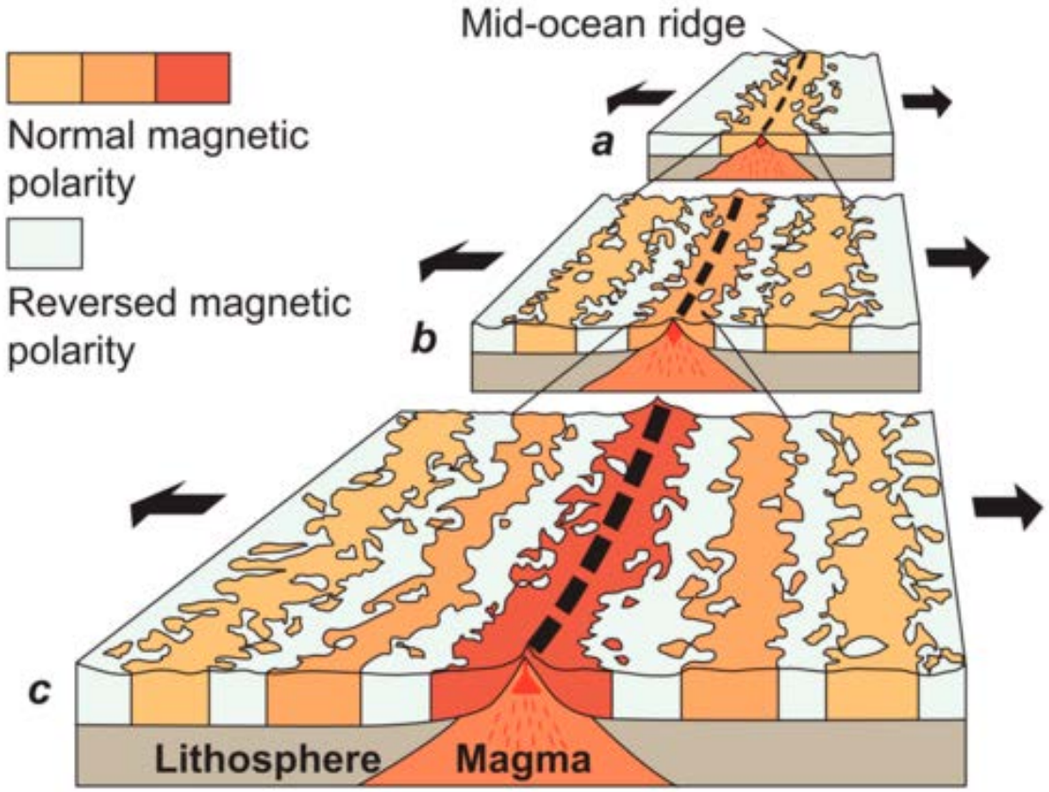


Figure 9.21

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.

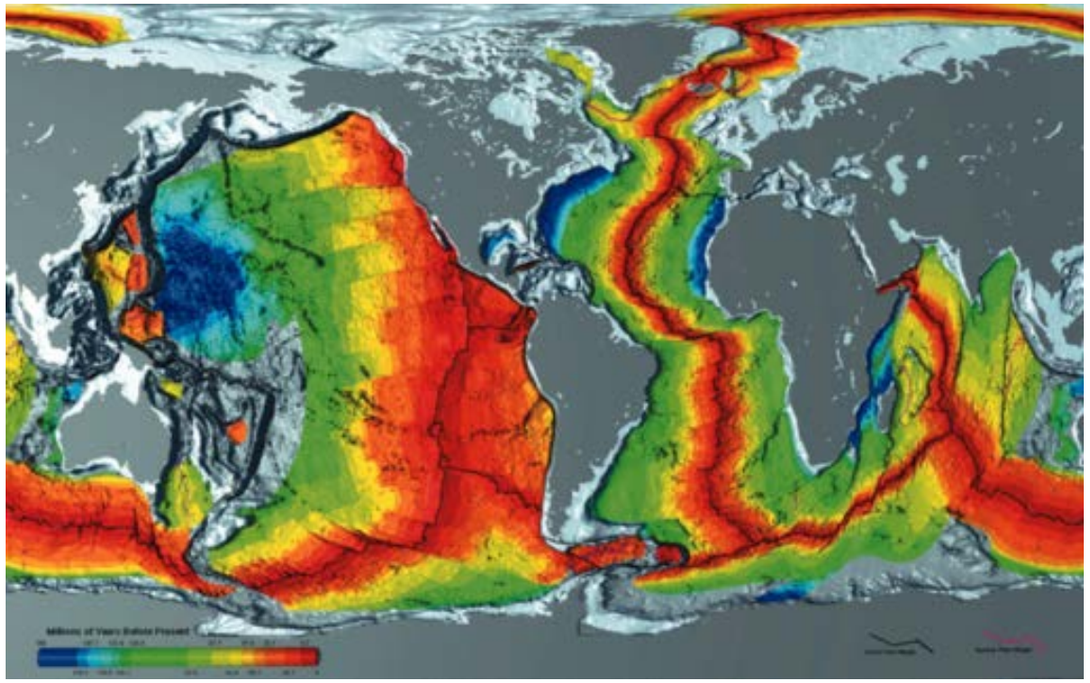


Figure 9.22

Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

The characteristics of the rocks and sediments change with distance from the ridge axis as seen in the **Table** below .

	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

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** above). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that seafloor was being destroyed in a relatively short 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 .

The Seafloor Spreading Hypothesis

Scientists brought these observations together in the early 1960s to create the **seafloor spreading** hypothesis. In this hypothesis, hot buoyant mantle rises up a mid-ocean ridge, causing the ridge to rise upward (**Figure** below).

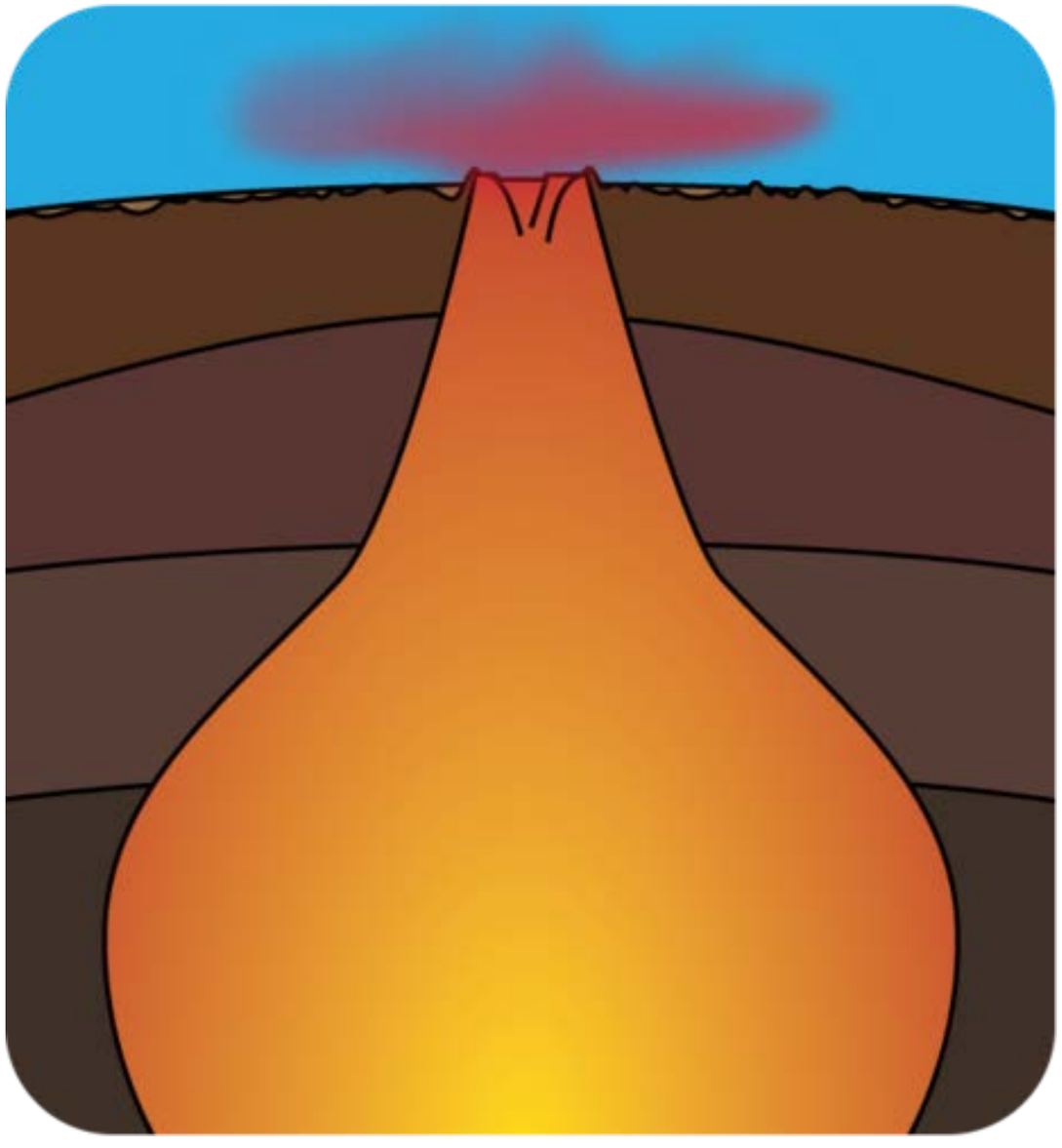


Figure 9.23

Magma at the mid-ocean ridge creates new seafloor.

The hot magma at the ridge erupts as lava that forms new seafloor. When the lava cools, the magnetite crystals take on the current magnetic polarity. As more lava erupts, it pushes the seafloor horizontally away from ridge axis.

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 ; http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A55.gif .

The magnetic stripes continue across the seafloor.

- 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.

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.

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&feature=rec-LGOUT-exp_fresh+div-1r-2 (8:05).



Click on the image above for more content

Lesson Summary

- Using technologies developed to fight World War II, scientists were able to gather data that allowed them to recognize seafloor spreading as the mechanism for Wegener's drifting continents.
- Bathymetric maps revealed high mountain ranges and deep trenches in the seafloor.
- Magnetic polarity stripes give clues to seafloor ages and the importance of mid-ocean ridges in the creation of oceanic crust.

•Seafloor spreading processes create new oceanic crust at mid-ocean ridges and destroy older crust at deep sea trenches.

Review Questions

1.Describe how sound waves are used to develop a map of the features of the seafloor.
2.Why is the oldest seafloor less than 180 million years when the oldest continental crust is about 4 billion years old?
3.Describe the major features and the relative ages of mid-ocean ridges, deep sea trenches, and abyssal plains.
4.Describe how continents move across the ocean basins as if they are on a conveyor belt.
5.If you were a paleontologist who studies fossils of very ancient life forms, where would be the best place to look for very old fossils: on land or in the oceans?
6.Imagine that Earth's magnetic field was fixed in place and the polarity didn't reverse. What effect would this have on our observations of seafloor basalts?
7.Look at a map of the Atlantic seafloor with magnetic polarity stripes and recreate the history of the Atlantic Ocean basin.

Further Reading / Supplemental Links

•A basic description of sea floor spreading with animations: http://www.pbs.org/wnet/savageearth/hellscrust/index.html .

Points to Consider

•How were the technologies that were developed to fight World War II used by scientists for the development of the seafloor spreading hypothesis?
•In what two ways did magnetic data lead scientists to understand more about continental drift and plate tectonics?
•How does seafloor spreading provide a mechanism for continental drift?
•Look at the features of the North Pacific Ocean basin and explain them in seafloor spreading terms.
•What would have to happen if oceanic crust was not destroyed at oceanic trenches, but new crust was still created at mid-ocean ridges?

Section 4

Theory of Plate Tectonics

Theory of Plate Tectonics

Lesson Objectives

- Describe what a plate is and how scientists can recognize its edges.
- Explain how mantle convection moves lithospheric plates.
- List the three types of boundaries. Are they prone to earthquakes or volcanoes?
- Describe how plate tectonics processes lead to changes in Earth's surface features.

Vocabulary

- batholith
- continental volcanic arc
- continental rifting
- convergent plate boundary
- divergent plate boundary
- epicenter
- hotspot
- intraplate activity
- lithospheric plate
- mantle plume
- plate boundary
- plate tectonics
- subduction
- subduction zone
- supercontinent cycle
- transform fault
- transform plate boundary
- volcanic island arc

Introduction

When the concept of seafloor spreading came along, scientists recognized that it was the mechanism to explain how continents could move around Earth's surface. Like the scientists before us, we will now merge the ideas of continental drift and seafloor spreading into the theory of plate tectonics.

Continental drift and the mechanism of seafloor spreading create plate tectonics: continental drift to plate tectonics

Earth's Tectonic Plates

Seafloor and continents move around on Earth's surface, but what is actually moving? What portion of the Earth makes up the "plates" in plate tectonics? This question was also answered because of technology developed during war times - in this case, the Cold War. The **plates** are made up of the lithosphere.

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 could be used to locate an earthquake's **epicenter** , the point on Earth's surface directly above the place where the earthquake occurs.

Earthquake epicenters outline the plates. Mid-ocean ridges, trenches, and large faults mark the edges of the plates, and this is where earthquakes occur (**Figure** below).

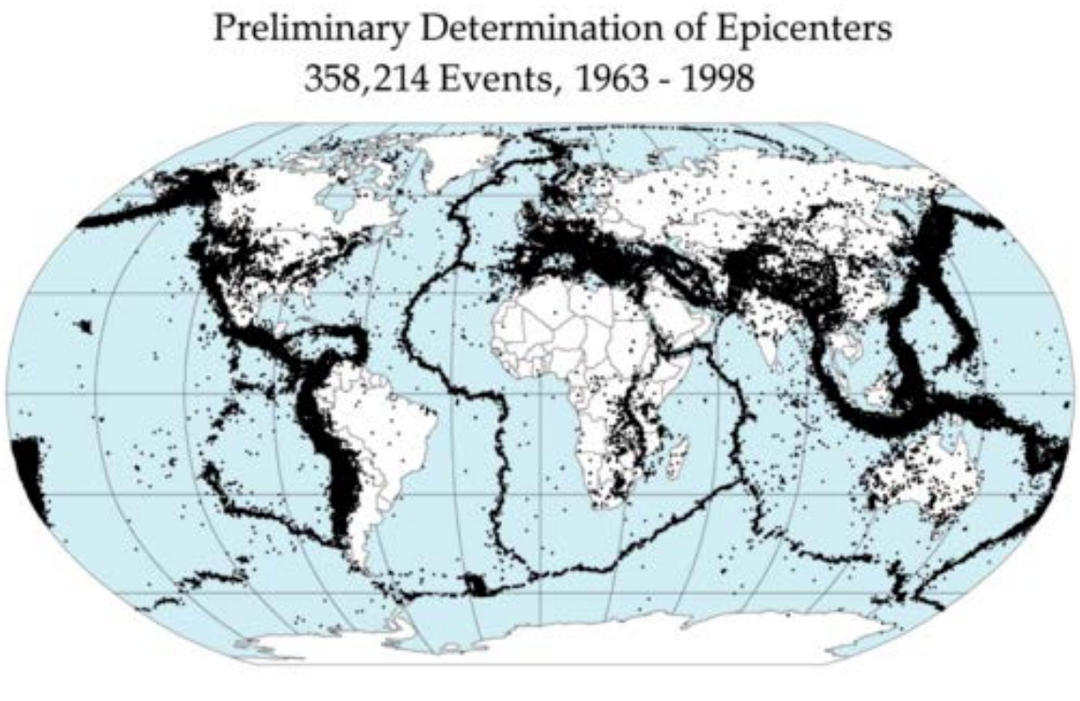


Figure 9.24

Earthquakes outline the plates.

The lithosphere is divided into a dozen major and several minor plates (**Figure** below). The plates' edges can be drawn by connecting the dots that mark earthquakes' epicenters. 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.

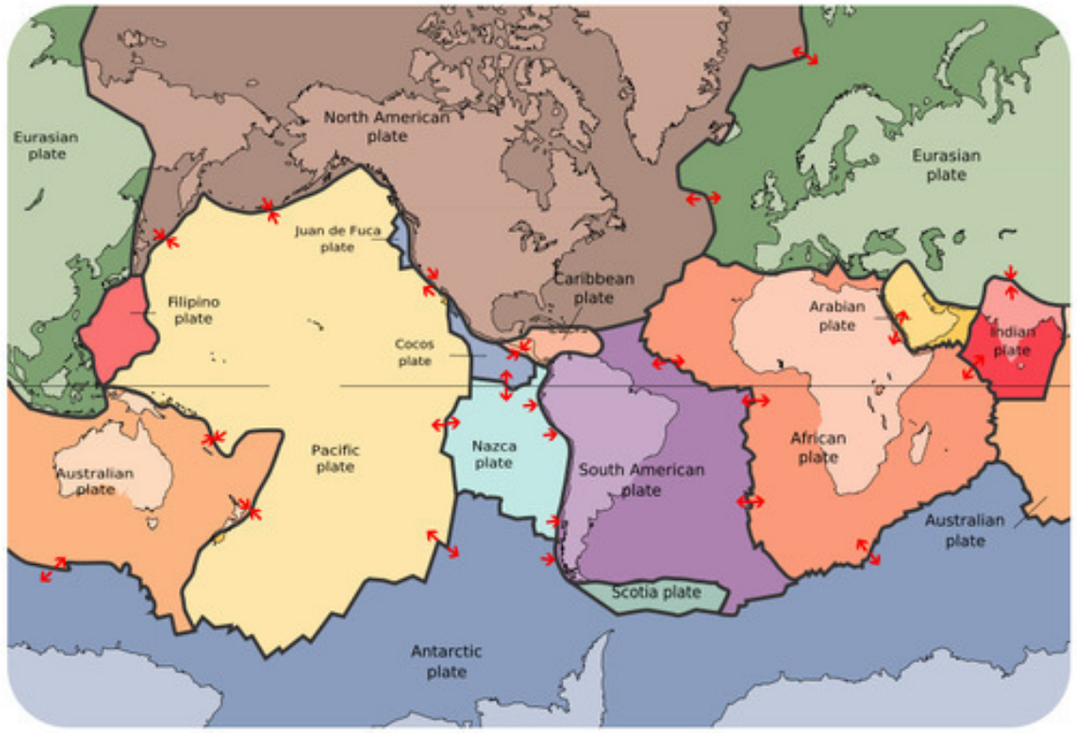


Figure 9.25

The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

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.

Three mechanisms for plate movement

Slab Pull

This force occurs as a subducting plate sinks into the hot mantle beneath it. The subducting plate, usually basalt, is denser than the

material it is subducting into, purely due to its difference in temperature. As the plate sinks into the mantle, it acts to pull the rest of the plate behind it. This force is considered by some to be the primary force driving plate motion at collisional zones.

Ridge Push

Ridge push is considered to be of significance, especially where there is little or no slab pull acting on the plate. The name given to this force is actually quite deceiving and has led to a misunderstanding of this process. When new sea floor is created, it is hot and relatively thin, as well as being much higher in elevation than the abyssal plains and trenches. As the rock moves away from the spreading centre, the rocks continue to cool. Additional material is pasted onto the base of the crust from the mantle below. This means that as a plate moves away from the spreading zone it gets denser, heavier and thicker.

Mantle Convection

Mantle convection is considered a small contributor behind plate motion. Throughout the mantle there are convection currents circulating, caused by the difference in temperature at the earth's interior and surface. Hot material from the earth's outer core rises very slowly (over millions of years) throughout the mantle. This hot material eventually cools enough to sink back down towards the core. It has been proposed that these convection currents act as a sort of converyor belt, carrying the lithospheric plates along above it.

See all three mechanisms in the picture below of two convection cells side-by-side in the mantle. **Figure** below .

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.

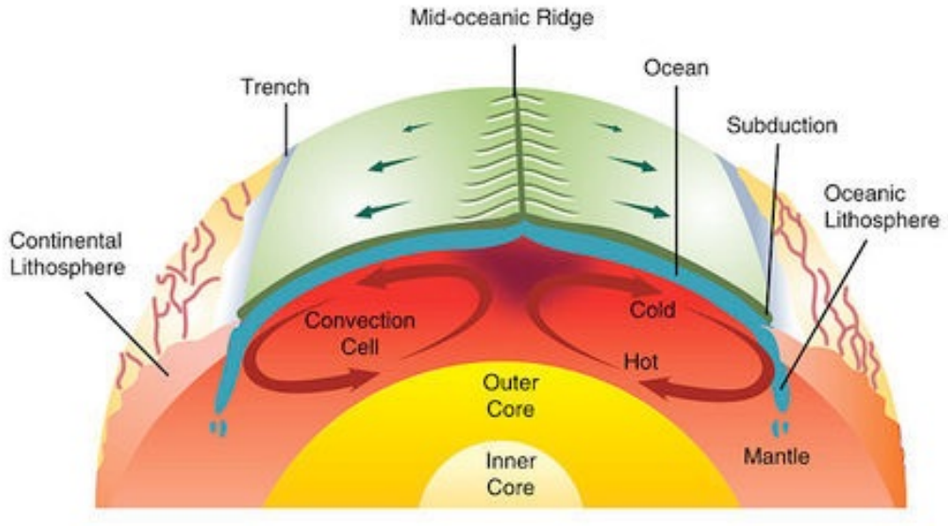


Figure 9.26

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. Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. How can two plates move relative to each other?

- **Divergent plate boundaries** : two plates move away from each other. ← ι →
- **Convergent plate boundaries** : two plates move towards each other. → ι ←
- **Transform plate boundaries** : two plates slip past each other. ↑ l ↓

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.

Divergent Plate Boundaries

Plates move apart at mid-ocean ridges where new seafloor forms. Between the two plates is a rift valley. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. So the entire ridge system is made up of igneous rock that is either extrusive or intrusive. Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking. The vast majority of mid-ocean ridges are located deep below the sea (**Figure** below).

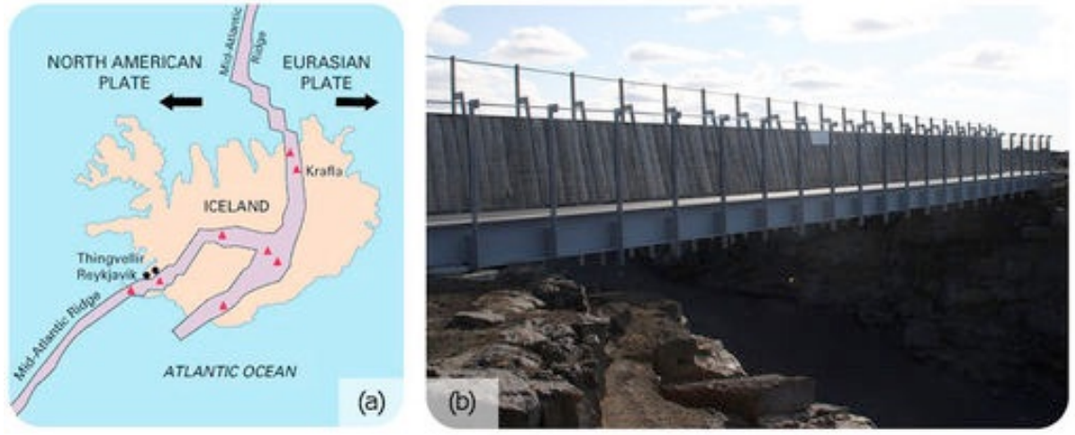


Figure 9.27

(a) Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates; (b) The rift valley in the Mid-Atlantic Ridge on Iceland.

USGS animation of divergent plate boundary at mid-ocean ridge: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&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 .

Can divergent plate boundaries occur within a continent? What is the result? In **continental rifting** (**Figure** below), magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, creating an ocean between continents.



Figure 9.28

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

Convergent Plate Boundaries

When two plates converge, the result depends on the type of lithosphere the plates are made of. No matter what, smashing two enormous slabs of lithosphere together results in magma generation and earthquakes.

Ocean-continent : 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 (**Figure** below). 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** below). The volcanoes are known as a **continental arc** .

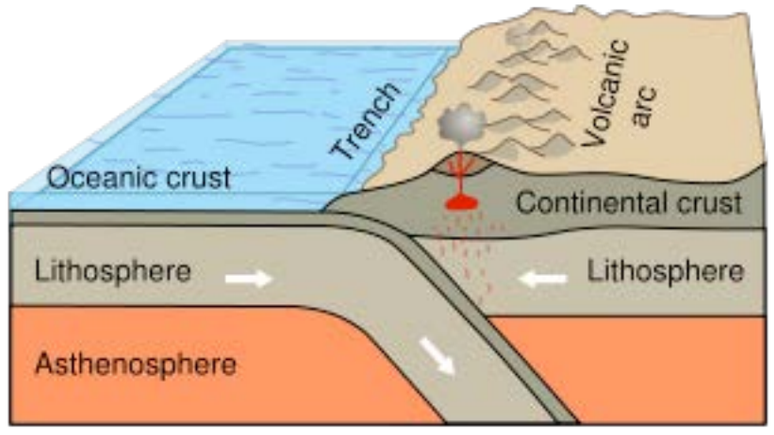


Figure 9.29

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://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html .

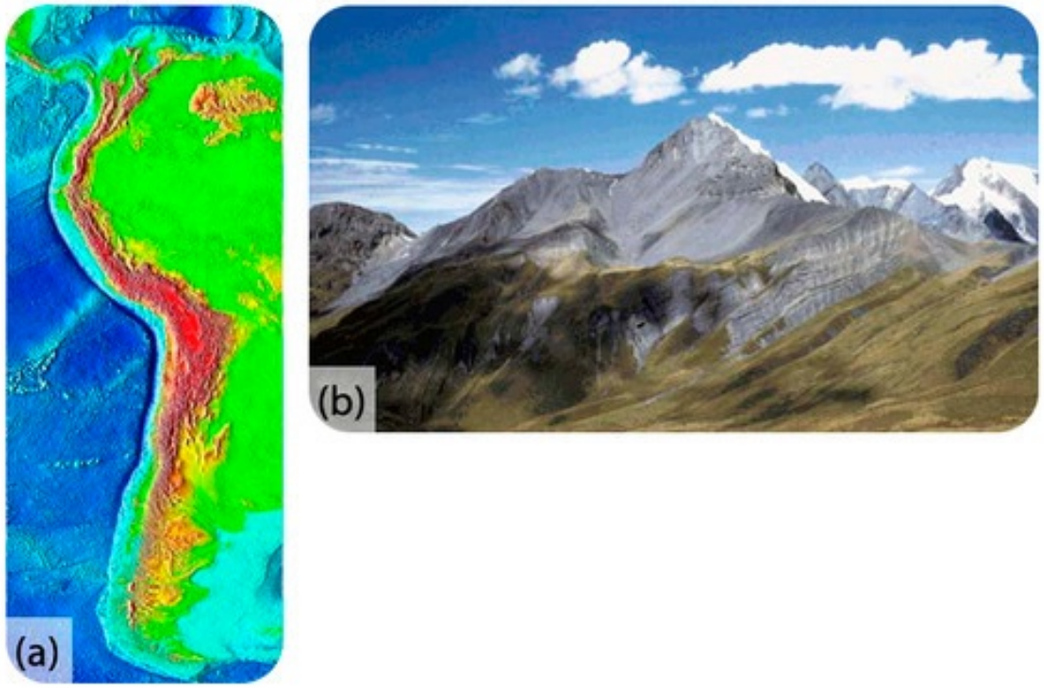


Figure 9.30

(a) At the trench lining the western margin of South America, the Nazca plate is subducting beneath the South American plate, resulting in the Andes Mountains (brown and red uplands); (b) Convergence has pushed up limestone in the Andes Mountains where volcanoes are common.

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** below). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

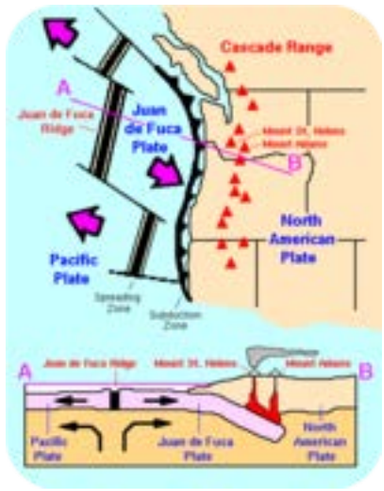


Figure 9.31

The Cascade Mountains of the Pacific Northwest are a continental arc.

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 (**Figure** below).



Figure 9.32

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.

Ocean-ocean : When two oceanic plates converge, the older, denser plate will subduct into the mantle. An ocean trench marks the location where the plate is pushed down into the mantle. 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** below)?

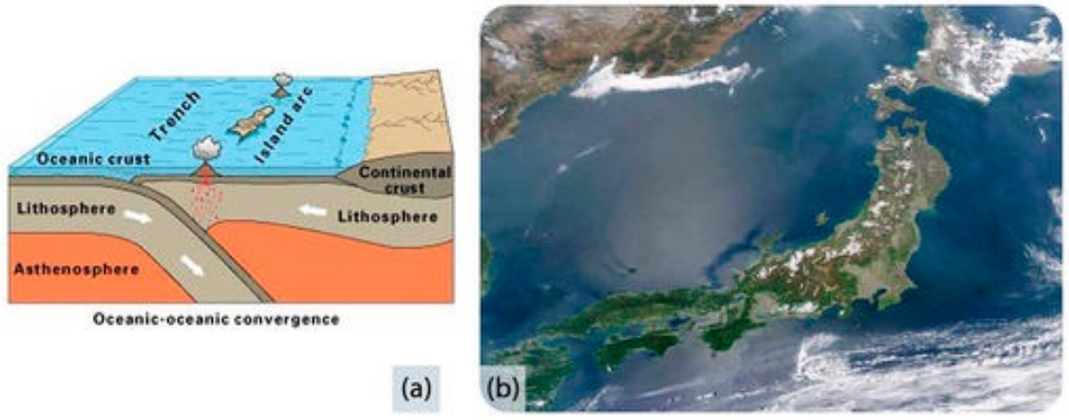


Figure 9.33

(a) Subduction of an ocean plate beneath an ocean plate results in a volcanic island arc, an ocean trench and many earthquakes. (b) Japan is an arc-shaped island arc composed of volcanoes off the Asian mainland, as seen in this satellite image.

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 .

Continent-continent : Continental plates are too buoyant to subduct. What happens to continental material when it collides? Since it has nowhere to go but up, this creates some of the world's largest mountains ranges (**Figure** below). 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.

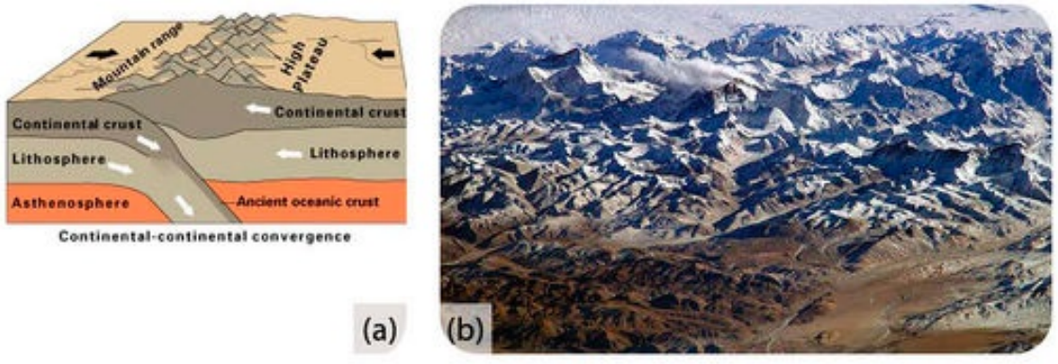


Figure 9.34

(a) In continent-continent convergence, the plates push upward to create a high mountain range. (b) The world's highest mountains, the Himalayas, are the result of the collision of the Indian Plate with the Eurasian Plate, seen in this photo from the International Space Station.

A short animation of the Indian Plate colliding with the Eurasian Plate: http://www.scotese.com/indianim.htm .

An animation of the Himalaya rising: http://www.youtube.com/watch?v=ep2_axAA9Mw&NR=1 .

The Appalachian Mountains are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago.

Transform Plate Boundaries

Transform plate boundaries are seen as **transform faults** , where two plates move past each other in opposite directions. Transform faults on continents bring massive earthquakes (**Figure** below).

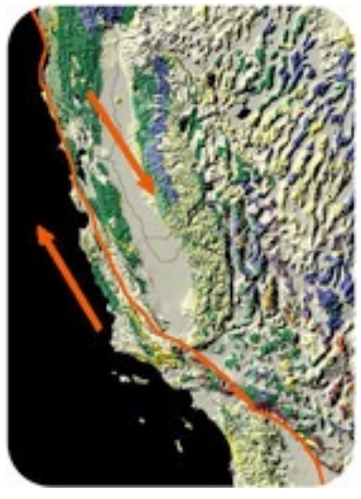


Figure 9.35

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.

California is very geologically active. What are the three major plate boundaries in or near California (**Figure** below)?

1. A transform plate boundary between the Pacific and North American plates creates the San Andreas Fault, the world's most notorious transform fault.
2. Just offshore, a divergent plate boundary, Juan de Fuca ridge, creates the Juan de Fuca plate.
3. A convergent plate boundary between the Juan de Fuca oceanic plate and the North American continental plate creates the Cascades volcanoes.

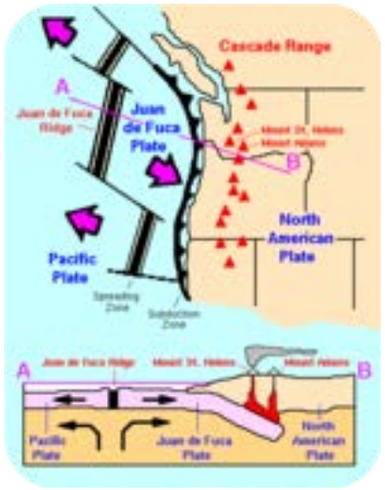
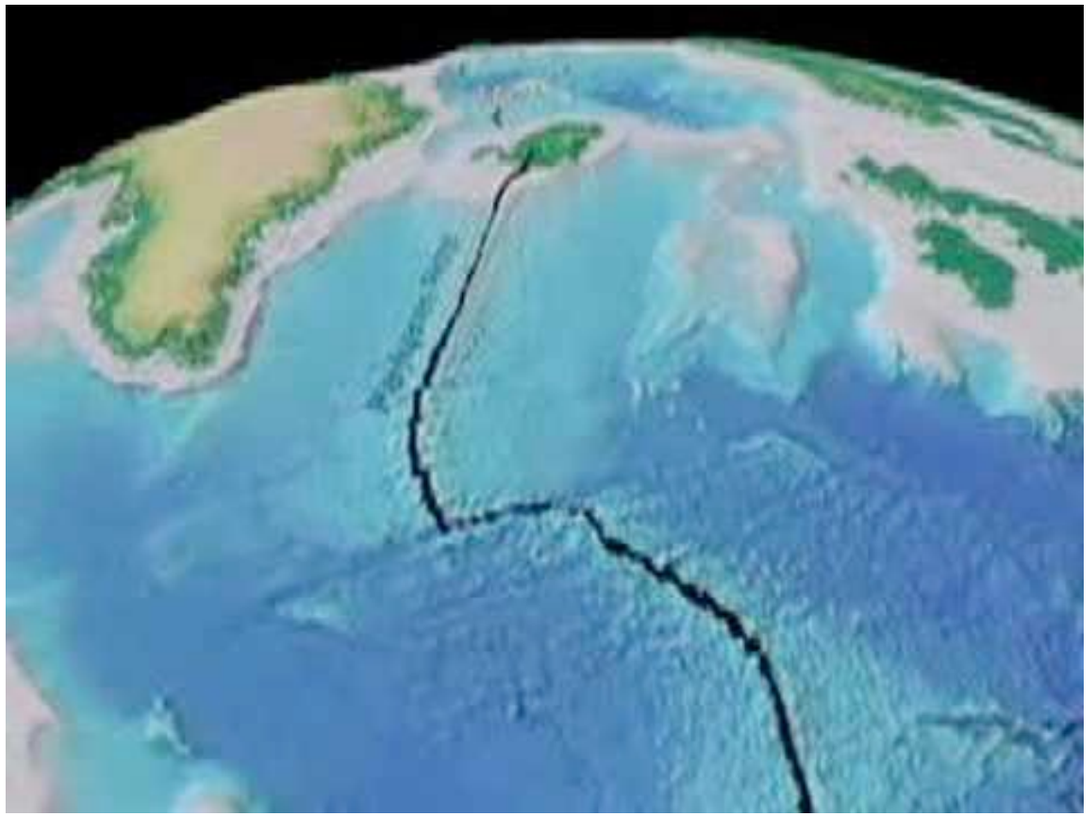


Figure 9.36

This map shows the three major plate boundaries in or near California.

A brief review of the three types of plate boundaries and the structures that are found there is the subject of this wordless video **(3b)** : http://www.youtube.com/watch?v=ifke1GsjNN0 (4:50).



Click on the image above for more content

Earth's Changing Surface

Geologists know that Wegener was right because the movements of continents explain so much about the geology we see. Most of the geologic activity that we see on the planet today is because of the interactions of the moving plates.

In the map of North America (**Figure** below), where are the mountain ranges located? Using what you have learned about plate tectonics, try to answer the following questions:



Figure 9.37

Mountain ranges of North America.

1.What is the geologic origin of the Cascades Range? The Cascades are a chain of volcanoes in the Pacific Northwest. They are not labelled on the diagram but they lie between the Sierra Nevada and the Coastal Range.
2.What is the geologic origin of the Sierra Nevada? (Hint: These mountains are made of granitic intrusions.)
3.What is the geologic origin of the Appalachian Mountains along the Eastern US?

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. The Appalachian mountains formed at a convergent plate boundary as Pangaea came together (**Figure** below).



Figure 9.38

About 200 million years ago, the Appalachian Mountains of eastern North America were probably once as high as the Himalaya, but they have been weathered and eroded significantly since the breakup of Pangaea.

Before Pangaea came together, the continents were separated by an ocean where the Atlantic is now. The proto-Atlantic ocean shrank as the Pacific ocean grew. Currently, the Pacific is shrinking as the Atlantic is growing. This **supercontinent cycle** is responsible for most of the geologic features that we see and many more that are long gone (**Figure** below).

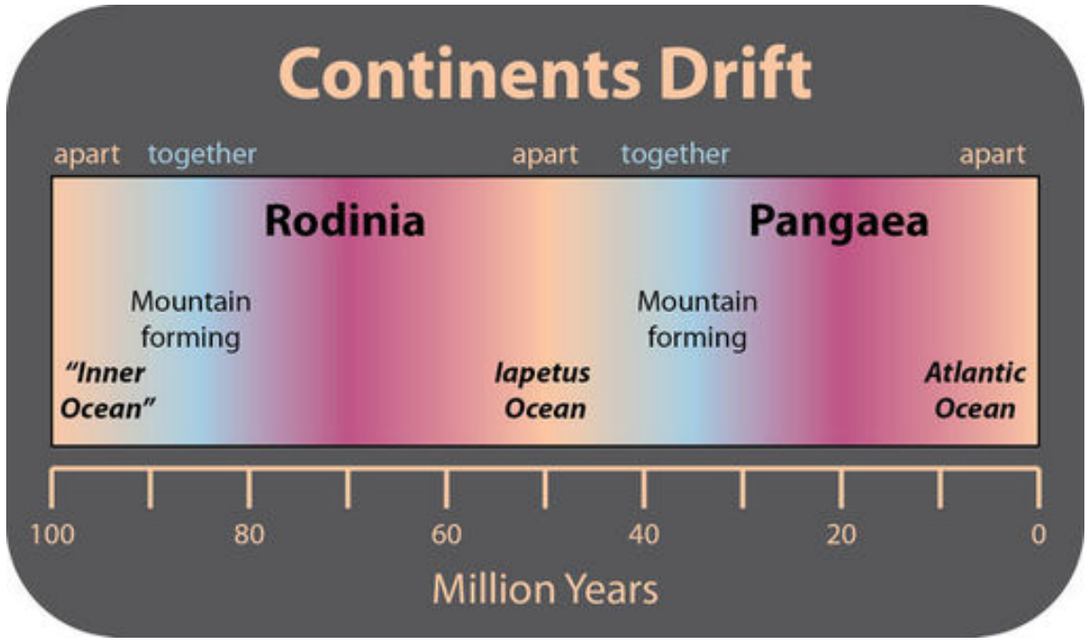


Figure 9.39

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.

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 .

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** below). 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 .

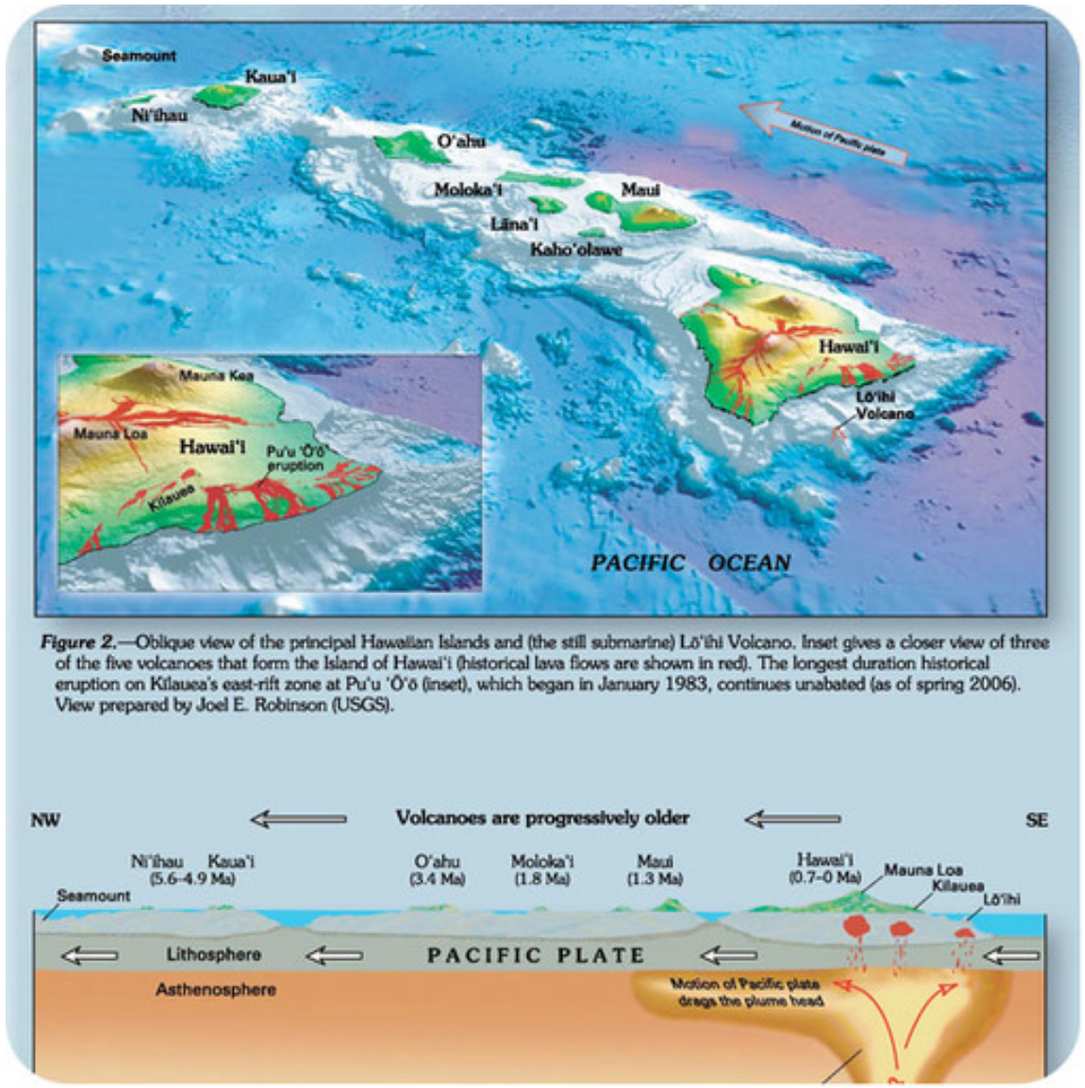


Figure 9.40

The Hawaiian Islands are a beautiful example of a hotspot chain. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a lower rate. The islands get progressively older to the northwest because they are further from the hotspot. Loihi, the youngest volcano, is still below the sea surface.

Geologists use some hotspot chains to tell the direction and the speed a plate is moving (**Figure** below).

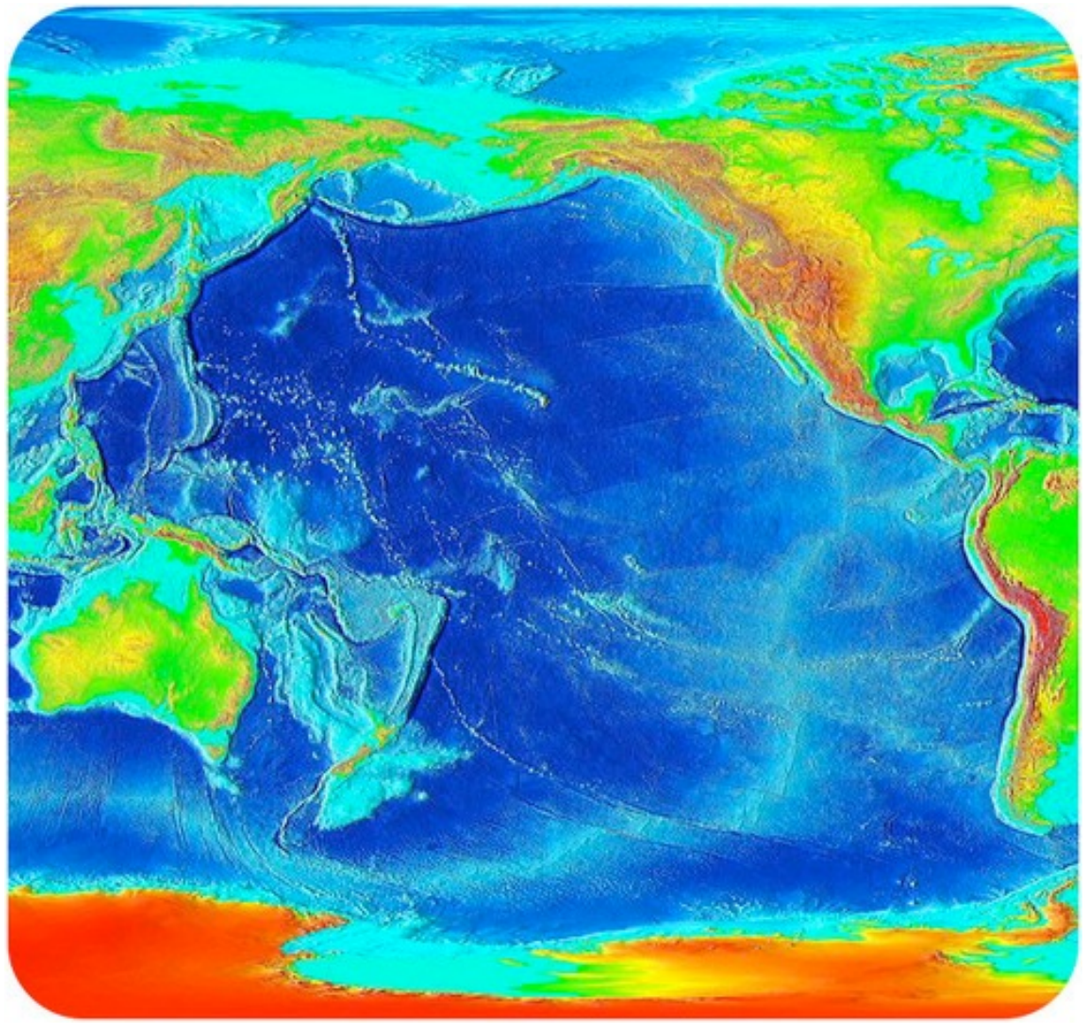


Figure 9.41

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.

Hotspot magmas rarely penetrate through thick continental crust. One exception is the Yellowstone hotspot (**Figure** below).

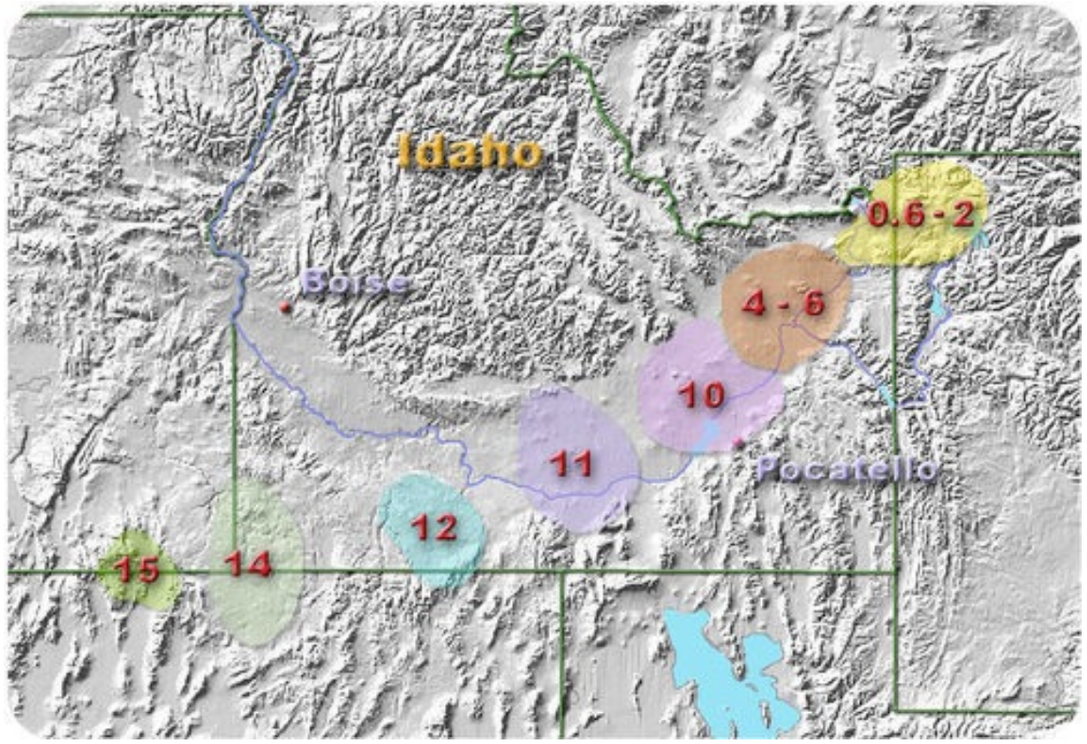


Figure 9.42

Volcanic activity above the Yellowstone hotspot on the North American Plate can be traced from 15 million years ago to its present location.

Plate Tectonics Theory

Plate tectonics is the unifying theory of geology. Plate tectonics theory explains why:

- •Earth's geography has changed through 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.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Lesson Summary

- •Plates of lithosphere move because of convection currents in the mantle. One type of motion is produced by seafloor spreading.
- •Plate boundaries can be located by outlining earthquake epicenters.
- •Plates interact at three types of plate boundaries: divergent, convergent and transform.
- •Most of the Earth's geologic activity takes place at plate boundaries.
- •At a divergent boundary, volcanic activity produces a mid ocean ridge and small earthquakes.
- •At a convergent boundary with at least one oceanic plate, an ocean trench, a chain of volcanoes develops and many earthquakes occur.
- •At a convergent boundary where both plates are continental, mountain ranges grow and earthquakes are common.
- •At a transform boundary, there is a transform fault and massive earthquakes occur but there are no volcanoes.
- •Processes acting over long periods of time create Earth's geographic features.

Review Questions

Use this diagram to review this chapter (**Figure** below).

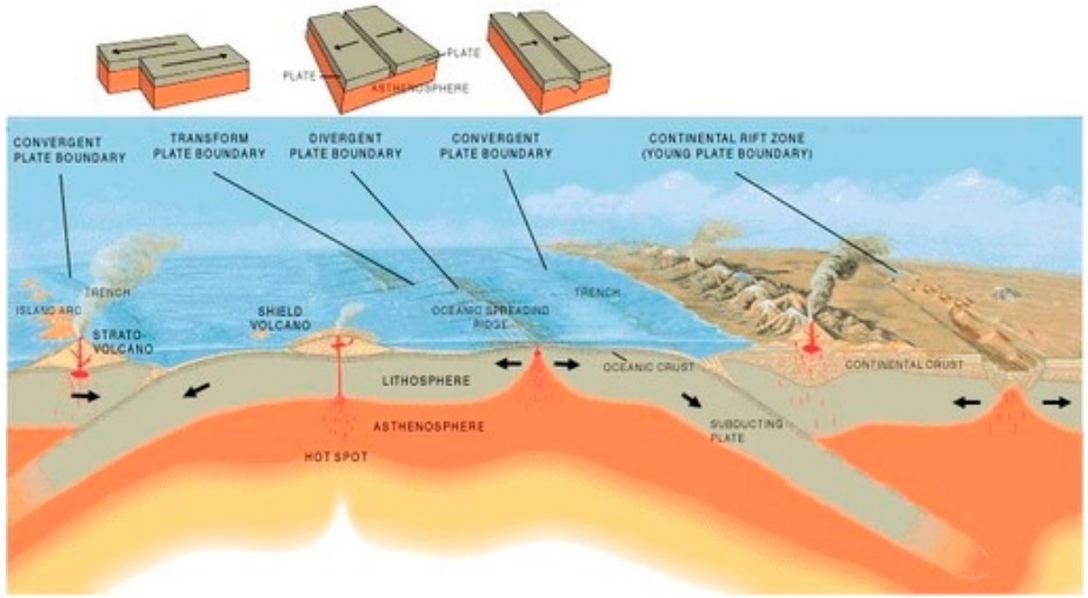


Figure 9.43

Plate boundaries

1.What are the three types of plate boundaries and what type of geologic activity is found at each?
2.As a geologist, you come across a landscape with a massive fault zone that produces a lot of large earthquakes but has no volcanoes. What type of plate boundary is this? What are the movements of plates there? Where is this type of boundary found in California?
3.Next you find a chain of volcanoes along a coast on land, not too far inland from the ocean. The region experiences

frequent large earthquakes. What type of plate boundary is this? What types of plates are involved? Where is this type of boundary found in California?
4.What is the driving force behind the movement of lithospheric plates on the Earth's surface? About how fast do the plates move?
5.How does the theory of plate tectonics explain the locations of volcanoes, earthquakes, and mountain belts on Earth?
6.What causes earthquakes and at what types of plate boundaries are earthquakes common? Explain.
7.Thinking about the different types of plate boundaries, where do mountain ranges that do not include volcanoes occur and why?
8.Why are there no volcanoes along transform plate boundaries? At continent-continent convergent plate boundaries?

Points to Consider

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

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Ch. 10: Stress in Earth's Crust

Section 1

Stress in the Earth's Crust

Stress in Earth’s Crust

Lesson Objectives

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

Vocabulary

- anticline
- basin
- compression
- confining stress
- deformation
- dip
- dip-slip fault
- dome
- elastic deformation
- fault
- fold
- fracture
- joint
- monocline
- normal fault
- plastic deformation
- reverse fault
- shear
- slip
- strain
- stress
- strike-slip fault
- syncline
- tension
- thrust fault
- uplift

Introduction

Enormous slabs of lithosphere move unevenly over the planet’s spherical surface, resulting in earthquakes. In this section we will discuss two types of geological activity that occur because of plate tectonics: mountain building and earthquakes. First, we will consider what can happen to rocks when they are exposed to various types of stress.

Causes and Types of Stress

Stress is defined as the force applied to an object. More specifically, in geology, stress is the force per unit area that is placed on a rock. There are four types of stress that act upon rocks.

•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** below). Compression is the most common stress at convergent plate boundaries.



Figure 10.1

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** below). Shear stress is the most common stress at transform plate boundaries.

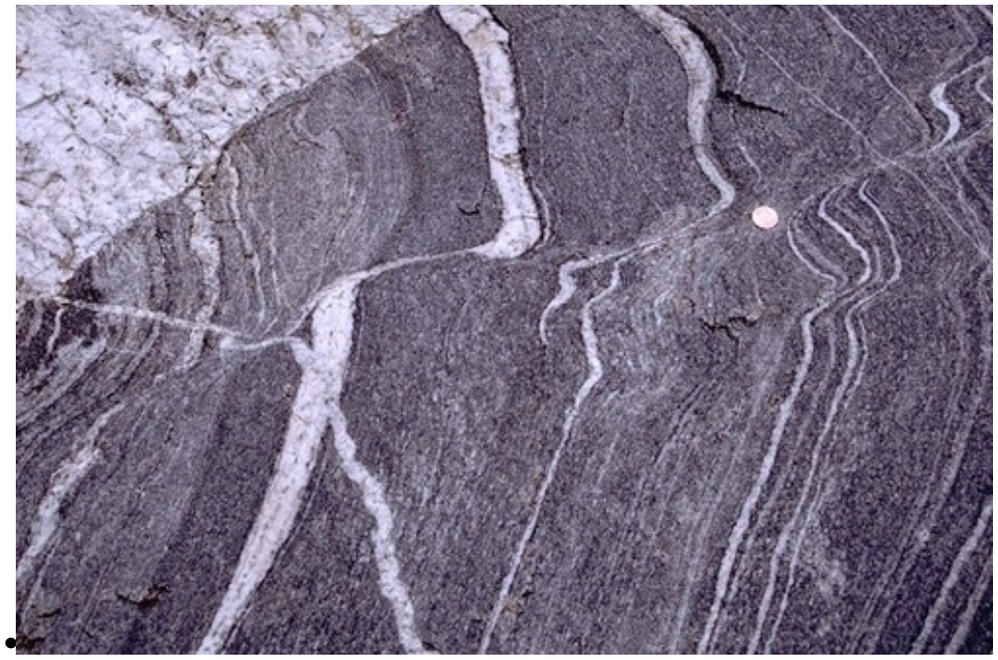


Figure 10.2

Shearing in rocks. The white quartz vein has been elongated by shear.

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, and pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

Rocks have three possible responses to increasing stress (illustrated in **Figure** below):

1.**elastic deformation** : the rock returns to its original shape when the stress is removed.
2.**plastic deformation** : the rock does not return to its original shape when the stress is removed.
3.**fracture** : the rock breaks.

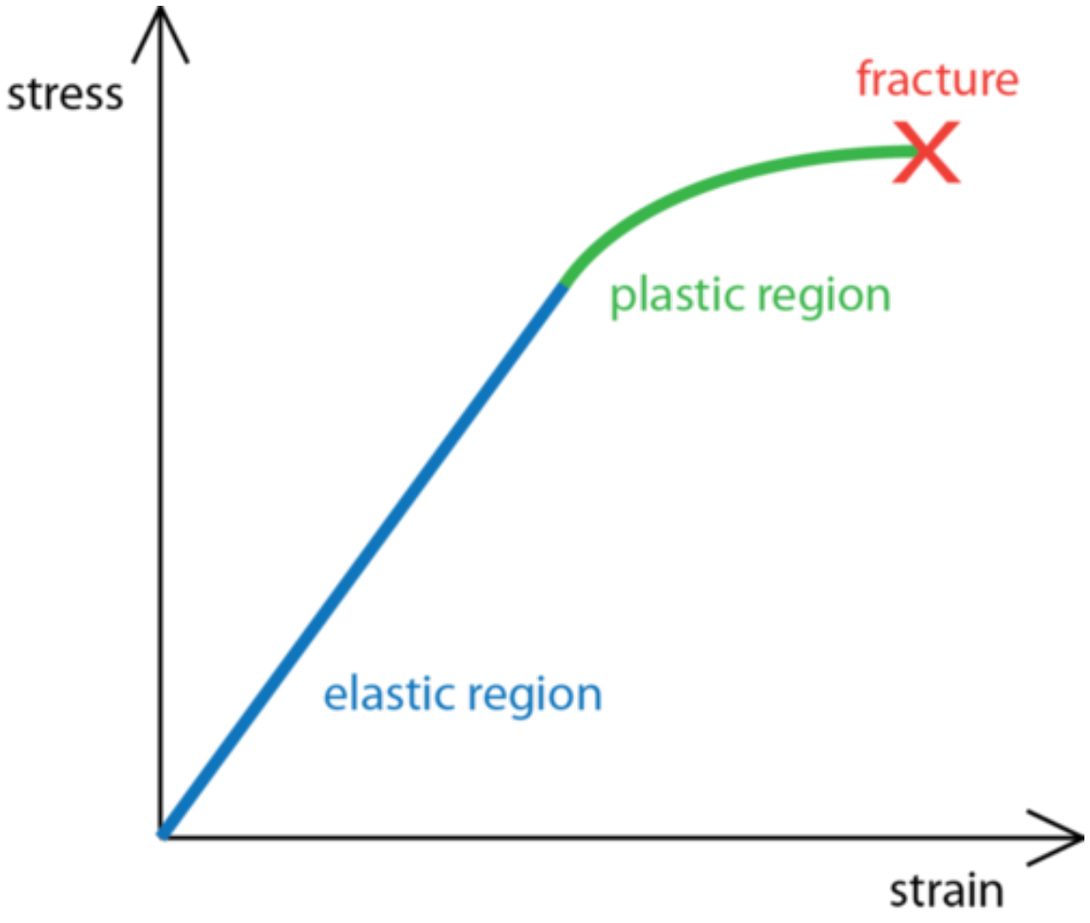


Figure 10.3

With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

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.

Geologic Structures

Sedimentary rocks are important for deciphering the geologic history of a region because they 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.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position (**Figure** below). This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses (**Figure** below). Using the rules listed above, try to figure out the geologic history of the geologic column below.

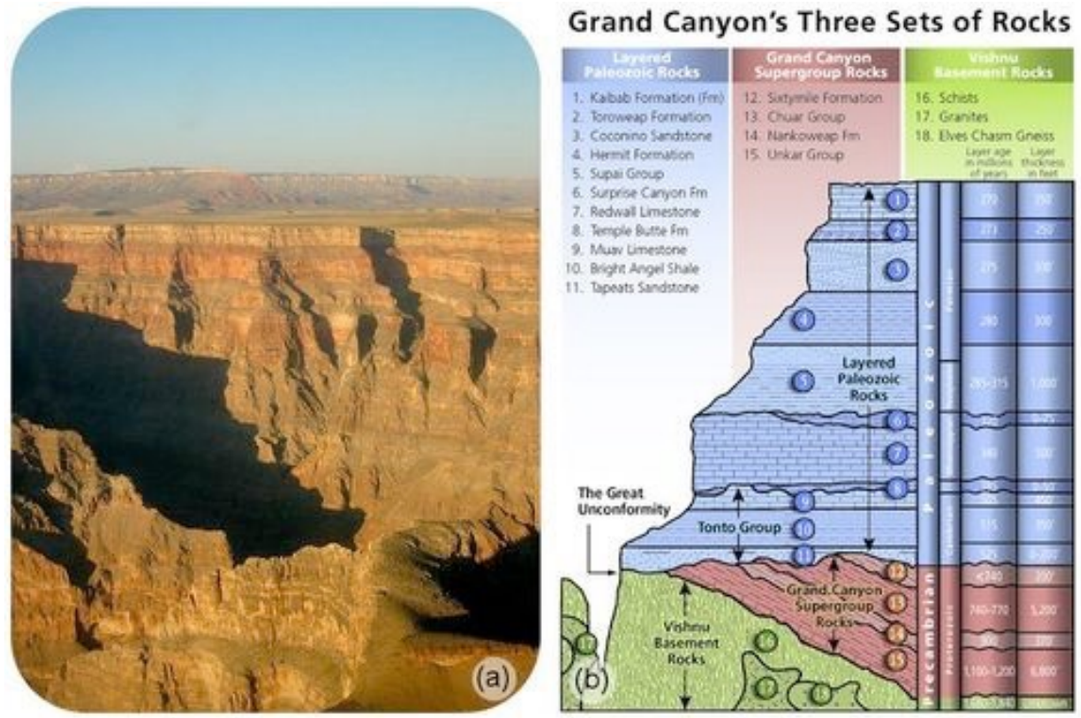


Figure 10.4

(a) 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. (b) In this geologic column of the Grand Canyon, the sedimentary rocks of the "Layered Paleozoic Rocks" column (layers 1 through 11) are still horizontal. Grand Canyon Supergroup rocks (layers 12 through 15) have been tilted. Vishnu Basement Rocks are not sedimentary (rocks 16 through 18). The oldest layers are on the bottom and youngest are on the top.

Folds

Rocks deforming plastically under compressive stresses crumple into **folds** (**Figure** below). They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.



Figure 10.5

Snow accentuates the fold exposed in these rocks in Provo Canyon, Utah.

Three types of folds are seen.

- Mononcline: A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure** below for an example).



Figure 10.6

At Colorado National Monument, the rocks in a monocline plunge towards the ground.

•Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** below). The oldest rocks are at the center of an anticline and the youngest are draped over them.



Figure 10.7

An Anticline exposed in a road cut in New Jersey.

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** below).



Figure 10.8

This syncline is in Rainbow Basin, California.

When rocks bend downward in a circular structure, that structure is called a **basin** (**Figure** below). If the rocks are exposed at the surface, where are the oldest rocks located?

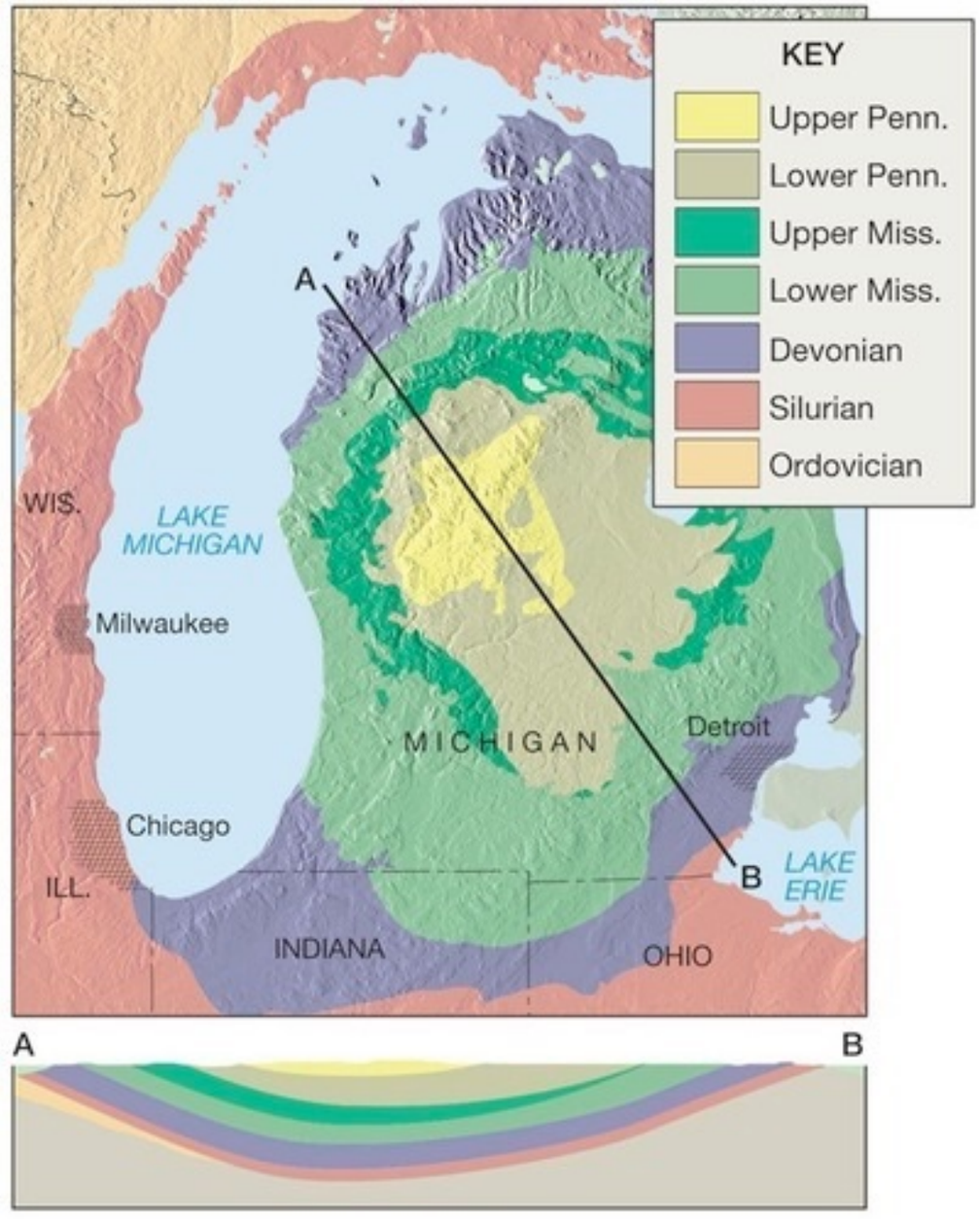


Figure 10.9

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.

Faults

A rock under enough stress will fracture. If there is no movement on either side of a fracture, the fracture is called a **joint** , as shown in (**Figure** below).



Figure 10.10

Granite rocks in Joshua Tree National Park showing horizontal and vertical jointing. These joints formed when the confining stress was removed from the granite.

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** below). Sudden motions along faults cause rocks to break and move suddenly. The energy released is an earthquake.



Figure 10.11

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** below). There are two types of dip-slip faults. In **normal faults** , the hanging wall drops down relative to the footwall. In **reverse faults** , the footwall drops down relative to the hanging wall.

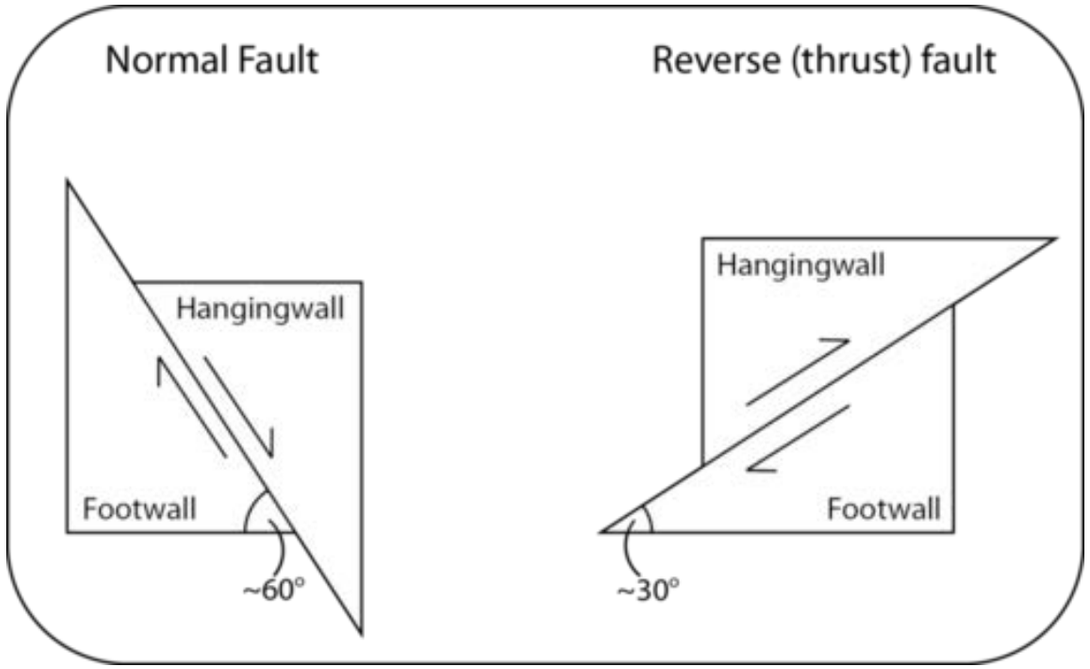


Figure 10.12

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.

An animation of a normal fault is seen here: https://www.youtube.com/watch?v=tJDnfT1pqhQ

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** below). A reverse fault can be seen in this video: https://www.youtube.com/watch?v=4b81nXSVA34



Figure 10.13

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?

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional stress (**Figure** below).



Figure 10.14

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

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. (**Figure** below).

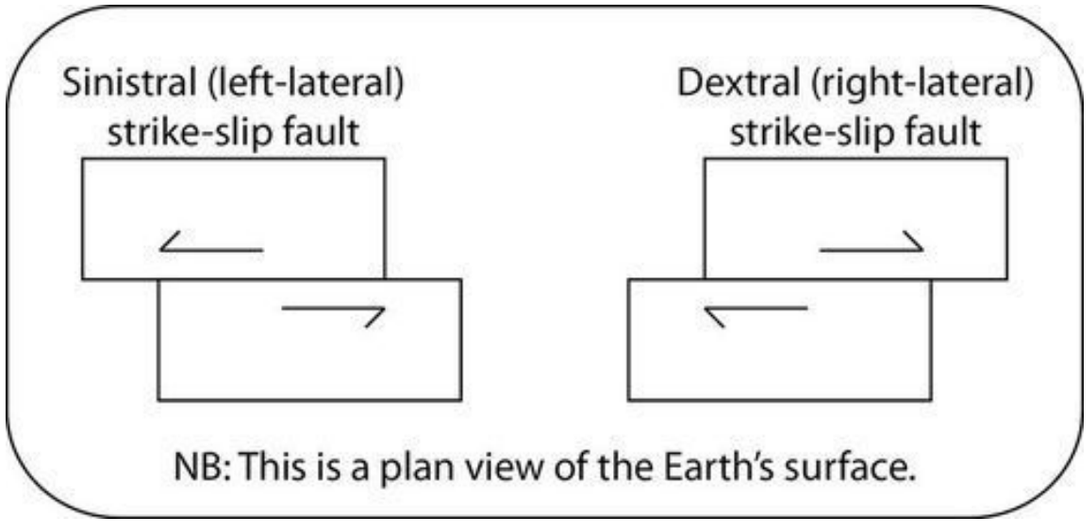


Figure 10.15

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.

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (**Figure** below).

A strike-slip fault animation: https://www.youtube.com/watch?v=MrrLJ4vXHCs

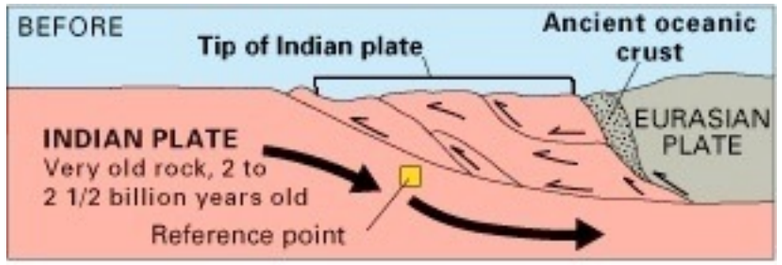


Figure 10.16

The San Andreas is a massive transform fault.

Stress and Mountain Building

Two converging continental plates smash upwards to create mountain ranges (**Figure** below). Stresses from this **uplift** cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards.



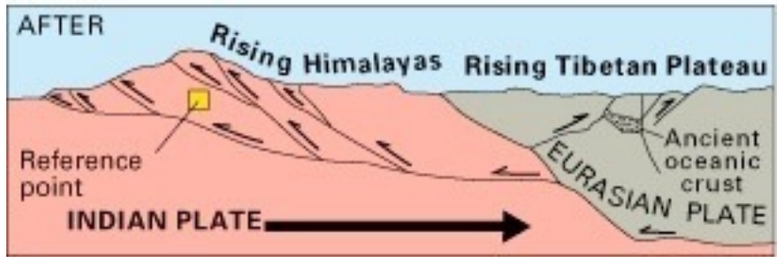


Figure 10.17

The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

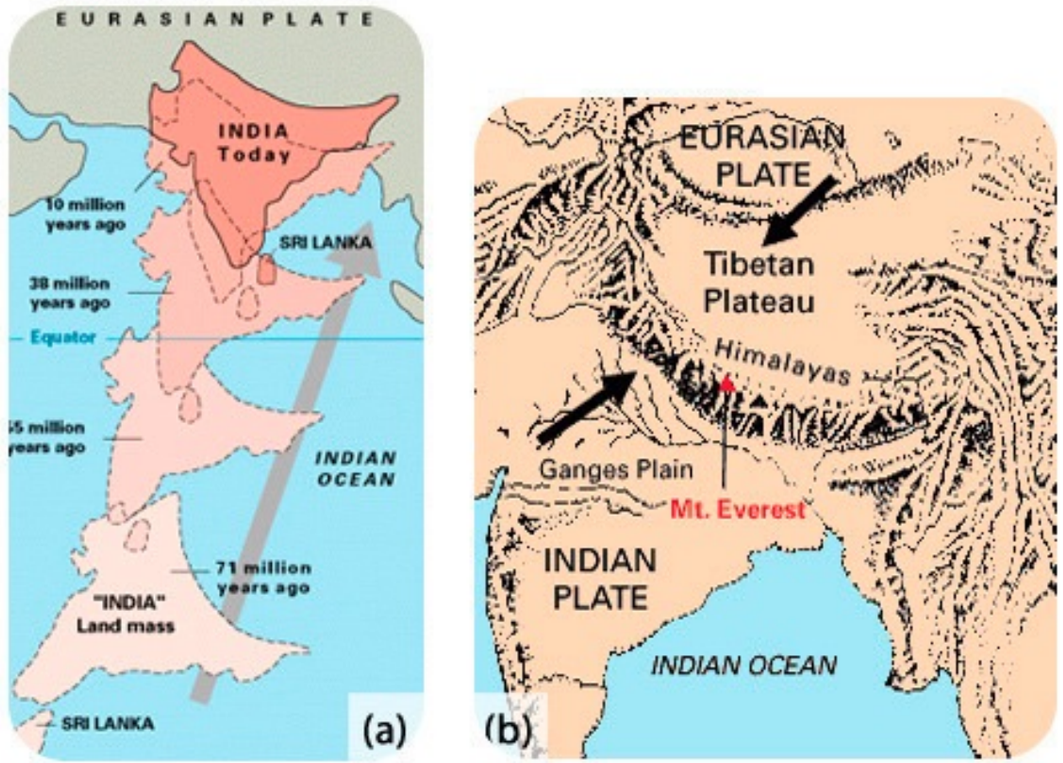


Figure 10.18

Another look at the Himalayan formation.

Click this link to to examine the colliding plates that are forming the Himalayas.

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges (**Figure** below).



Figure 10.19

The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

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. Here is a video further explain this concept: https://www.youtube.com/watch?v=TvvWqAdNV84 .

Lesson Summary

•Stress is the force applied to a rock and may cause deformation. The three main types of stress are typical of the three types of plate boundaries: compression at convergent boundaries, tension at divergent boundaries, and shear at transform boundaries.
•Where rocks deform plastically, they tend to fold. Brittle deformation brings about fractures and faults.
•The two main types of faults are dip-slip (the fault plane is inclined to the horizontal) and strike-slip (the fault plane is perpendicular to the horizontal).
•The world's largest mountains grow at convergent plate boundaries, primarily by thrust faulting and folding.

Review Questions

1.Why don't rocks deform under confining stress?
2.What type of stress is compression and at what type of plate boundary is this found?
3.What type of stress is tension and at what type of plate boundary is it found?
4.What type of stress is shear and at what type of plate boundary is it found?
5.What is the difference between plastic and elastic strain?
6.Under what conditions is a rock more likely to deform plastically than to break?
7.In the picture of the Grand Canyon geologic column (**Figure** above), what type of fold do you see?
8.While walking around in the field you spot a section of rocks in which the oldest are on top and the youngest are on the bottom. How do you explain this?
9.Describe an anticline and name the age order of rocks.
10.Describe a syncline and name the age order of rocks.
11.What are domes and basins and what is the age order of rocks in each?
12.Name one similarity and one difference between a fracture and a fault.

13.What are the two types of dip-slip faults and how are they different from each other?
14.Why are so many severe earthquakes located along the San Andreas Fault?
15.Describe the plate tectonics processes and associated stresses that have led to the formation of the Himalayas, the world's largest mountain range.

Points to Consider

•Where in an ocean basin would you find features that indicate tensional stresses? Where would you find the features that indicate compressional stresses?
•Earthquakes are primarily the result of plate tectonic motions. List the three types of plate boundaries and what you think the stresses are that would cause earthquakes there.
•Which type of plate boundary do you think has the most dangerous earthquakes? How do earthquakes cause the greatest damage?

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The Nature of Earthquakes

The Nature of Earthquakes

Lesson Objectives

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

Vocabulary

- amplitude
- body waves
- crest
- earthquake
- elastic rebound theory
- epicenter
- focus
- P wave
- S wave
- seismology
- surface waves
- trough
- tsunami
- wavelength

Introduction

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. Each year there are more than 150,000 earthquakes strong enough to be felt by people and 900,000 recorded by seismometers!

Causes of Earthquakes

The description of how earthquakes occur is called **elastic rebound theory** (**Figure** below). As stress is built up on both sides of a fault, the rocks begin to deform plastically (Time 2 in the image below). 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.

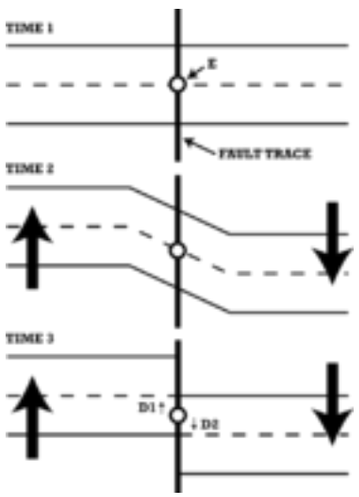


Figure 11.1

Elastic rebound theory

Elastic rebound theory in an animation: https://www.youtube.com/watch?v=-5BgKKutxBs#

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. 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 (**Figure** below).

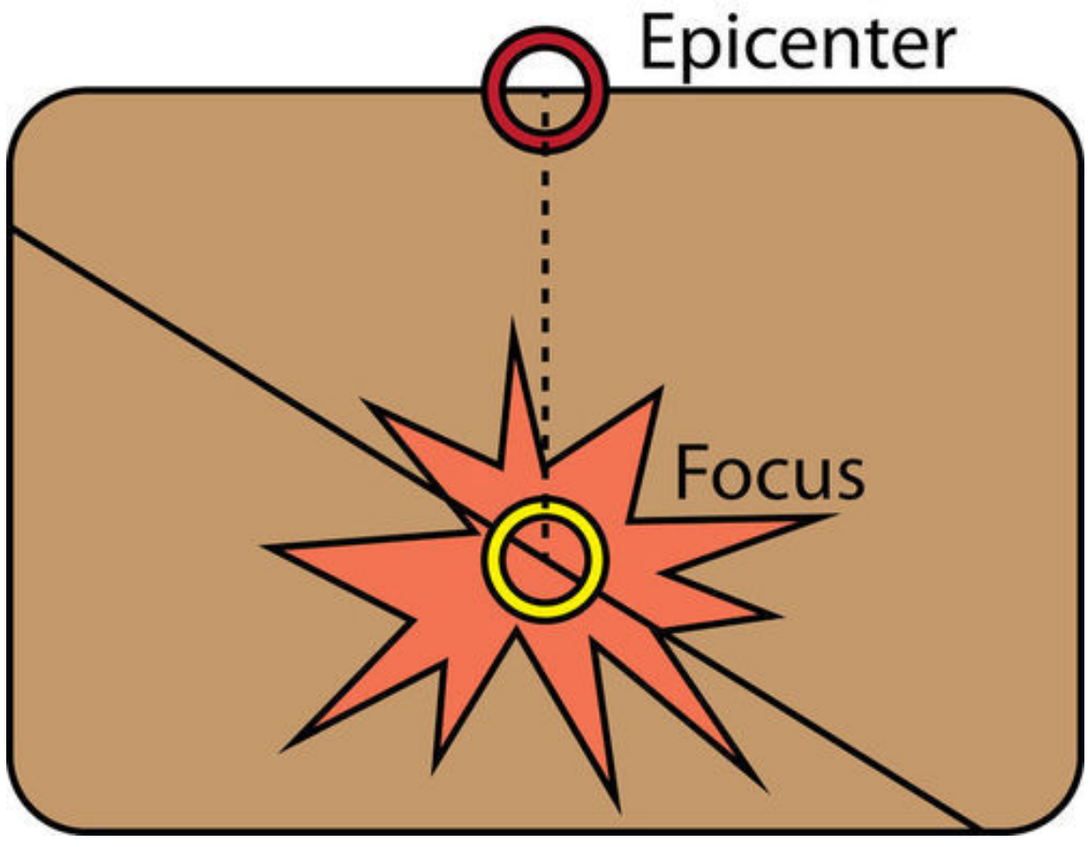


Figure 11.2

In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

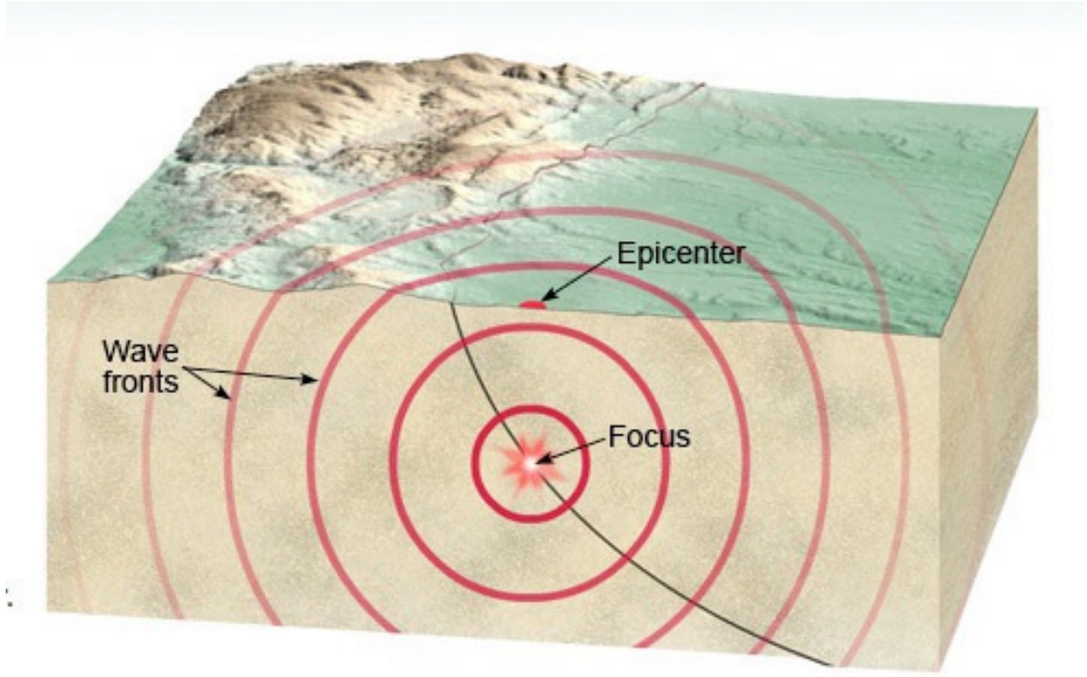


Figure 11.3

Focus and Epicenter of an Earthquake

This animation shows the relationship between focus and epicenter of an earthquake: http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::640::480::/sites/dl/free/0072402466/30425/16_04.swf::Fig.%20%2016.4%20-%20Focus%20of%20an%20Earthquake .

Seismic 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 the **Figure** below .

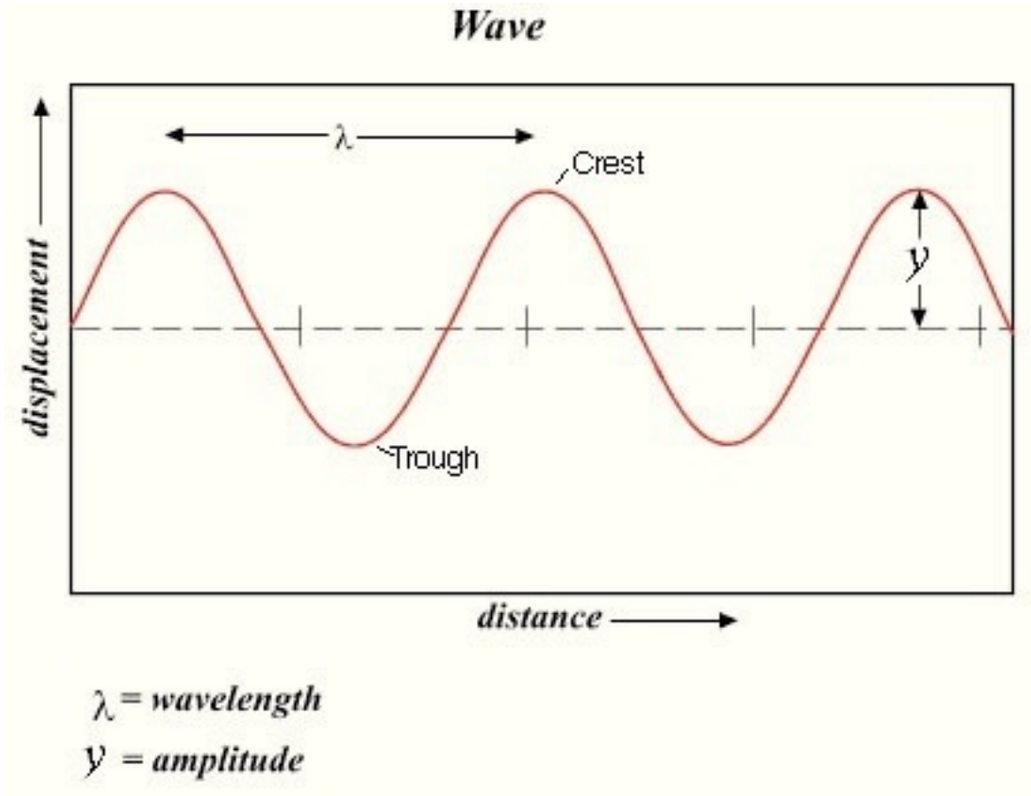


Figure 11.4

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

The energy from earthquakes travels in seismic waves, which is discussed in the chapter "Plate Tectonics." 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.

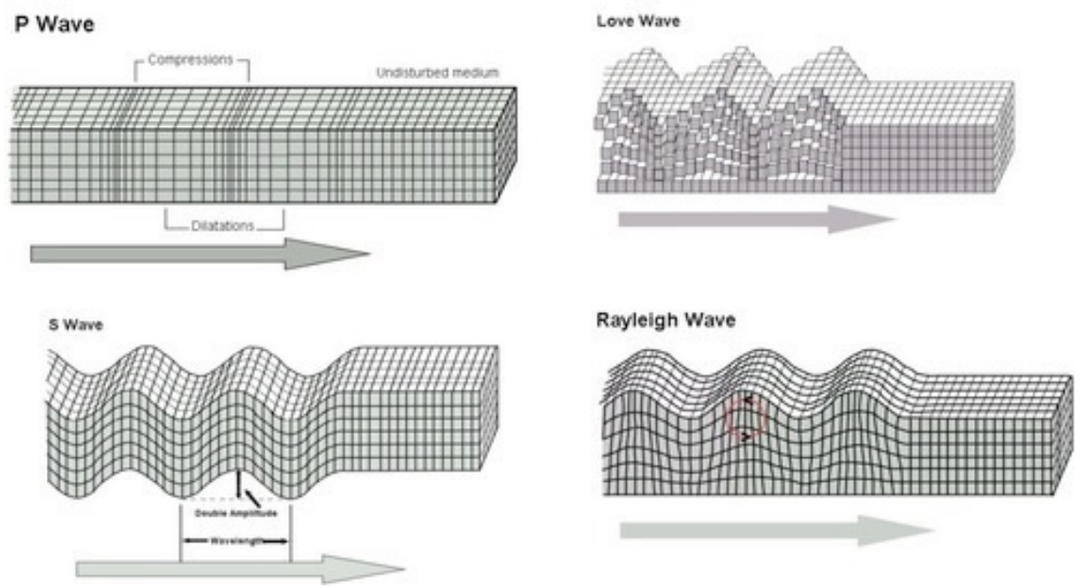
The two types of seismic waves described in "Plate Tectonics," P-waves and S-waves, are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. P waves are known as compressional waves or primary waves. P waves squeeze and stretch rock materials as they pass through Earth.

S waves are called shear waves, or secondary waves. S-waves only move through solids and not liquids or gases. They cause particles of rock material to move at right angles to the direction in which the waves are traveling.

The rate at which P waves and S waves move depends upon the type and density of the material through which they travel. The velocity of these waves is greater through materials that is rigid and dense than it is through material that is less rigid and less dense. Through all types of solid material, S waves usually travel at a little more than half the speed of P 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. As the name implies, surface waves are earthquake waves that travel along earth surface. When P waves and S waves reach Earth surface, they produce surface waves. The two types of surface waves are Love waves and Rayleigh waves. (**Figure** below).

Love waves cause particles of material to move from side to side, in a direction perpendicular to the waves' direction of travel. Rayleigh waves travel more slowly than Love waves and cause particles of material to move in elliptical patterns. The Rayleigh wave pattern is similar to the movement of particles in the ripples that appear on the surface of the lake into which a pebble has been tossed. Even though surface waves travel more slowly than either P waves or S waves, they are often perceptible far from the epicenter of the earthquake and can cause considerable damage. In an earthquake, body waves produce sharp jolts. The rolling motions of surface waves do most of the seismic damage in an earthquake.



P-waves move material forward and backward in the direction they are traveling. The material returns to its original size and shape after the P-wave goes by. S-waves move up and down, perpendicular to the direction the wave is traveling. This motion produces shear stresses.

•An interesting video about earthquakes by National Geographic is seen here: https://www.youtube.com/watch?v=VSgB1IWr6O4#

Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries, but earthquakes do occur along all 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** below).

•About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate creating Mountain Building.
•The remaining 5% are scattered around other plate boundaries or are intraplate earthquakes.

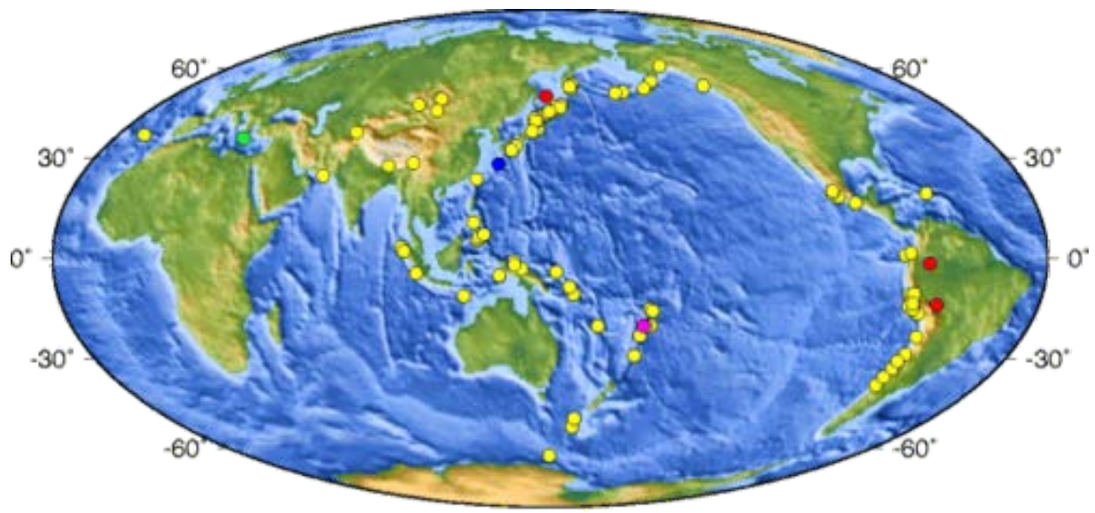


Figure 11.6

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.

Transform plate boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. Why do you

think this is so? 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** below).

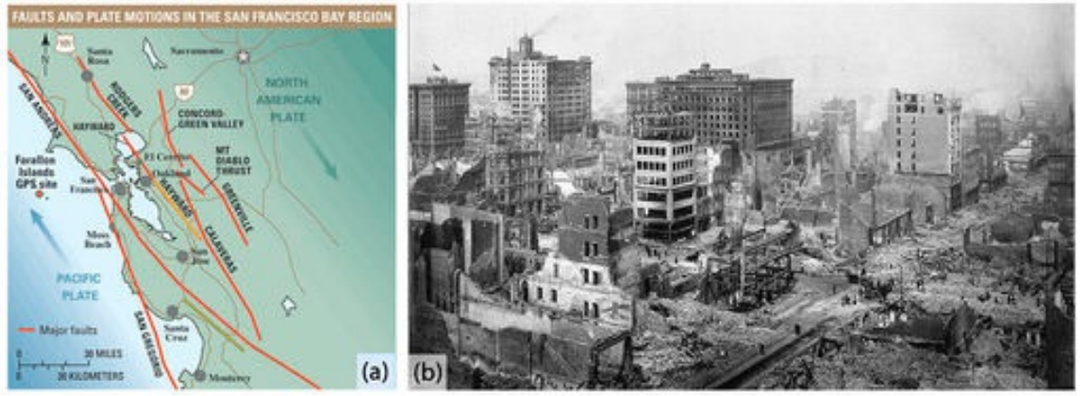


Figure 11.7

(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. About 3,000 people died and 28,000 buildings were lost, mostly in the fire.

Recent California earthquakes:

- 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.

New Zealand also has strike-slip earthquakes, about 20,000 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.

Convergent plate boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle (**Figure** below). Eventually the plate heats up enough deform plastically and earthquakes stop.

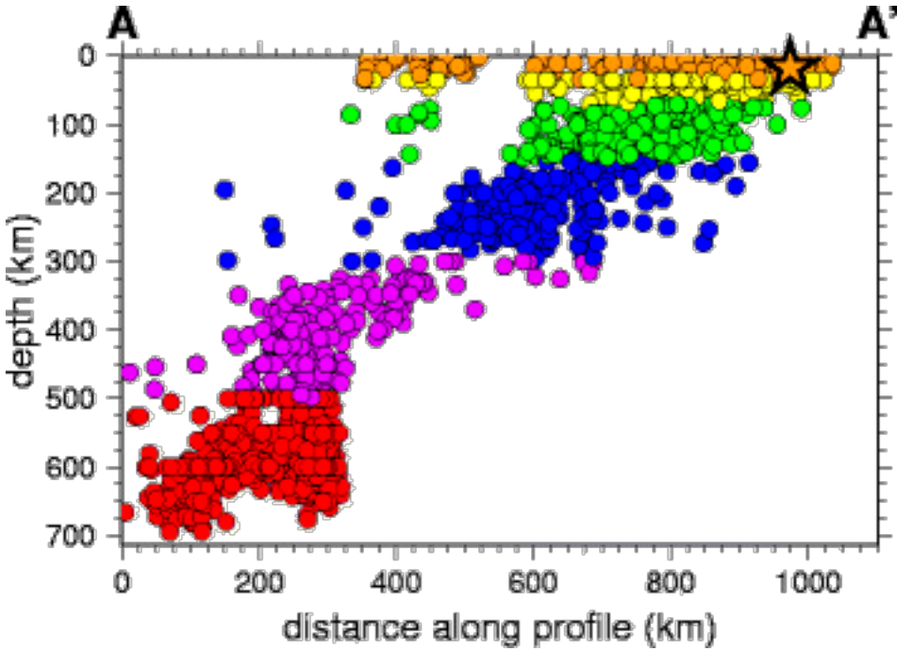


Figure 11.8

This cross section of earthquake epicenters with depth outlines the subducting plate with shallow, intermediate, and deep earthquakes.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin. The Philippine Plate and the Pacific Plate

subduct beneath Japan, creating a chain of volcanoes 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** below). Two months after the earthquake, about 25,000 people were dead or missing, and 125,000 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 11.9

Destruction in Ofunato, Japan, from the 2011 Tōhoku Earthquake.

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. Subduction of the Juan de Fuca plate beneath North America produces active volcanoes, but large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9.

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: https://www.youtube.com/watch?v=Wt_jJUnTFhg#

Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge (**Figure** below). The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.



Figure 11.10

Damage from the 2005 Kashmir earthquake.

Divergent Plate Boundaries

Earthquakes at mid-ocean ridges are small and shallow because the plates are young, thin, and hot. On land where continents split apart, earthquakes are larger and stronger.

Intraplate Earthquakes

Intraplate earthquakes are the result of stresses caused by plate motions acting in solid slabs of lithosphere. 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** below). A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

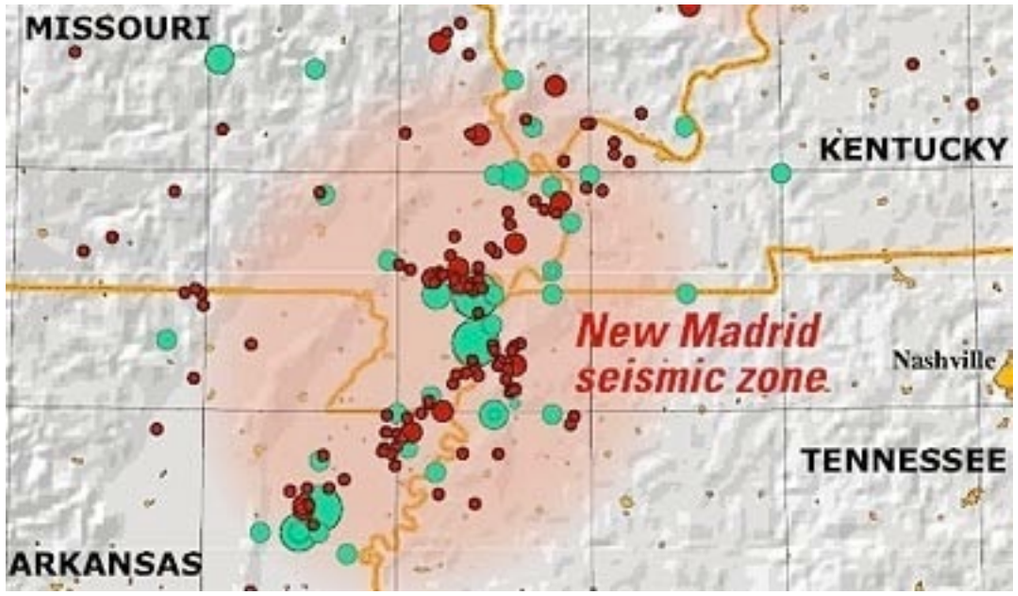


Figure 11.11

The New Madrid Seismic Zone is within the North American plate. Around 4,000 earthquakes have occurred in the region since 1974.

Tsunami

Tsunami are deadly ocean waves from an earthquake. The sharp jolt of an undersea quake causes displacement of tectonic plates

which forms a set of waves that travel through the sea entirely unnoticed. When they come onto shore, they can grow to enormous heights. Fortunately, few undersea earthquakes generate tsunami.

How a tsunami forms is shown in this animation: https://www.youtube.com/watch?v=aHljDIDf6js#

The Boxing Day Tsunami of December 26, 2004 was by far the deadliest of all time (**Figure** below). 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.

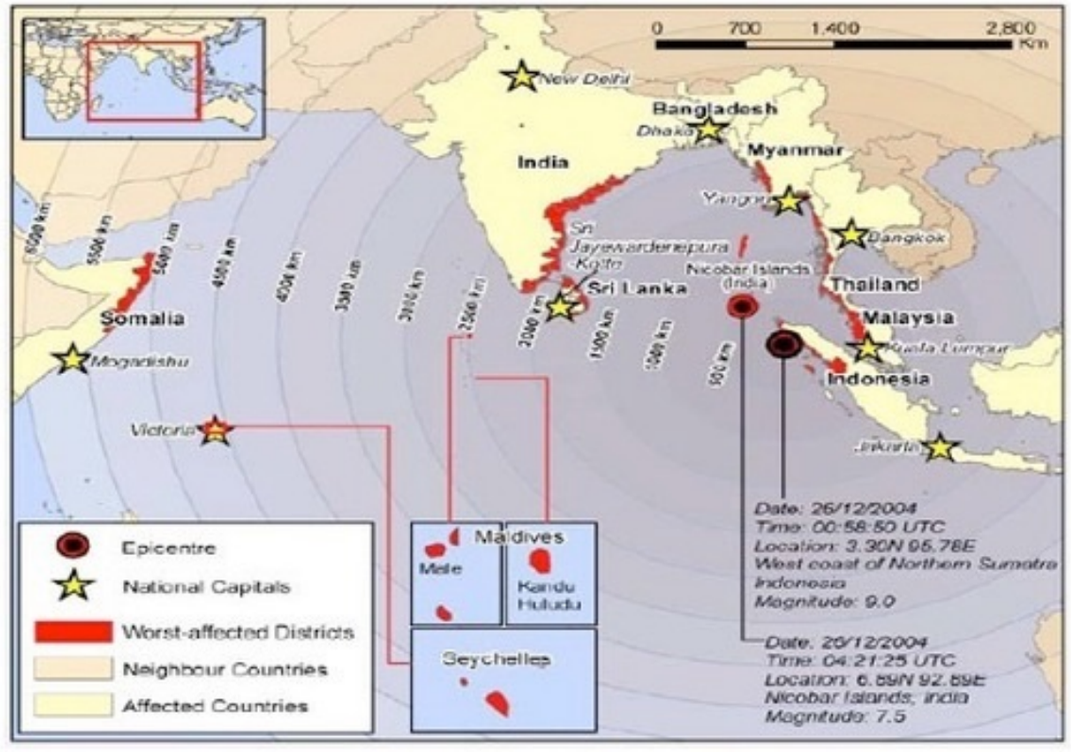


Figure 11.12

The countries that were most affected by the 2004 Boxing Day tsunami.

About 230,000 people died in eight countries (**Figure** below) with 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 11.13

The Boxing Day tsunami strikes a beach in Thailand.

The 2011 Tōhoku earthquake in Japan created massive tsunami waves that hit the island nation. As seen in **Figure** below , waves in some regions topped 9 meters (27 feet). The tsunami did much more damage than the massive earthquake (**Figure** below). Worst was the damage done to nuclear power plants along the northeastern coast. The following video shows Tidal Wave make land fall in Sendai in the 2011 Tōhoku earthquake: https://www.youtube.com/watch?v=w3AdFjklR50#

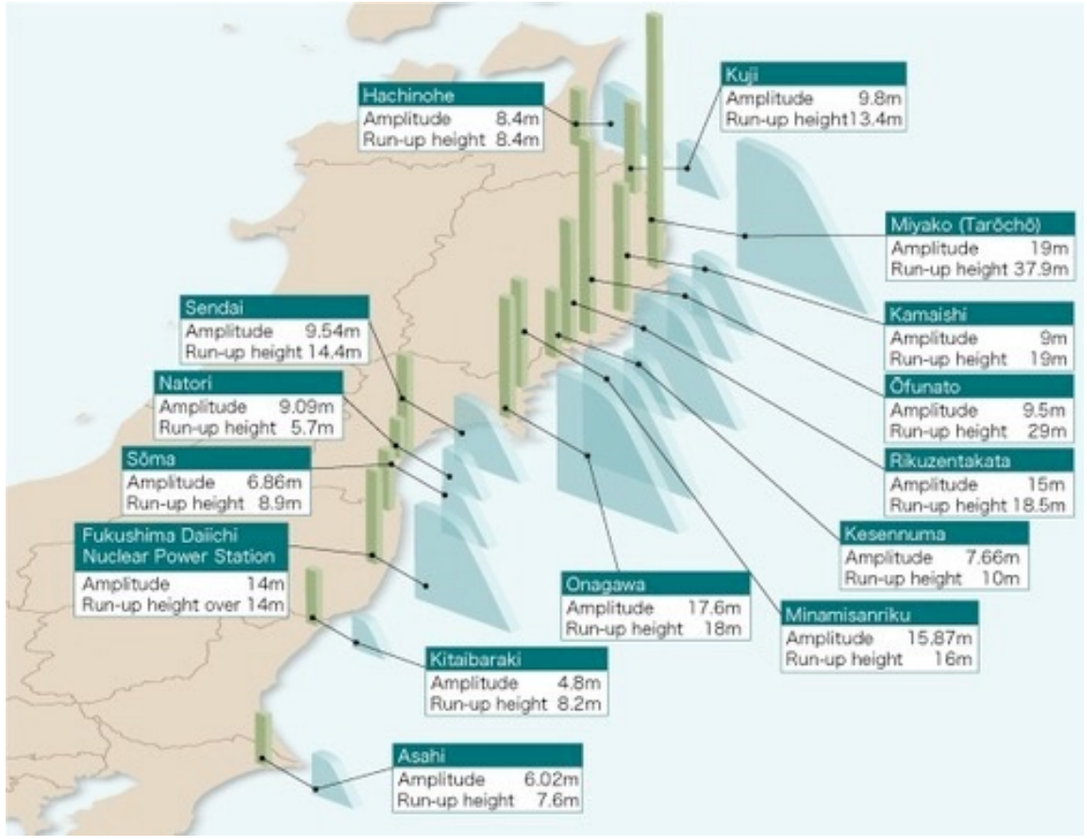


Figure 11.14

This map shows the peak tsunami wave heights.



Figure 11.15

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.

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. In comparison, a warning system has been in effect around the Pacific Ocean for more than 50 years (**Figure** below). Why do you think a Pacific warning system has been in place for so long? The system was used to warn of possible tsunami waves after the Tōhoku earthquake. People were evacuated along many pacific coastlines although the waves were not nearly as large as those that struck Japan shortly after the quake.



Figure 11.16

This sign indicates a tsunami hazard zone in California.

Lesson Summary

- During an earthquake, the ground shakes as stored up energy is released from rocks.
- Elastic rebound theory states that rock will deform plastically as stresses build up until the stresses become too great and the rock breaks.
- Earthquakes occur at all types of plate boundaries.
- The Pacific Ocean basin and the Mediterranean-Asiatic Belt are the two geographic regions most likely to experience quakes.
- Surface waves do the most damage in an earthquake.

•Body waves travel through the planet and travel faster than surface waves.
•Tsunami are deadly ocean waves that are caused by undersea earthquakes.

Review Questions

1.What is an earthquake's focus? What is its epicenter?
2.Why do most earthquakes take place along plate boundaries?
3.Using elastic rebound theory, describe what triggers an earthquake.
4.Why are there far more earthquakes around the Pacific Ocean than anywhere else?
5.What causes intraplate earthquakes?
6.Besides the San Andreas Fault zone, what other type of plate boundary in or near California can produce earthquakes?
7.Using plate tectonics and elastic rebound theory, describe why Juan de Fuca plate subduction produces so few earthquakes. What will happen in the future?
8.What type of faulting is found where two slabs of continental lithosphere are converging?
9.What are the characteristics of body waves? What are the two types?
10.What types of materials can P-waves travel through and how fast are they? Describe a P-wave's motion.
11.What material can S-waves travel through and how fast are they? Describe an S-wave's motion.
12.How are surface waves different from body waves? Which are more damaging?

Further Reading / Supplemental Links

•The U.S. Geological survey earthquake site is found here: http://earthquake.usgs.gov/ .
•Fault line discusses seismic science: http://www.exploratorium.edu/faultline/index.html .
•How the geography of the Pacific Northwest reflects the plate tectonic features is found here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/2.NWplateRollover.swf .

Points to Consider

•Do the largest earthquakes cause the most deaths and the most damage to property?
•The last time there was a large earthquake on the Hayward Fault in the San Francisco Bay area of California was in 1868. Use elastic rebound theory to describe what may be happening along the Hayward Fault today and what will likely happen in the future.
•Why is California so prone to earthquakes?
•How could coastal California be damaged by a tsunami? Where would the earthquake occur? How could such a tsunami be predicted?

References

1.Christopher Auyeung. CK-12 Foundation .
2.Jodi So. CK-12 Foundation . CC BY-NC 3.0
3.Courtesy of the US Geological Survey. http://earthquake.usgs.gov/earthquakes/eqarchives/year/mag8/magnitude8_1900_date.php . Public Domain
4.(a) Courtesy of US Geological Survey; (b) Photographed by HD Chadwick and courtesy of National Archives and Records Administration. (a) http://pubs.usgs.gov/fs/old.

2003/fs039-03/; (b) http://commons.wikimedia.org/wiki/File:Post-and-Grant-Avenue.-Look.jpg . Public Domain
5.Courtesy of the US Geological Survey. http://neic.usgs.gov/neis/eq_depot/2009/eq_090929_mdbi/neic_mdbi_c.html . Public Domain
6.Courtesy of Mass Communication Specialist 1st Class Matthew M. Bradley/US Navy. http://www.flickr.com/photos/fncinsider/5529591463/ .
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12.Courtesy of the US Navy. http://commons.wikimedia.org/wiki/File:SH-60B_helicopter_flies_over_Sendai.jpg . Public Domain
13.Flickr:youngthousands. http://www.flickr.com/photos/theyoungthousands/2609041263/ .

Section 3

Measuring and Predicting

10.3 Measuring and Predicting Earthquakes

Lesson Objectives

- Describe how to find an earthquake epicenter.
- Describe the different earthquake magnitude scales and what the numbers for moment magnitude mean.
- Describe how earthquakes are predicted and why the field of earthquake prediction has had little success.

Vocabulary

- foreshocks
- moment magnitude scale
- richter scale
- seismic gap
- seismogram
- seismograph
- seismometer

Introduction

Seismograms record seismic waves. Over the past century, scientists have developed several ways of measuring earthquake intensity. The currently accepted method is the **moment magnitude scale** , which measures the total amount of energy released by the earthquake. At this time, seismologists have not found a reliable method for predicting earthquakes.

Measuring Earthquakes

A **seismograph** produces a graph-like representation of the seismic waves it receives and records them onto a **seismogram** (**Figure** below). 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.

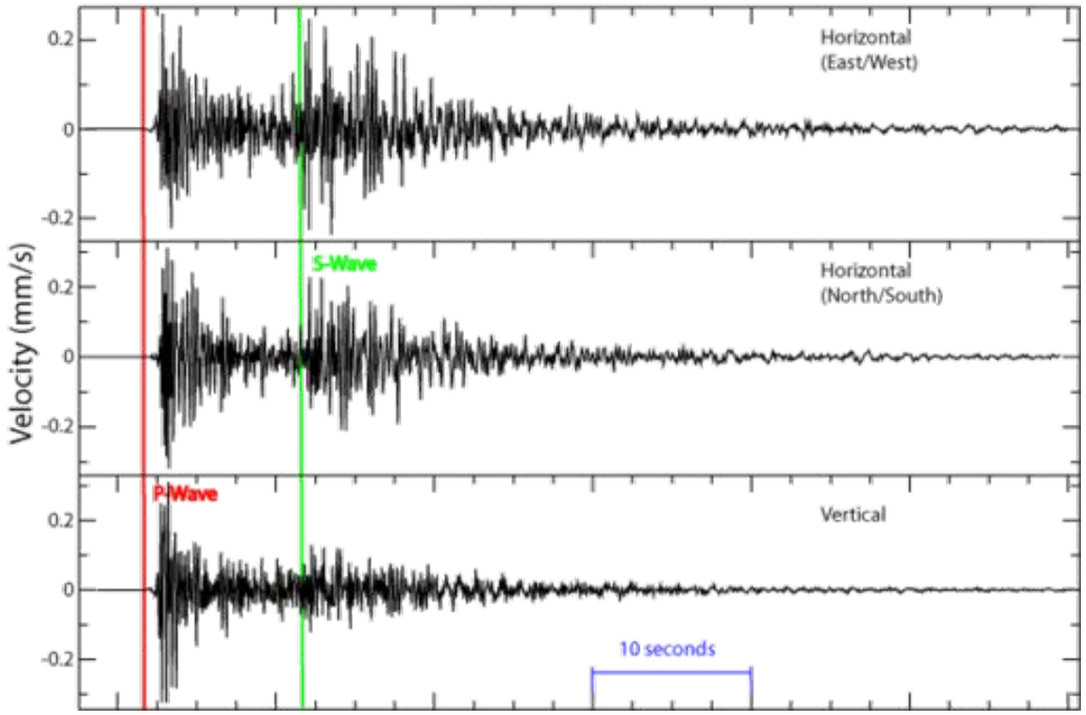


Figure 12.1

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.

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 three different stations picking up seismic waves: https://www.youtube.com/watch?v=4nS10xNBfVE#

Measurement Scales

People have always tried to quantify the size of and damage done by earthquakes. Since early in the 20th century, there have been three methods. What are the strengths and weaknesses of each?

1. **Mercalli Intensity Scale:** Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures.
2. **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.
3. **Moment magnitude 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.

The Richter scale and the moment magnitude scale are logarithmic. The logarithm of a number is the exponent to which another fixed value, the base, must be raised to produce that number. Why is this important?

- 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.

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 following video shows magnitude differences from various modern-day earthquakes: https://www.youtube.com/watch?v=yNN7eDXzlMo#

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** below) and (**Table** below). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.



Figure 12.2

The 1964 Good Friday Earthquake centered in Prince William Sound, Alaska released the second most amount of energy of any earthquake in recorded history.

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

Finding the Epicenter

To locate an earthquake epicenter:

1. Scientists first 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 distance is determined using P, S, and surface waves: https://www.youtube.com/watch?v=4g_bPpPiFEE#

2. The scientist then draws a circle with a radius equal to the distance from the epicenter for that seismograph. The epicenter is somewhere along that circle. This is done 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** below). Although useful for decades, this technique has been replaced by digital calculations.

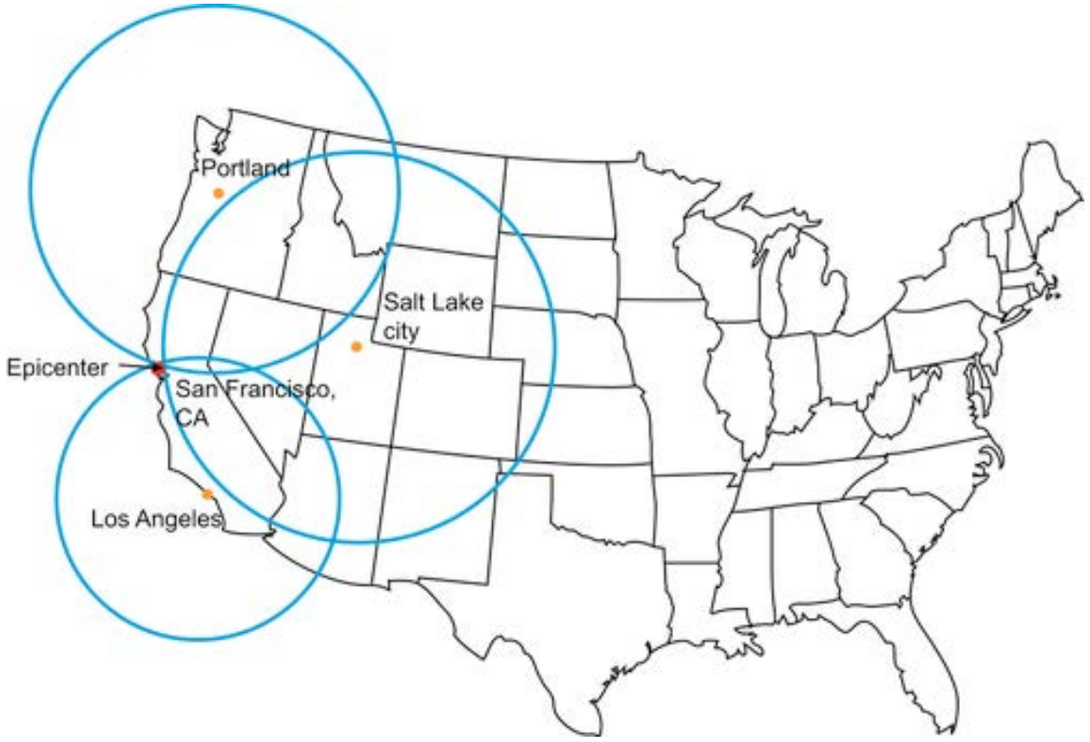


Figure 12.4

Circles are drawn with radii representing the distance from each seismic station to the earthquake's epicenter. The intersection of these three circles is the earthquake's epicenter.

Seismic stations record ten earthquakes in this animation: https://www.youtube.com/watch?v=RpapSLE8AfI#

Earthquake Prediction

Scientists are a long way from being able to predict earthquakes. A good prediction must be accurate as to where an earthquake will occur, when it will occur, and at what magnitude it will be so that people can evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

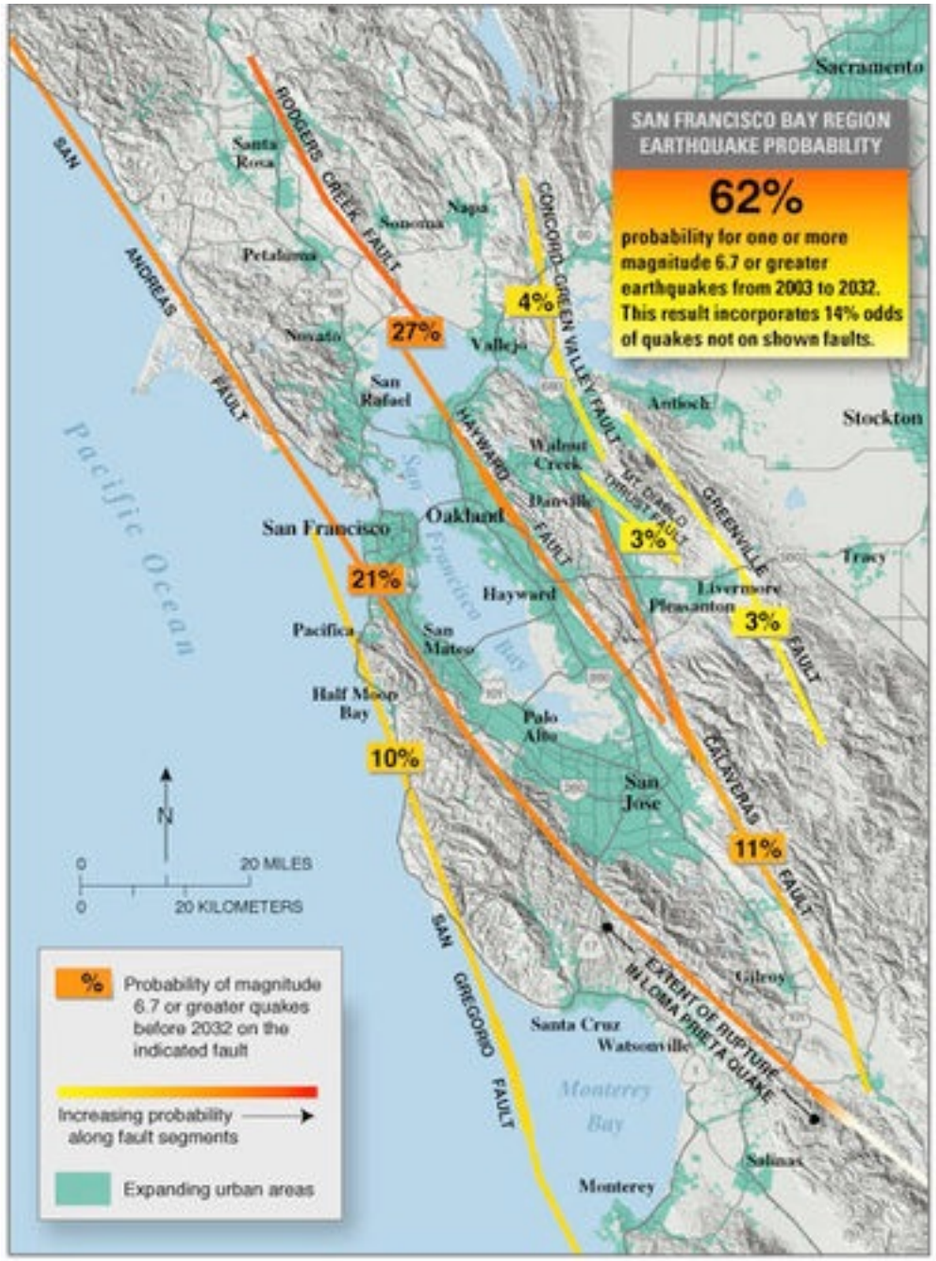


Figure 12.5

The probabilities of earthquakes striking along various faults in the San Francisco area between 2003 (when the work was done) and 2032.

Where an earthquake will occur is the easiest feature to predict. Scientists know that earthquakes take place at plate boundaries and tend to happen where they've occurred before (**Figure** above). Areas along a fault line that have not experienced an earthquake in a long time are known as **Seismic Gaps** , and are thought of as areas that can experience an earthquake at any moment (**Figure** below). Earthquake-prone communities should always be prepared for an earthquake. These communities can implement building codes to make structures earthquake safe.

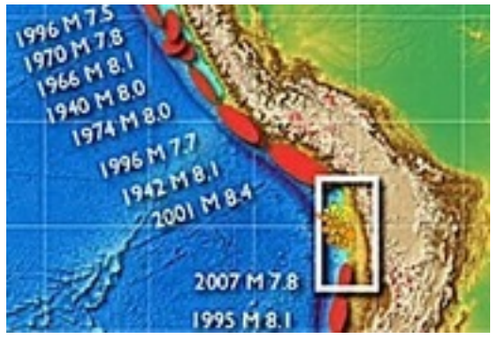


Figure 12.6

This map shows the coastline of Chile with a noticeable seismic gap (marked by a white box) along the fault line.

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** below). But so far scientists cannot predict when quakes will occur even to within a few years.

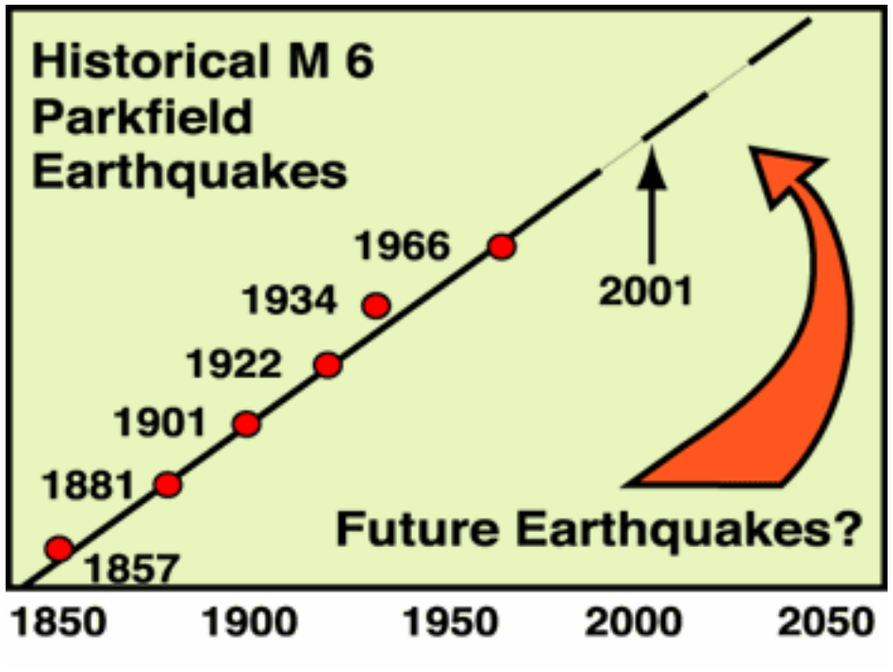


Figure 12.7

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.

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. Often, the rocks around a fault will dilate as microfractures form. 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.

KQED: Earthquakes: Breaking New Ground

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. Learn more with this video: http://science.kqed.org/quest/video/earthquakes-breaking-new-ground/ .

Lesson Summary

- Seismograms indicate an earthquake's strength, how far away it is, and how long it lasts.
- Epicenters can be calculated using the difference in the arrival times of P- and S-waves from three seismograms.
- Three different methods can be used to determine an earthquake's strength. The Mercalli Scale identifies the damage done and what people felt after an earthquake has occurred, the Richter scale measures the greatest single shock, and the moment magnitude scale measures the total energy released.
- Seismologists have not come too far in their ability to predict earthquakes.

Review Questions

1. How can a seismograph measure ground shaking if all parts of it must be attached to the ground?
2. On a seismogram, which waves arrive first, second, third, and last?
3. What information is needed to calculate the distance from a seismic station to an earthquake's epicenter?
4. If a seismogram records P-waves and surface waves but not S-waves, where was the earthquake epicenter located relative to the seismograph and why?
5. On the Richter or magnitude moment scale, what is the difference in energy released by an earthquake that is a 7.2 versus an 8.2 in magnitude? A 7.2 versus a 9.2?
6. Why do you need at least three seismographs to locate an earthquake epicenter?
7. What were the problems with the Mercalli scale of measuring earthquake magnitudes? Why did Richter and moment magnitude scales need to be developed?
8. Why is the moment magnitude scale thought to be more accurate than the Richter scale for measuring earthquake magnitudes?
9. What is the difference in energy released between a 6 and a 7 on the Richter scale? How about a 6 and a 7 on the moment magnitude scale?
10. How do seismologists use earthquake foreshocks to predict earthquakes? Why are foreshocks not always an effective prediction tool?
11. For earthquake prediction to be really useful, what would need to be predicted?

Further Reading / Supplemental Links

- How to triangulate for an earthquake epicenter: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/swf_earthquake_triangulation/p_activity_eqtriangulation.html .

Points to Consider

•If you live in an earthquake prone area, how do you feel about your home now? What can you do to minimize the risk to you and your family? If you do not live in an earthquake prone area, what would it take to get you to move to one? What risks from natural disasters do you face where you live?
•What do you think are the most promising clues that scientists might someday be able to use to predict earthquakes?
•What good does information about possible earthquake locations do for communities in those earthquake-prone regions?

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2.Courtesy of the US Army. http://commons.wikimedia.org/wiki/File:AlaskaQuake-FourthAve.jpg .
3.Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Eq-prob.jpg . Public Domain
4.Hana Zavadska. CK-12 Foundation .

Staying Safe in Earthquakes

10.4 Staying Safe in Earthquakes

Lesson Objectives

- Describe different types of earthquake damage.
- Describe the features that make a structure earthquake safe.
- Describe how to protect a person or household in earthquake country.

Vocabulary

- liquefaction

Introduction

Earthquakes are natural disasters that cause enormous amounts of damage, second only to hurricanes. Earthquake-safe construction techniques, securing heavy objects, and preparing an emergency strategy are among the precautions people can take to minimize damage.

Damage from Earthquakes

Earthquakes kill people and cause property damage. However, the ground shaking almost never kills people. The damage depends somewhat on the earthquake size but mostly on the quality of structures. Structures falling on people injure and kill 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** below).



Figure 13.1

A landslide in a neighborhood in Anchorage, Alaska, after the 1964 Great Alaska earthquake.

•Ground type. Solid bedrock vibrates less than soft sediments so there is less damage in bedrock. Sediments that are saturated with water undergo **liquefaction** and become like quicksand (**Figure** below). Liquefaction can be more prevalent in areas that are closer to large bodies of water, such as islands or peninsulas. Loose soil that sits on a hillside has a large chance of turning into a landslide.

Seismic wave effects on buildings on different ground types can be seen in this animation:
https://www.youtube.com/watch?v=536xSZ_XkSs#t=65



Figure 13.2

Liquefaction of sediments in Mexico City caused the collapse of many buildings in the 1985 earthquake.

•Size is actually not a factor. Only about 2,000 people died in the 1960 Great Chilean earthquake, the largest earthquake ever recorded. Why is that? 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.

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** below). This allows planners to locate new hospitals and schools more safely.

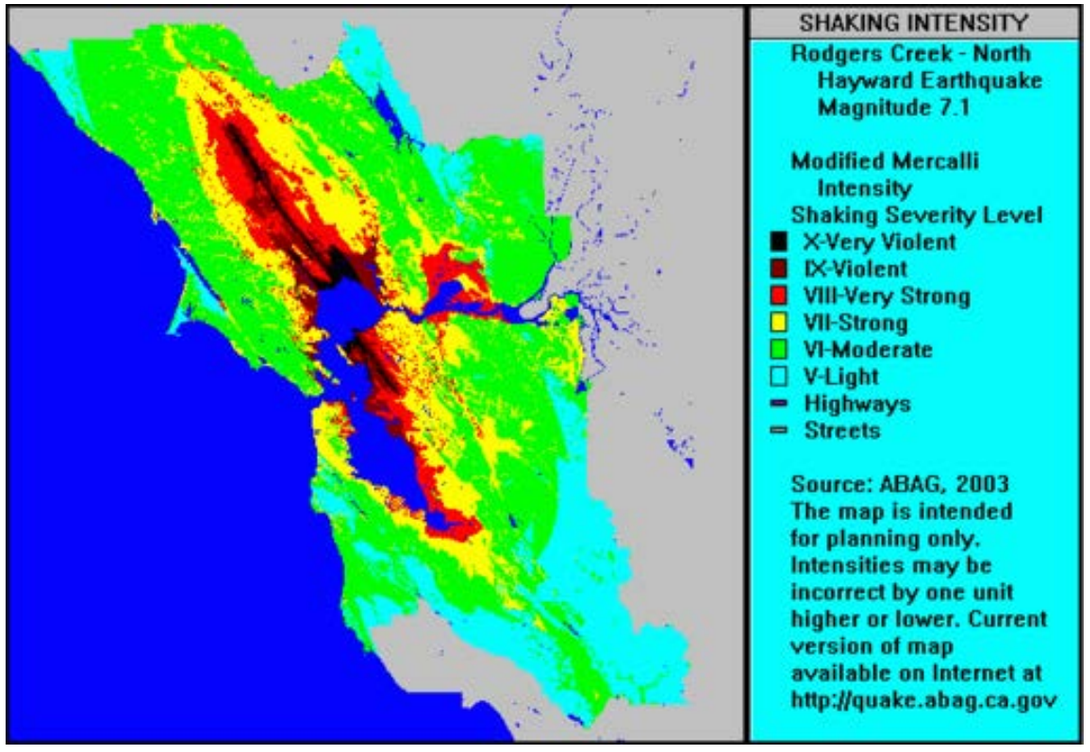


Figure 13.3

The expected Modified Mercalli Intensity Scale for an earthquake of magnitude 7.1 on the northern portion of the Hayward Fault.

Earthquake-Safe Structures

Construction is a large factor in what happens during 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. A few simple Earthquake Safety guidelines are:

1.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.
2.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.
3.Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams are used to hold down sway. To make older buildings more earthquake safe, retrofitting with steel or wood can reinforce a building's structure and its connections (Example below). Elevated freeways and bridges can also be retrofitted so that they do not collapse.



Figure 13.4

Steel trusses were added to this building at the University of Stanford in Palo Alto, CA. The San Adreas Fault runs just west of the university.

4.Large buildings can be placed on rollers so that they move with the ground.
5.Buildings may be placed on layers of steel and rubber to absorb the shock of the waves. These rubber layers are known as Base Isolators .
6.Connections, such as where the walls meet the foundation, must be made strong.
7.In a multi-story building, the first story must be well supported (**Figure** below).



Figure 13.5

The first floor of this San Francisco building is collapsing after the 1989 Loma Prieta earthquake.

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** below).

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.



Figure 13.6

In the 1906 San Francisco earthquake, fire was much more destructive than the ground shaking.

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.

KQED: The Hayward Fault: Predictable Peril

In 1868, 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. Learn more at: https://www.youtube.com/watch?v=3jtAKPO4iHA

Protecting Yourself in an Earthquake

Being involved firsthand in an earthquake can be a a physically, emotionally and mentally challenging experience. But, if you live in an earthquake-prone area, there are many ways that you can (1) Prepare yourself for an earthquake, (2) Act accordingly during an earthquake, and (3) Recover swiftly from an earthquake.

1. 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 (Figure below).
- 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.



Figure 13.7

A section of an Alaskan pipeline, that runs across the Denali Fault, has been fitted with sliding pads to prevent future rupture.

2. During the Earthquake

- If you are in a building, get beneath a sturdy table, cover your head, and hold on.
  - As all schools nationwide are required to demonstrate Fire Drills, schools in California are required to demonstrate Shake Out Drills. Here is an example of a Shake Out Drill .

•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.

3. 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.

Lesson Summary

•A person standing in an open field in an earthquake will almost certainly be safe. Nearly all earthquake danger is from buildings falling, roadways collapsing, or from the fires and tsunami that come after the shaking stops.
•Communities can prepare for earthquakes by requiring that buildings be earthquake safe and by educating citizens on how to prepare.
•Individuals and households can prepare in two ways: by making sure that their house and its contents are not a hazard and by being ready to live independently for a few days.

Review Questions

1.What usually kills or injures people in an earthquake?
2.In two earthquakes of the same magnitude, what could produce more damage in a location further from the epicenter than in one nearer the epicenter?
3.Describe why Mexico City was so devastated in 1985 by an 8.1 earthquake with an epicenter far from the city.
4.What is liquefaction and how does it cause damage in an earthquake?
5.If you live in an old home in an earthquake-prone region, what should you do to minimize the harm that will come to yourself and your home?
6.What can an architect do to make a skyscraper earthquake safe?
7.Which types of buildings deserve the greatest protection from earthquake hazards?
8.Using what you know about elastic strength, will a building better withstand an earthquake if it is built absolutely solid or if it is able to sway? Why?
9.Why do wealthy communities tend to have greater earthquake protection than poorer communities, e.g. communities in developed versus developing nations?
10.What are the two goals of earthquake preparation?
11.What should you include in an earthquake kit?
12.Under what circumstances should you run outside in an earthquake?

Points to Consider

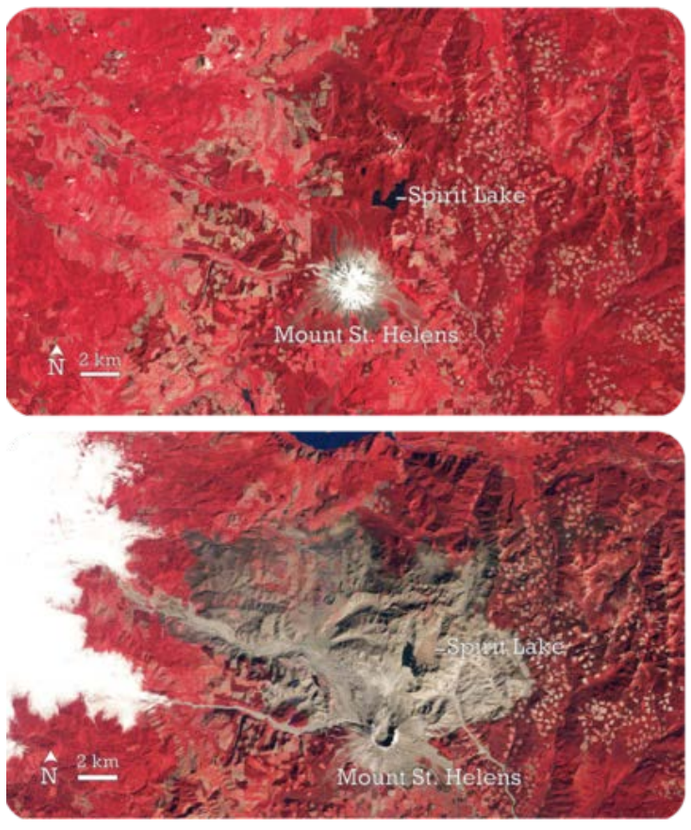
•Many people think that in a large earthquake, California will fall into the ocean and that Arizona and Nevada will be beachfront property. Why is this not true?

•If you were the mayor of a small city in an earthquake-prone area, what would you like to know before choosing the building site of a new hospital?
•How are decisions made for determining how much money to spend preparing people and structures for earthquakes?
•Why do wealthy communities (such as those in California) tend to have greater earthquake protection than poorer communities (such as those in developing nations)?

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Ch. 11: Volcanoes



Above are two false-color Landsat satellite images of Mount St. Helens and vicinity. The first image is from August 29, 1979. Just months later, in March 1980, the ground began to shake. Red indicates vegetation; patches of lighter color are where the region was logged.

The second image is from September 24, 1980, four months after the large eruption on May 18. The relics of the eruption are everywhere. The mountain's northern flank has collapsed, leaving a horseshoe shaped crater. Rock and ash have blown over 230 square miles. Dead trees are floating in Spirit Lake and volcanic mudflows clog the rivers. A more recent image shows that vegetation has begun to colonize at the farther reaches of the area affected by the eruption.

Courtesy of Robert Simmon and NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=43999. Public Domain.

Section 1

Volcanic Eruptions

Volcanic Eruptions

Lesson Objectives

- Explain how magma composition affects the type of eruption.
- Compare the types of volcanic eruptions.
- Distinguish between different types of lava and the rocks they form.
- Describe a method for predicting volcanic eruptions.

Vocabulary

- a'a
- active volcano
- andesitic magma
- ash
- basaltic magma
- dormant volcano
- effusive eruption
- eruption
- explosive eruption
- extinct volcano
- lahar
- lapilli
- lava
- magma
- magma chamber
- pahoehoe
- pyroclastic flow
- rhyolitic magma
- tephra
- viscosity

Introduction

Introduction

In 79 C.E. Mt. Vesuvius erupted in a dark cloud of volcanic gases, ash, bombs, and lapilli. As the volcano erupted the small town of Pompeii was rattled as people franticly rush to escape the choking fumes and scorching ash and debris. The overwhelming volcanic debris buried the town in 6 meters of ash preserving the scene until archeologists unearthed this town in the late 19 th century.



Figure 14.1

The story of Pompeii illustrates the unpredictability and destructive force volcanoes pose. A volcano is a landform that results from magma (molten rock within the earth) erupting at the surface. The size and shape of a volcano reflect how often it erupts, the size and type of eruptions, and the composition of the magma it produces.

If asked to draw a volcano, most people will sketch a steep, cone-shaped mountain, usually with clouds billowing from the summit. This is one type, but some of the most explosive volcanoes are less obvious, and represented by large depressions that may be filled with water.

Magma Composition

Each volcano is a distinct landform with a style of eruption and specific type of magma which is unique to each. These differences reflect the main type of magma erupted:

- Basaltic magma at the volcanic fields and shield volcanoes
- Andesitic magma at the cone volcanoes
- Rhyolitic magma at the calderas and composite volcanoes

Magmas contain almost all of earth's known chemical elements, but typically they consist of just nine: silicon, oxygen, aluminium, magnesium, iron, calcium, sodium, potassium and titanium. Oxygen and silicon together are the most abundant elements, making up 48–76% by weight of most magmas. The chemistry of magma, especially silicon content, is important for influencing the way it erupts. Three main magma types, and resulting volcanic rocks, are identified on the basis of their chemical composition.

Basaltic magma is rich in iron and magnesium, but has less silicon than other magmas. It erupts at very high temperatures (around 1100–1200°C) as a very fluid magma. Basaltic magma with very little gas cools to form black, dense lava, but where magma erupts with lots of gas it cools to form ragged scoria.

Andesitic magma is intermediate in composition and physical properties. Erupting at around 800–1,000°C it is more viscous than basalt, but much less viscous than rhyolitic. Andesitic magma cools to form dark grey lava if gas-poor, or scoria if gas-rich.

Magma Formation

Volcanic eruptions are the result of magma rising to the surface becoming lava in a variety of forms and environments. The

formation of magma depends upon rock melting in the mantle due to increasing temperature, decreasing pressure, and/or the addition of water. The melted rock may rise to the surface if it is less dense then the surrounding rock material. These conditions matched with the composition and gas content will determine whether the eruption is gentle or violent.

Remember from the Rocks chapter that 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. Magma collects in **magma chambers** in the crust at 160 kilometers (100 miles) beneath the surface.

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 (**Figure** below).



Figure 14.2

Honey flows slowly. It is more viscous than water.

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 and so it gets stuck. Dissolved gases become trapped by thick magma. The magma churns in the chamber and the pressure builds.

Eruptions

The type of magma in the chamber determines the type of volcanic eruption. Although the two major kinds of eruptions – explosive and effusive - are described in this section, there is an entire continuum of eruption types. Which magma composition do you think leads to each type?

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. Felsic magmas erupt explosively. Hot, gas-rich magma churns within the chamber. The pressure becomes so great that the magma eventually breaks the seal and explodes, just like when a cork is released from a bottle of champagne. Magma, rock, and ash burst upward in an enormous explosion. The erupted material is called **tephra** (**Figure** below).



Figure 14.3

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.

Tephra, or pyroclastic material, is easily classified by grainsize. Volcanic ash is not ash in the sense of the remains of something that has been burnt. Grains less than 2 millimetres across are called ash. Those from 2 to 64 millimetres are called lapilli (from the Latin word for little stones). Larger material is called a block if it is dense and angular, or a bomb if it is full of gas bubbles and partly rounded.

Scorching hot tephra, ash, and gas may speed down the volcano's slopes at 700 km/h (450 mph) as a **pyroclastic flow.** Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F) (**Figure** below.).

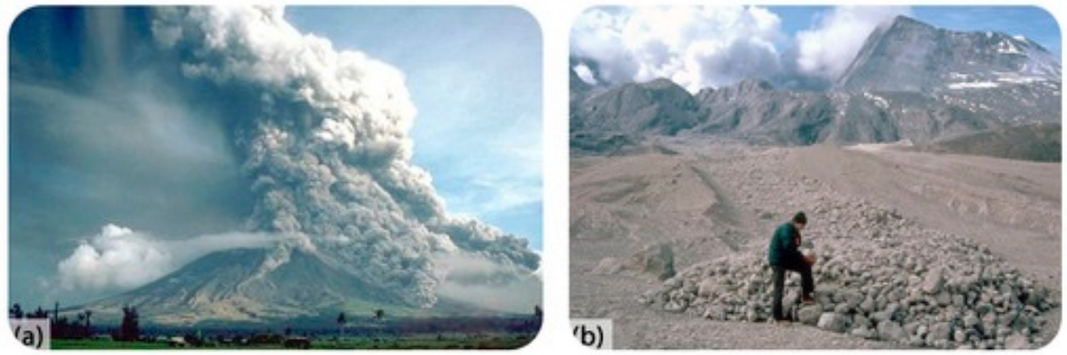


Figure 14.4

(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.

A pyroclastic flow is seen in this video:

http://science.howstuffworks.com/nature/7153-volcanoes-pyroclastic-flow-video.htm

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** below).

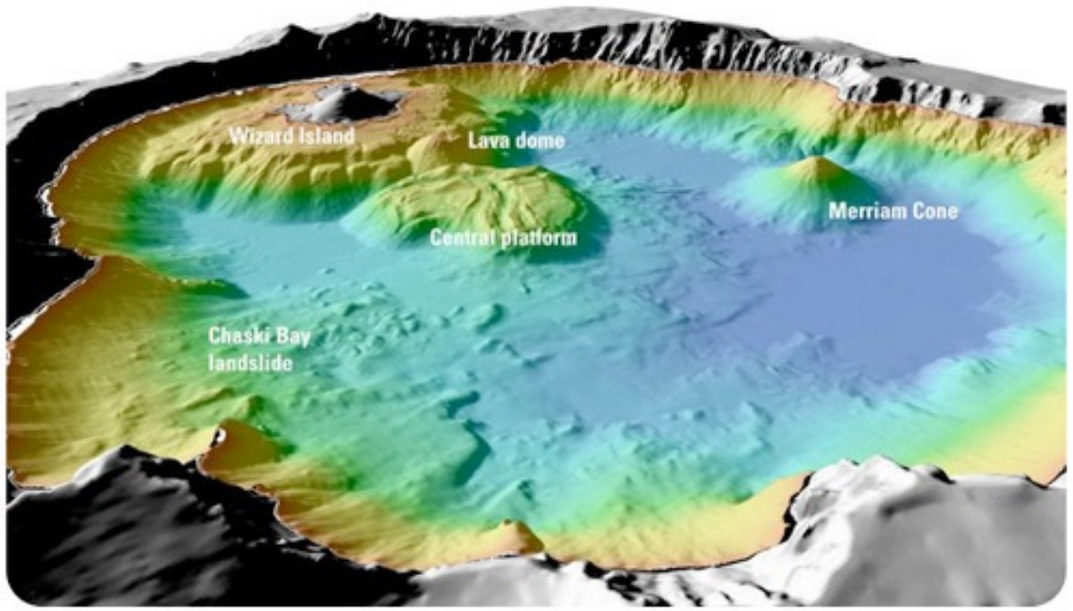


Figure 14.5

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 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** below).

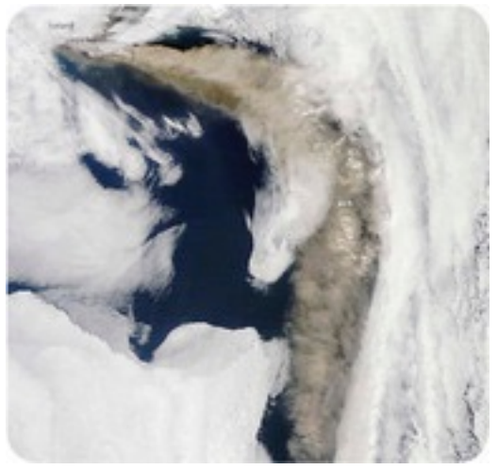


Figure 14.6

The ash plume from Eyjafjallajökull volcano in Iceland disrupted air travel across Europe for six days in April 2010.

Volcanoes are nothing unusual on Iceland, but the eruption that started June 8, 1783 was one of the deadliest. More than 9.000 people were killed by the direct effects of the eruption, like lava and poisonous gases. The ash was carried away with the wind and poisoned the land and the sea, killing half of the Icelandic cattle population and a quarter of the sheep and horses population. Nothing would grow on the fields and no more fish could be found in the sea. In the resulting famine (1783-1784) estimated twenty thousand people – one-third of the population of Iceland – died.

But the Laki eruption had possibly even more widespread effects. In the years after the eruption the climate in Europe deteriorated,

characterized by cool and rainy summers. The resulting crop failures triggered one of the most famous insurrections of starving people in history – the French Revolution of 1789-1799.
Furthermore. the foundation of the Marianist Community began during the French Revolution which makes your experience a very loose result of the 1783 eruption.

Effusive Eruptions

Basaltic 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. People can usually be evacuated before an effusive eruption, so they are much less deadly. Magma pushes toward the surface through fissures. Eventually, the magma reaches the surface and erupts through a vent (**Figure** below).

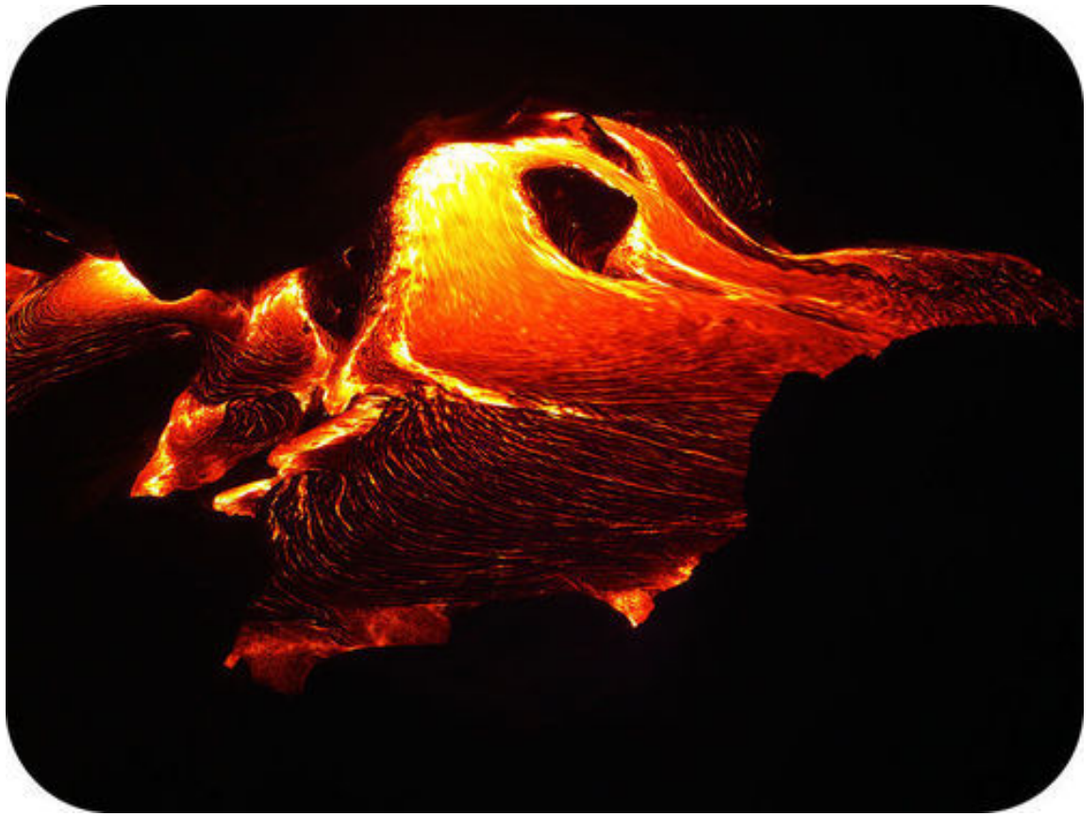


Figure 14.7

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 .

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 (**Figure** below).

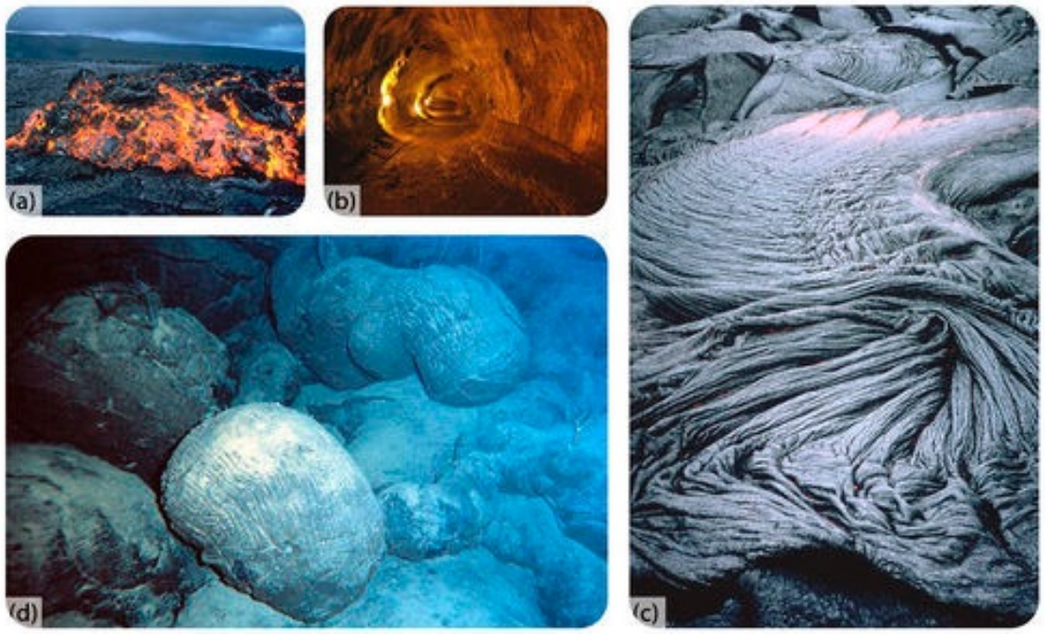


Figure 14.8

(a) 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. (b) Pāhoehoe lava forms lava tubes where fluid lava flows through the outer cooled rock crust, as can be seen at the Thurston Lava Tube in Hawai'i Volcanoes National Park. (c) Pāhoehoe lava is less viscous than a'a lava so its surface looks is smooth and ropy. (d) Mafic lava that erupts underwater creates pillow lava. The lava cools very quickly to roughly spherical rocks. Pillow lava is common at mid-ocean ridges.

- 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 .

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** below).



Figure 14.9

A road is overrun by an eruption at Kilauea volcano in Hawaii.

Predicting Volcanic Eruptions

Volcanologists attempt to forecast volcanic eruptions, but this has proven to be nearly as difficult as predicting an earthquake. 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. Which of these categories does the volcano fit into?

- **Active:** currently erupting or showing signs of erupting soon.
- **Dormant:** no current activity, but has erupted recently (**Figure** below).
- **Extinct:** no activity for some time; will probably not erupt again.



Figure 14.10

Mount Vesuvius destroyed Pompeii in 79 AD. Fortunately this volcano is dormant because the region is now much more heavily populated.

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** below) or, in some cases, from a distance using satellites. The amounts of gases and their ratios are calculated to help predict eruptions.



Figure 14.11

Scientists monitoring gas emissions at Mount St. Helens.

Remote Monitoring

Some gases can be monitored using satellite technology (**Figure** below). Satellites also monitor temperature readings and deformation. As technology improves, scientists are better able to detect changes in a volcano accurately and safely.



Figure 14.12

A satellite above Earth.

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.

Lesson Summary

- The style of a volcanic eruption depends on magma viscosity.

•Felsic magmas produce explosive eruptions. Mafic magmas produce effusive eruptions.
•Explosive eruptions happen along the edges of continents and produce tremendous amounts of material ejected into the air.
•Non-explosive eruptions produce lavas, such as a'a, pahoehoe, and pillow lavas.
•Volcanoes are classified as active, dormant, or extinct.
•Signs that a volcano may soon erupt include earthquakes, surface bulging, and gases emitted, as well as other changes that can be monitored by scientists.

Review Questions

1. What are the two basic types of volcanic eruptions?

2. Several hundred years ago, a volcano erupted near the city of Pompeii, Italy. Archaeologists have found the remains of people embracing each other, suffocated by ash and rock that covered everything. What type of eruption must have this been?

3. What is pyroclastic material?

4. Name three substances that have low viscosity and three that have high viscosity.

5. Why might the addition of water make an eruption more explosive?

6. What are three names for non-explosive lava?

7. What factors are considered in predicting volcanic eruptions?

8. Why is predicting a volcanic eruption so important?

9. Given that astronomers are far away from the planets they study, what evidence might they look for to determine the composition of a planet on which a volcano is found?

Further Reading / Supplemental Links

•The top five volcano web cams and video: http://news.discovery.com/videos/earth-top-5-volcano-webcams-and-videos.html

Points to Consider

•What would you look for to determine if an old eruption was explosive or non-explosive?
•Given the different styles of eruptions discussed above, what do you think the shapes of volcanoes are?
•Where do you think the names a'a and pāhoehoe came from?
•Do earthquakes always indicate an imminent eruption? What factors about an earthquake might indicate a relationship to a volcanic eruption?

Section 2

Where Volcanoes Are Lo-

Where Volcanoes Are Located

Lesson Objectives

•Describe how the locations of volcanoes are related to plate tectonics.
•Suggest why volcanoes are found at convergent and divergent plate boundaries.
•Describe how intraplate volcanoes can form.

Vocabulary

•fissure
•ring of fire

Introduction

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.

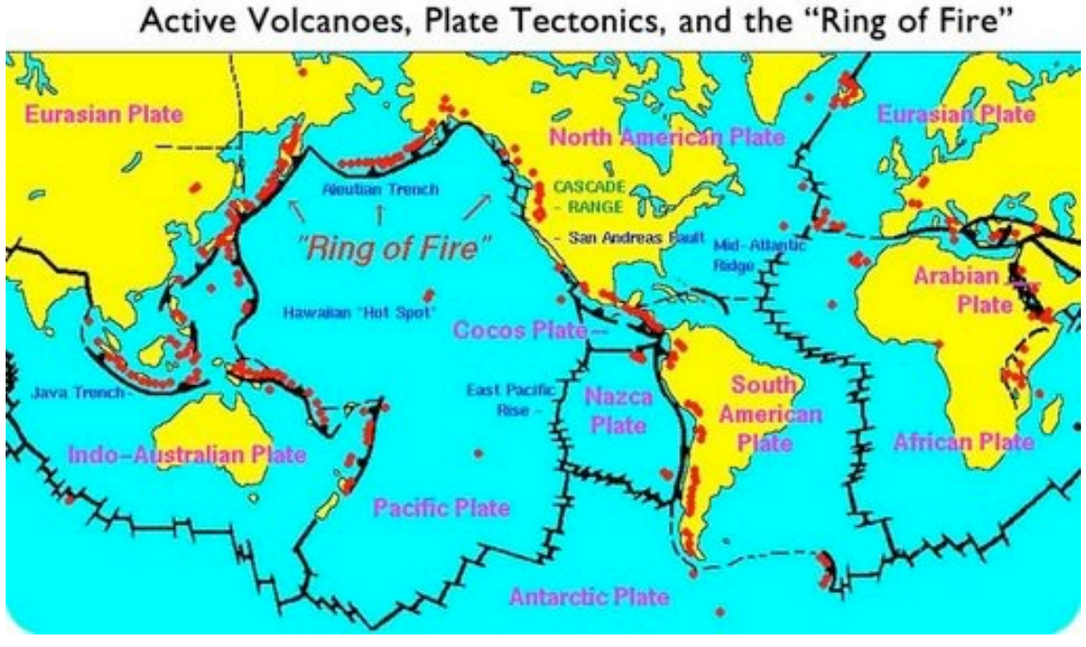


Figure 14.13
World map of active volcanoes.

See if you can give a geological explanation for the locations of all the volcanoes in **Figure** above . What is the Pacific Ring of Fire? Why are the Hawaiian volcanoes located away from any plate boundaries? What is the cause of the volcanoes along the mid-Atlantic ridge?

Convergent Plate Boundaries

Why does melting occur at convergent plate boundaries? 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. This water lowers the melting point of the mantle material, which increases melting. Volcanoes at convergent plate boundaries are found on the overriding plate as the more dense plate subducts and melts. All along the Pacific Ocean basin, primarily at the edges of

the Pacific, Cocos, and Nazca plates volcanoes mark the plate boundaries. Trenches mark subduction zones,although only the Aleutian Trench and the Java Trench appear on the map in **Figure** above .

Remember your plate tectonics knowledge. Large earthquakes are extremely common along convergent plate boundaries. Since the Pacific Ocean is rimmed by convergent and transform boundaries, about 80% of all earthquakes strike around the Pacific Ocean basin (**Figure** below). Why are 75% of the world's volcanoes found around the Pacific basin? Of course, these volcanoes are caused by the abundance of convergent plate boundaries around the Pacific.

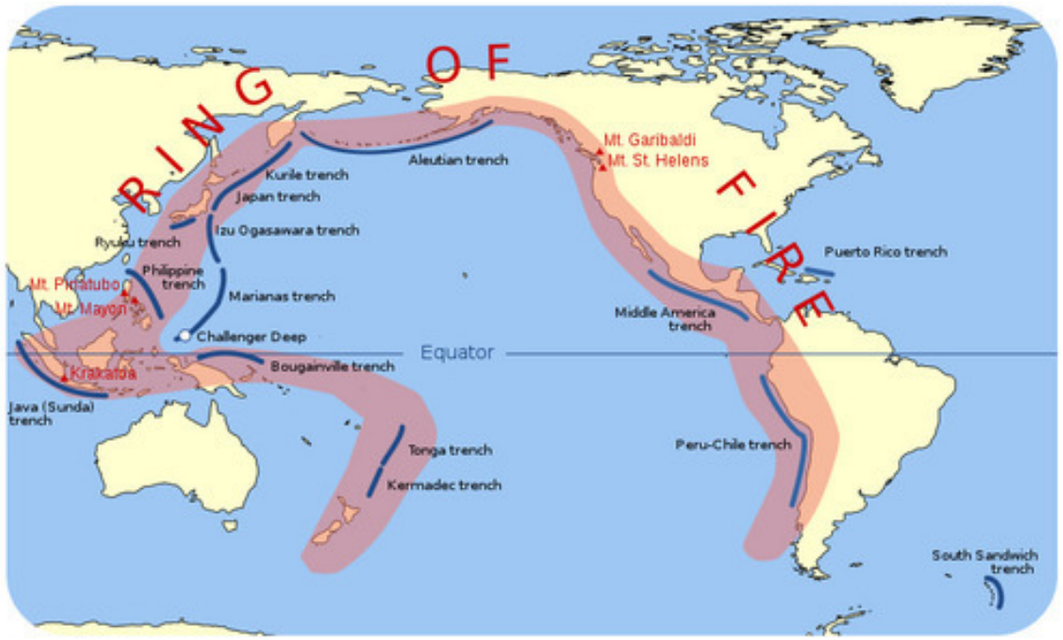


Figure 14.14

The Pacific Ring of Fire is where the majority of the volcanic activity on the Earth occurs.

A description of the Pacific Ring of Fire along western North America is a description of the plate boundaries.

- Subduction at the Middle American Trench creates volcanoes in Central America.
- The San Andreas Fault is a transform boundary.
- Subduction of the Juan de Fuca plate beneath the North American plate creates the Cascade volcanoes.
- Subduction of the Pacific plate beneath the North American plate in the north creates the Aleutian Islands volcanoes.

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 .

This incredible explosive eruption of Mount Vesuvius in Italy in A.D. 79 is an example of a composite volcano that forms as the result of a convergent plate boundary **(3f)** : http://www.youtube.com/watch?v=1u1Ys4m5zY4 (1:53).



Click on the image above for more content

Divergent plate boundaries

Most of the magma that reaches Earth's surface does so at divergent plate boundaires, along the mid-ocean ridges. Why does melting occur at divergent plate boundaries? Hot mantle rock rises where the plates are moving apart. This releases pressure on the mantle, which lowers its melting temperature. Lava erupts through long cracks in the ground, or **fissures.**

Footage of Undersea Volcanic Eruptions is seen in National Geographic Videos, Environment Video, Habitat, Ocean section: http://video.nationalgeographic.com/video/player/environment/ .

- Fantastic footage of undersea volcanic eruption is in the "Deepest Ocean Eruption Ever Filmed."
- "Giant Undersea Volcano Revealed" explores a volcano and its life off of Indonesia.

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** below).



Figure 14.15

A volcanic eruption at Surtsey, a small island near Iceland.

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in **Figure** below are in the East African Rift between the African and Arabian plates.



Figure 14.16

Mount Gahinga, a mountain in Uganda, located in the East African Rift valley.

Volcanic Hotspots

A volcanic "hotspot" is an area in the mantle from which heat rises as a thermal plume from deep in the Earth . High heat and lower pressure at the base of the lithosphere (tectonic plate) facilitates melting of the rock. This melt, called magma, rises through cracks and erupts to form volcanoes. As the tectonic plate moves over the stationary hot spot, the volcanoes are rafted away and new ones form in their place. This results in chains of volcanoes, such as the Hawaiian Islands.

The Hawaiian Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific plate. These islands are in the middle of the Pacific plate. The youngest island sits directly above a column of hot rock called a mantle plume. As the plume rises through the mantle, pressure is released and mantle melts to create a hotspot (**Figure** below).

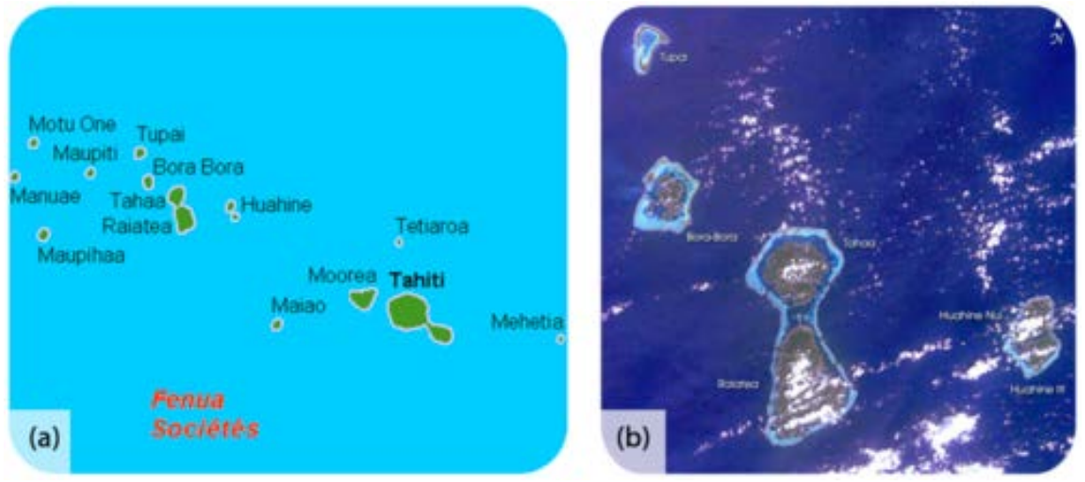


Figure 14.17

(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.

Earth is home to about 50 known hot spots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. The hotspots that are known beneath continents are extremely large, such as Yellowstone (**Figure** below).

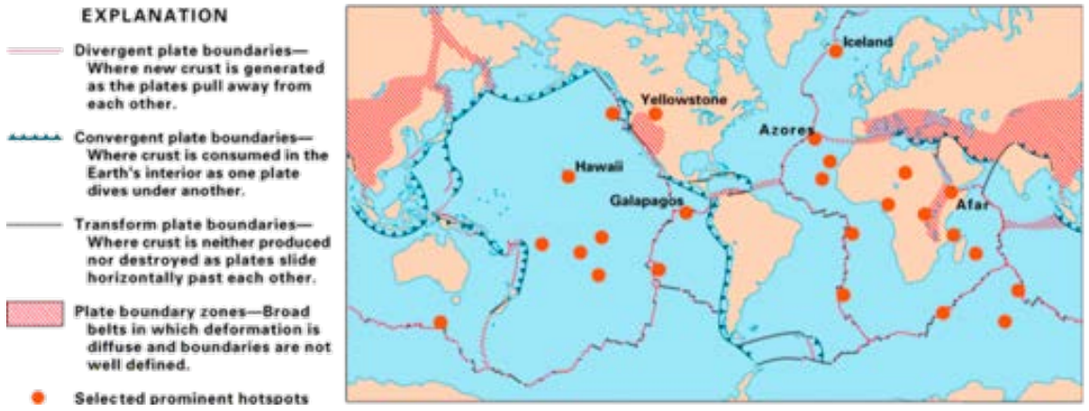


Figure 14.18

Prominent hotspots of the world.

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 (2:06).



Click on the image above for more content

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.

Lesson Summary

- Most volcanoes are found along convergent or divergent plate boundaries.
- The Pacific Ring of Fire is the most geologically active region in the world.

•Volcanoes such as those that form the islands of Hawaii form over hotspots, which are melting zones above mantle plumes.

Review Questions

1.Why are there volcanoes along the west coast of the United States?
2.Why does melting occur at divergent plate boundaries?
3.In **Figure** above , explain the geologic reason for every group of volcanoes in the diagram.
4.How did the Pacific Ring of Fire get its name? Does it deserve it?
5.What is a mantle plume?
6.Suppose a new volcano suddenly formed in the middle of the United States. How might you explain what caused this volcano?

Points to Consider

•Some volcanoes are no longer active. What could cause a volcano to become extinct?
•Hot spots are still poorly understood by Earth scientists. Why do you think it's hard to understand hotspots? What clues are there regarding these geological phenomena?
•Volcanoes have been found on Venus, Mars, and even Jupiter's moon Io. What do you think this indicates to planetary geologists?

Section 3

Types of Volcanoes

Types of Volcanoes

Lesson Objectives

- Describe the basic shapes of volcanoes.
- Compare the features of volcanoes.
- Describe the stages in the formation of volcanoes.

Vocabulary

- caldera
- cinder cone
- composite volcano
- shield volcano
- supervolcano

Introduction

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** below). As you might expect, the shape of a volcano is related to the composition of its magma.



Figure 14.19

Mount St. Helens was a beautiful, classic, cone-shaped volcano. The volcano's 1980 eruption blew more than 400 meters (1,300 feet) off the top of the mountain.

Composite Volcanoes

Composite volcanoes are made of rhyolitic to andesitic rock. The high viscosity of the lava means that eruptions at these volcanoes are often explosive (**Figure** below).



Figure 14.20

Mt. Fuji, the highest mountain in Japan, is a dormant composite volcano.

The viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. Viscosity also causes some eruptions to explode as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other (**Figure** below). The result is the classic cone shape of composite volcanoes.

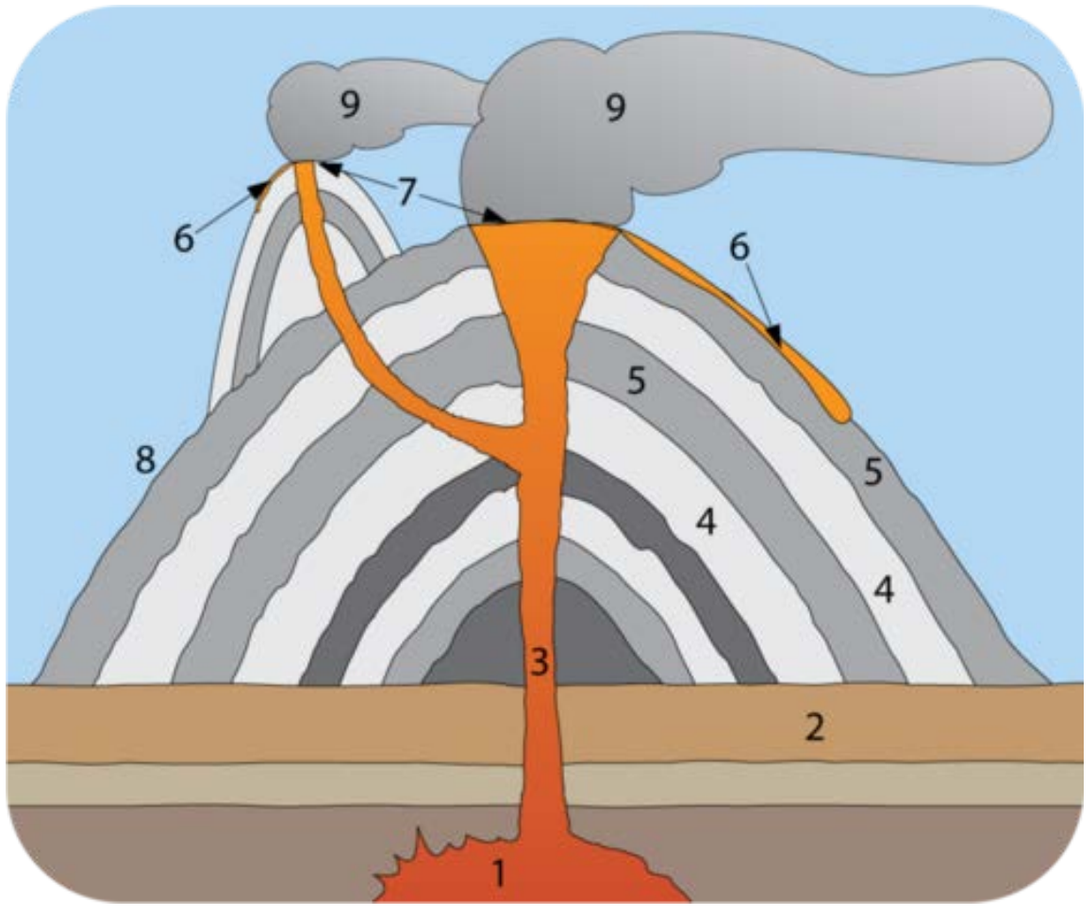


Figure 14.21

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.

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** below).

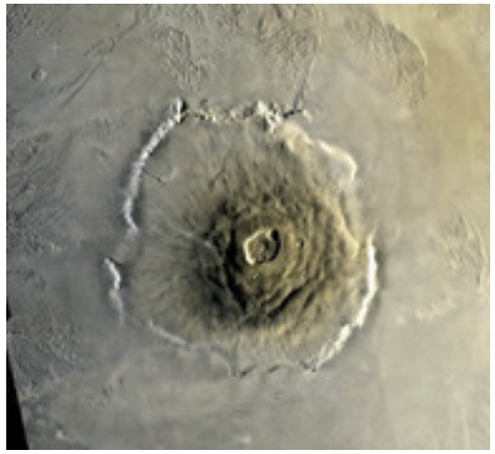


Figure 14.23



Figure 14.22

Mauna Loa Volcano in Hawaii (in the background) is the largest shield volcano on Earth with a diameter of more than 112 kilometers (70 miles). The volcano forms a significant part of the island of Hawaii.

The basaltic 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.

The largest volcano on Earth is Mauna Loa in the Hawaiian Island chain, a hot spot! However Mars in home to Olympus Mons, the largest shield volcano in our solar system. O lympus Mons is 624 km (374 mi) in diameter (approximately the same size as the state of Arizona), 25 km (16 mi) high, and is rimmed by a 6 km (4 mi) high scarp. A caldera 80 km (50 mi) wide is located at the summit of Olympus Mons. The volume of Olympus Mons is about 100 times larger than that of Mauna Loa. In fact, the entire chain of Hawaiian islands (from Kauai to Hawaii) would fit inside Olympus Mons!

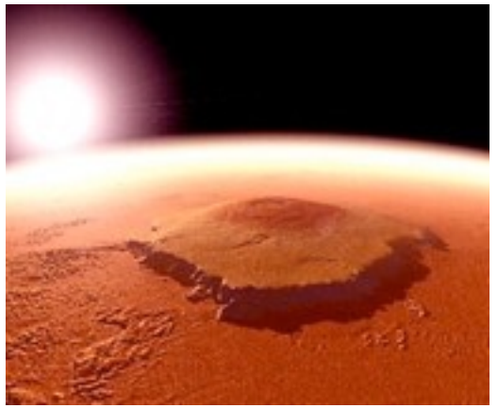


Figure 14.24

This *Volcanoes 101* video from National Geographic discusses where volcanoes are found and what their properties come from **(3e)** : http://www.youtube.com/watch?v=uZp1dNybgfc (3:05).



Click on the image above for more content

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 (**Figure** below). 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.



Figure 14.25

In 1943, a Mexican farmer first witnessed a cinder cone erupting in his field. In a year, Paricutín was 336 meters high. By 1952, it reached 424 meters and then stopped erupting.

Cinder cones are often found near larger volcanoes (**Figure** below).

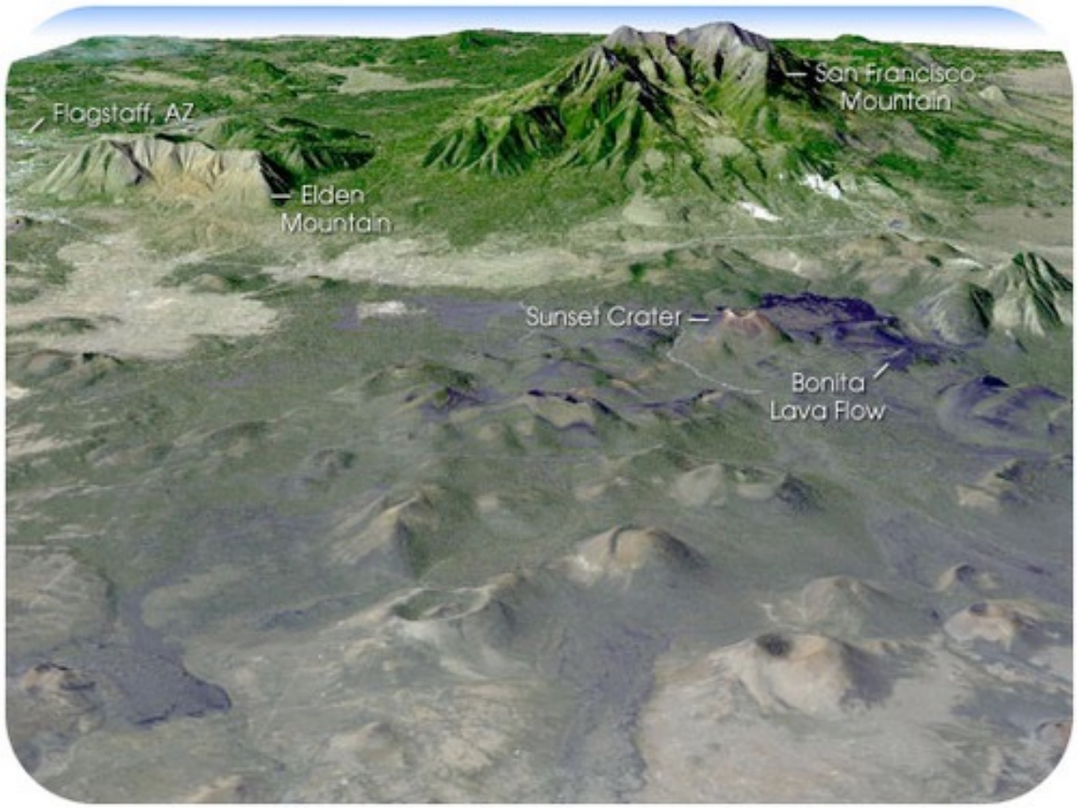


Figure 14.26

This Landsat image shows the topography of San Francisco Mountain, an extinct volcano, with many cinder cones near it in northern Arizona. Sunset crater is a cinder cone that erupted about 1,000 years ago.

Supervolcanoes

Supervolcano eruptions are extremely rare in Earth 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.

Supervolcanoes are a fairly new idea in volcanology. 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** below).



Figure 14.27

The caldera at Santorini in Greece is so large that it can only be seen by satellite.

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** below). Fortunately, current activity at Yellowstone is limited to the region's famous geysers.

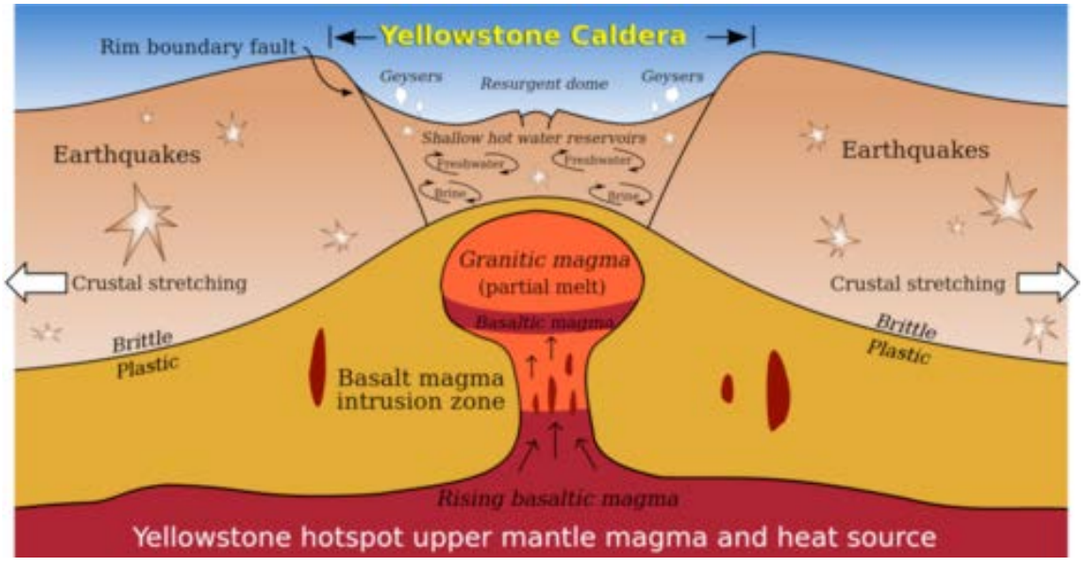


Figure 14.28

The Yellowstone hotspot has produced enormous felsic eruptions. The Yellowstone caldera collapsed in the most recent super eruption.

Long Valley Caldera, south of Mono Lake in California, is the second largest supervolcano in North America (**Figure** below). Long Valley had an extremely hot and explosive rhyolite about 700,000 years ago. An earthquake swarm in 1980 alerted geologists to the possibility of a future eruption, but the quakes have since calmed down.



Figure 14.29

The hot water that gives Hot Creek, California, its name is heated by hot rock below Long Valley Caldera.

- An interactive image of the geological features of Long Valley Caldera is available here:

http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/B&R_LongValleyCaldera.swf

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.

Lesson Summary

•Composite, shield, cinder cones, and supervolcanoes are the main types of volcanoes.
•Composite volcanoes are tall, steep cones that produce explosive eruptions.
•Shield volcanoes form very large, gently sloped mounds from effusive eruptions.
•Cinder cones are the smallest volcanoes and result from accumulation of many small fragments of ejected material.
•An explosive eruption may create a caldera, a large hole into which the mountain collapses.
•Supervolcano eruptions are devastating but extremely rare in Earth history.

Review Questions

1.Rank, in order, the four types of volcanoes from smallest to largest in diameter.
2.What factor best determines what type of volcano will form in a given area?
3.Which type of volcano is most common?
4.Why do pahoehoe and a'a lava erupt from shield volcanoes? Why don't they erupt from composite volcanoes?
5.Why are cinder cones short-lived?
6.If supervolcanoes are so big, why did it take so long for scientists to discover them?

Points to Consider

•Composite volcanoes and volcanic cones usually have craters on the top. Why are the craters sometimes U- or horseshoe-shaped?
•Think about plate boundaries again. What type of volcanoes do you think are found at convergent, divergent, and transform boundaries? How about at intraplate sites?
•Some people have theorized that if a huge asteroid hits the Earth, the results would be catastrophic. How might an asteroid impact and a supervolcano eruption be similar?

Section 4

Volcanic Landforms and

Volcanic Landforms and Geothermal Activity

Lesson Objectives

- List and describe landforms created by lava.
- Explain how magma creates different landforms.
- Describe the processes that create hot springs and geysers.

Vocabulary

- geyser
- hot spring
- lava dome
- lava plateau

Introduction

Volcanoes are associated with many types of landforms. The landforms vary with the composition of the magma that created them. Hot springs and geysers are also examples of surface features related to volcanic activity.

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 fissures (**Figure** below). The eruptions that created the entire ocean floor are essentially fissure eruptions.



Figure 14.30

A fissure eruption on Mauna Loa in Hawaii travels toward Mauna Kea on the Big Island.

Lava Domes

When lava is viscous, it is 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** below).



Figure 14.31

Lava domes are large, round landforms created by thick lava that does not travel far from the vent.

Lava flows often make mounds right in the middle of craters at the top of volcanoes, as seen in the **Figure** below .



Figure 14.32

Lava domes may form in the crater of composite volcanoes as at Mount St. Helens

Lava Plateaus

A **lava plateau** forms when large amounts of fluid lava flows over an extensive area (**Figure** below). When the lava solidifies, it creates a large, flat surface of igneous rock.



Figure 14.33



Figure 14.34

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.

Land

Lava creates new land as it solidifies on the coast or emerges from beneath the water (**Figure** below).

Lava hitting seawater creates new land.

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** below).

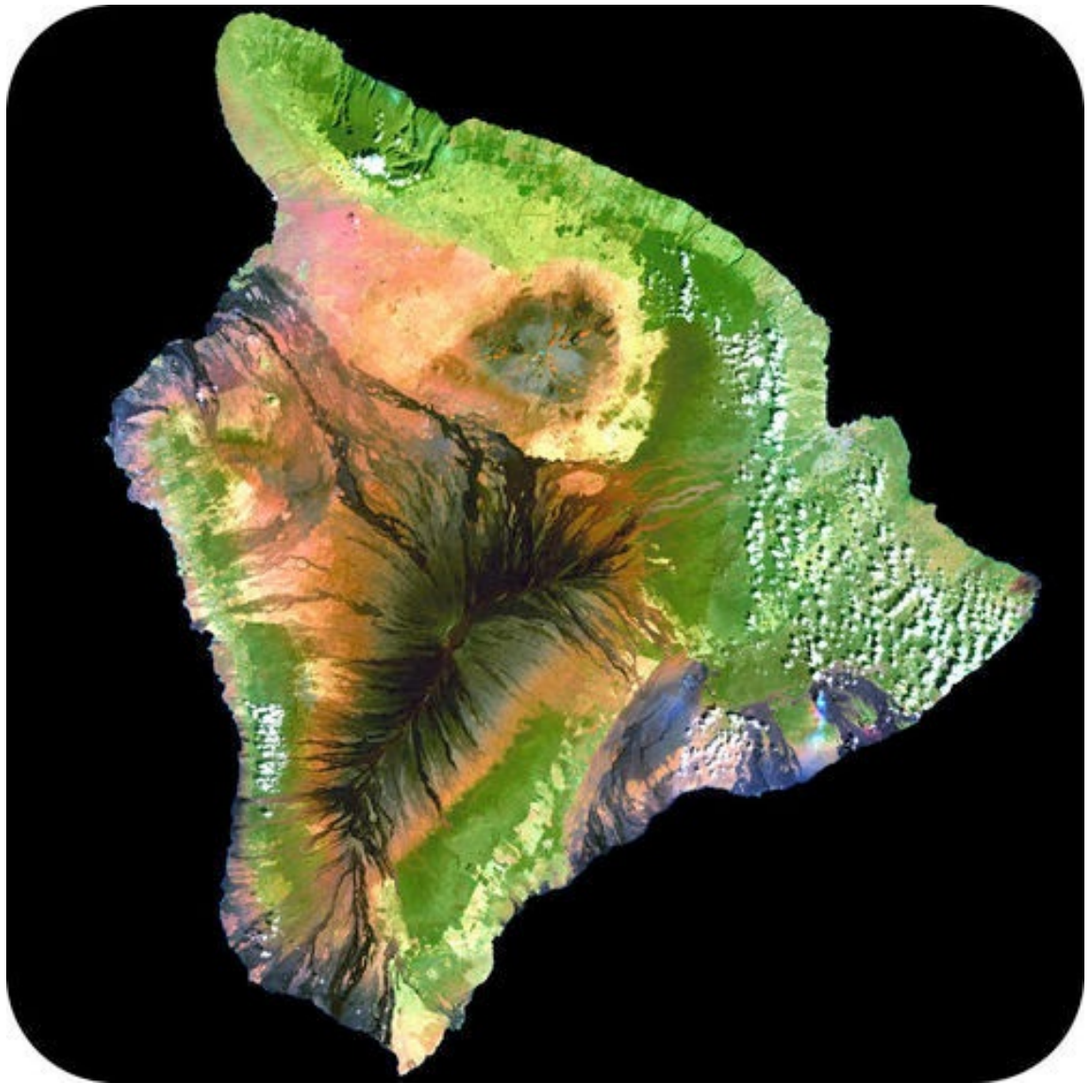


Figure 14.35

A compilation of satellite images of the Big Island of Hawaii with its five volcanoes.

Landforms from Magma

Magma intrusions can create landforms. Shiprock in New Mexico is the neck of an old volcano that has eroded away (**Figure** below).



Figure 14.36

The aptly named Shiprock in New Mexico.

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** (**Figure** below). The water in hot

springs may reach temperatures in the hundreds of degrees Celsius beneath the surface, although most hot springs are much cooler.



Figure 14.37

Even some animals enjoy relaxing in nature's hot tubs.

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. Eventually, the pressure grows so great that the superheated water bursts out onto the surface to create a geyser (**Figure** below).

Conditions are right for the formation of geysers in only a few places on Earth. Of the roughly 1,000 geysers worldwide and about half are found in the United States.



Figure 14.38

Castle Geyser is one of the many geysers at Yellowstone National Park. Castle erupts regularly, but not as frequently or predictably as Old Faithful.

Lesson Summary

•Viscous lava can produce lava domes along a fissure or within a volcano.
•Lava plateaus form from large lava flows that spread out over large areas.
•Many islands are built by or are volcanoes.
•Igneous intrusions associated with volcanoes may create volcanic landforms.
•When magma heats groundwater, it can reach the surface as hot springs or geysers.

Review Questions

1.What are four different landforms created by lava?
2.What is the major difference between hot springs and geysers?
3.The geyser called Old Faithful has been erupting for perhaps hundreds of years. One day, it could stop. Why might geysers completely stop erupting?
4.After earthquakes, hot springs sometimes stop bubbling, and new hot springs form. Why might this be?

Points to Consider

•What might the Earth look like if there were no tectonic plates? Are there any planets or satellites (moons) that may not have tectonic plates? How is their surface different from that of the Earth?
•The largest volcano in the solar system is Olympus Mons on Mars. How could this volcano have formed?
•What kind of land formations are the result of volcanic activity? Are all of these created by extrusive igneous rocks?
•How are hydrothermal vents at mid-ocean ridges like the geysers of Yellowstone?

References

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2.Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:MtRedoubtedit1.jpg . Public Domain
3.(a) Courtesy of CG Newhall/US Geological Survey; (b) Courtesy of DA Swanson/US Geological Survey. (a) http://commons.wikimedia.org/wiki/File:Pyroclastic_flows_at_Mayon_Volcano.jpg; (b) http://commons.wikimedia.org/wiki/File:Pyroclastic_Flow_St._Helens.jpg . Public Domain
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Ch. 12: Weathering and Formation of Soil



The solid granite rocks of Yosemite Valley appear to have been there forever and look as if they will be there forever. Yet this photo holds clues to the amazing changes that have taken place in the geologic history of Yosemite Valley and clues to what will lead to the Valley's eventual demise. The rounded domes are the way granitic rock breaks as pressure is released as it rises through the crust. Fractures seen in the granite expose weaknesses in the rock that can lead to boulders breaking off. Those boulders lie in the bottom of the valley.

Bridalveil Creek flows through a notch in the granite before plunging over a cliff as Bridalveil Falls. The creek has eroded a V-shaped valley for itself within the U-shaped valley that was once filled with a glacier. The falls plunge into another larger valley, Yosemite Valley, which also has a U-shape from the glacier that once flowed through it.

On the far left side of the photo is what's left of a granite dome that split in half. What will be left when the other half of Half Dome is gone?

Matt Howry. www.flickr.com/photos/mhowry/7117456309/. CC BY 2.0.

Section 1

Weathering

Weathering

Lesson Objectives

- Define mechanical and chemical weathering.
- Discuss agents of weathering.
- Give examples of each type of weathering.

Vocabulary

- abrasion
- chemical weathering
- climate
- erosion
- exfoliation domes
- external processes
- hydrolysis
- ice wedging
- leaching
- mass wasting
- mechanical weathering
- oxidation
- sheeting

Introduction

The footprints that astronauts left on the Moon will be there forever. Why? This is because the Moon has no atmosphere and, as a result, has little to no weathering. Weathering is one of the forces on Earth that destroy rocks and landforms. Without weathering, geologic features would build up but would be less likely to break down. What causes solid rock to crumble, and why does the typeand rate of weathering vary from place to place on Earth?

What is Weathering?

Weathering is the process that changes solid rock into sediments. With weathering, rock is disintegrated. It breaks into pieces. **Weathering** is the physical breakdown (disintegration) and chemical alteration (decomposition) of rocks at or near Earth's surface.

Once these sediments are separated from the rocks, erosion is the process that moves the sediments. The four forces of erosion are water, wind, glaciers, and gravity. Weathering, mass wasting, and erosion are all called **external processes** because they occur at or near Earth's surface and are powered by energy from the Sun. External processes are a basic part of the rock cycle because they are responsible for transforming solid rock into sediment.

- Water is responsible for most erosion. Water can move most sizes of sediments, depending on the strength of the force.
- Wind moves sand-sized and smaller pieces of rock through the air.
- Glaciers move all sizes of sediments, from extremely large boulders to the tiniest fragments.
- Gravity moves broken pieces of rock, large or small, downslope called **mass wasting** .

Erosion is the physical removal of material by mobile agents such as water, wind, or ice. Weathering cannot be easily separated from erosion and mass wasting because as weathering breaks apart the rock, it facilitates the movement of rock debris. Conversely, the transport of material by mass wasting and erosion further disintegrates and decomposes the rock.

While plate tectonics(an internal process) 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.

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** below). 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 15.1

A once smooth road surface has cracks and fractures, plus a large pothole.

Weathering occurs when rock is mechanically (disintegrated) and/or chemically altered (decomposed). **Mechanical weathering** is accomplished by physical forces that break rock into smaller and smaller pieces without changing the rock's mineral composition. **Chemical weathering** involves a chemical transformation of rock into one or more new compounds. These two concepts can be illustrated with a piece of paper. The paper can be disintegrated by tearing it into smaller and smaller pieces, whereas decomposition occurs when the paper is set afire and burned. The following sections will discuss the various modes of mechanical and chemical weaterhing.

Mechanical Weathering

Mechanical weathering (also called physical weathering) breaks rock into smaller pieces (disintegration). These smaller pieces are just like the bigger rock, just 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. Weathering is a basic part of the rock cycle and thus a key process in the Earth system. Many life-sustaining minerals and elements found in soil, and ultimately in the food we eat, were freed from solid rock by weathering processes.

The figure **below** shows that breaking rock into smaller pieces increases the surface area available for chemical attack.
Hence, by breaking rocks into smaller pieces, mechanical weathering increases the amount of surface area available for chemical weathering.

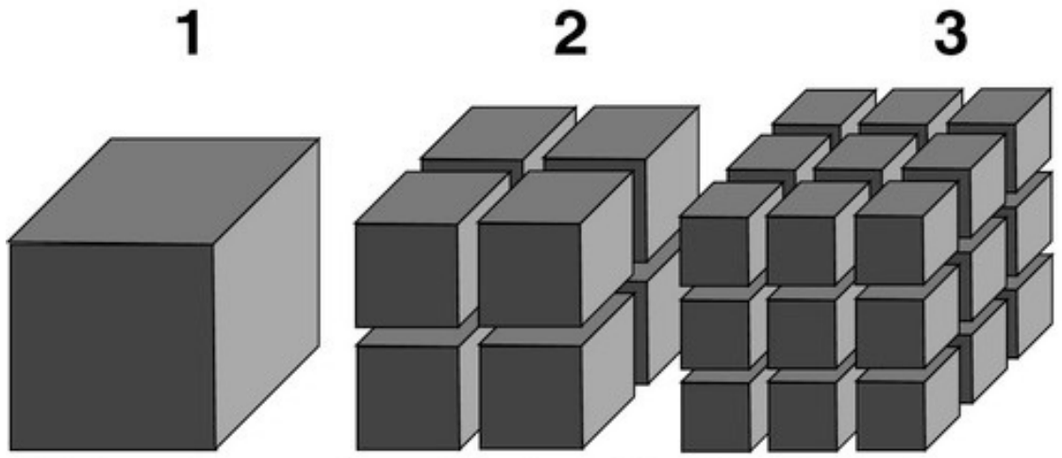


Figure 15.2

Chemical weathering can occur only to those portions of a rock that are exposed to the elements. Mechanical weathering breaks rock into smaller and smaller pieces, thereby increasing the surface area available for chemical attack.

There are many ways that rocks can be broken apart into smaller pieces and in turn increase surface area. One such example is called ice wedging/frost wedging.

1. Ice wedging is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point (**Figure** below). 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.

If you leave a glass bottle of water in the freezer a bit too long, you will find the bottle fractured. The bottle breaks becasue water has the unique property of expanding about 9 percent upon freezing. This is also the reason pporly insulated or exposed water pipes rupture during frigid weather. You might also expect this same process to fracture rocks in nature. This is, in fact, the basis for the traditional explanation of ice wedging. After water works its way into the cracks in rock, the freezing water enlarges the cracks and angular fragments are eventually produced.

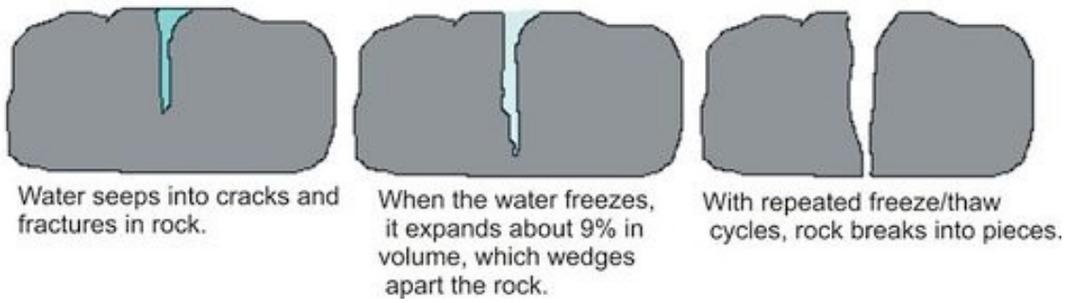


Figure 15.3

Ice wedging.

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.

2. 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** below).



Figure 15.4

Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

3. Biological Activity: Plants and animals can do the work of mechanical weathering (**Figure** below). 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 and move fresh material to the surface where physical and chemical processes can attack it. Decaying organisms also produce acids, which contribute to chemical weathering. Where rock has been blasted in search of minerals or for road construction, the impact of humans is particularly noticeable.



Figure 15.5

(a) Human activities are responsible for enormous amounts of mechanical weathering, by digging or blasting into rock to build homes, roads, subways, or to quarry stone. (b) Salt weathering of building stone on the island of Gozo, Malta.

4. Salt Crystal Growth: Another expansive force that can split rock is created by the growth of salt crystals. Rocky shorelines and arid regions are common settings for this process. It begins when sea spray from breaking waves or salty groundwater penetrates crevices and pore spaces in rock. As this water evaporates, salt crystals form. As these crystals gradually grow larger, they weaken the rock by pushing apart surrounding grains or enlarging tiny cracks.

This same process can also contribute to crumbling roadways where salt is spread to melt snow and ice in winter. The salt dissolves in water and seeps into cracks that quite likely originated from frost action. When the water evaporates, the growth of salt crystals further breaks the pavement.

5. Sheeting: When large masses of igneous rock, particularly those composed of granite, are exposed by erosion, concentric slabs begin to break loose. The process generating these onion-like layers is called **sheeting** and probably takes place in response to the great reduction in pressure that occurs when the overlying rock is eroded away. Accompanying this unloading, the outer layers expand more than the rock below and thus separate from the rock body. Continued weathering eventually causes the slabs to separate and fall off, creating **exfoliation domes** . Half Dome in Yosemite Noational Park is an excellent example (see introduction to this chapter).

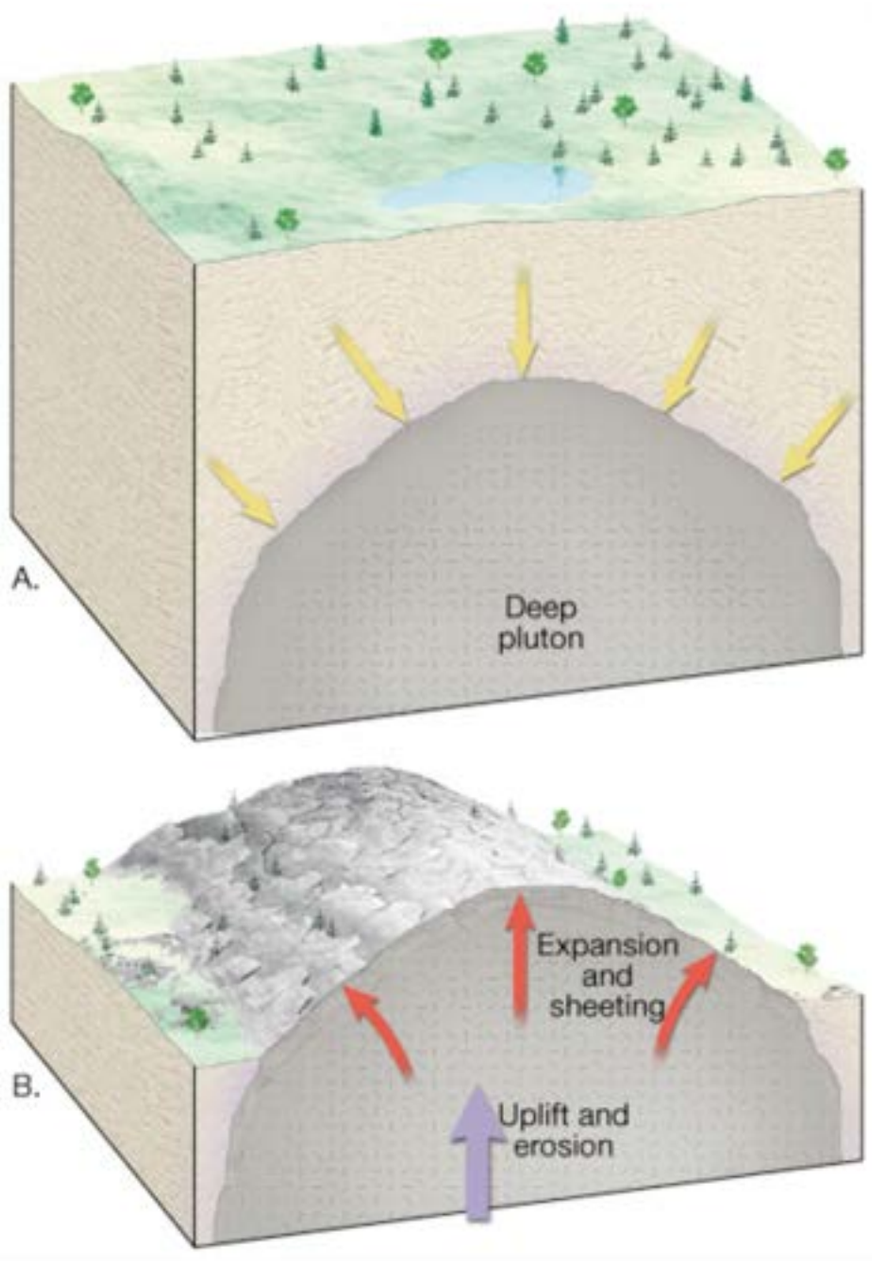


Figure 15.6

Sheeting is caused by expansion of crystalline rock as erosion removes the overlying material. When deeply buried pluton in A is exposed to the surface following uplift and erosion in B, the igneous mass fractures into thin slabs.

Chemical Weathering

Chemical weathering is the other important type of weathering. Chemical weathering is different from mechanical weathering because the rock changes, not just in size of pieces, but in composition. That is why one type of mineral can change into a different mineral. Chemical weathering works through chemical reactions that cause changes in the minerals.

It should be noted that chemical weathering contributes to mechanical weathering. It does so by weakening the outer portions of some rocks, which, in turn, makes them more susceptible to being broken by mechanical weathering processes.

Most minerals form at high pressure or high temperatures deep in the crust, or sometimes in the mantle. When these rocks reach the Earth's surface, they are now 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. Consequently, the products of chemical weathering will remain essentially unchanged as long as they remain in an environment similar to the one in which they formed.

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** below).



Figure 15.7

Deforestation in Brazil reveals the underlying clay-rich soil.

There are many types of chemical weathering because there are many agents of chemical weathering. Water is the most important agent of chemical weathering. Two other important agents of chemical weathering are carbon dioxide and oxygen.

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. 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.

> •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 undergone **leaching** . 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. The weathering of potassium feldspar from granite generates a residual clay mineral, a soluable salt, and some silica that enters into solution. When granite weathers, the feldspar crystals dull and slowly turn to clay, releasing the once interlocked quartz grains, which still retain their fresh, glassy appearance.

Chemical Weathering by Carbon Dioxide

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 accelerate chemical weathering (**Figure** below). Acids such as carbonic acid readliy decompose many rocks and produce certain products that are water soluable. For example, the mineral $CaCO_3$, which composes the common building stones marble and limestone, is easily attacked by even a weakly acidic solution.



Figure 15.8

This statue has been damaged by 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** below). Minerals that are rich in iron break down as the iron oxidizes and forms new compounds. When an iron nail is found in moist soil, it will have a coating of rust (iron oxide), and if the time of exposure has been long, the nail will be so weak that it can be broken as easily as a toothpick. Iron oxide produces the yellow-red color in soils.



Figure 15.9

When iron rich minerals oxidize, they produce the familiar red color found in rust.

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.

Influences on Weathering/Rates of Weathering

Weathering rates depend on several factors. We have already seen how mechanical weathering affects the rate of weathering. By

breaking rock into smaller pieces, the amount of surface area exposed to chemical weathering is increased. Other important factors include the composition of the rock and the minerals it contains as well as the climate of a region.

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. Devil's Tower in Wyoming is an igneous rock from beneath a volcano (**Figure** below). As the surrounding less resistant rocks were worn away, the resistant center of the volcano remained behind.



Figure 15.10

Devil's Tower is the central plug of resistant lava from which the surrounding rock weathered and eroded away.

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.

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 ◦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** below). This happens because plants and bacteria grow and multiply faster in warmer temperatures.

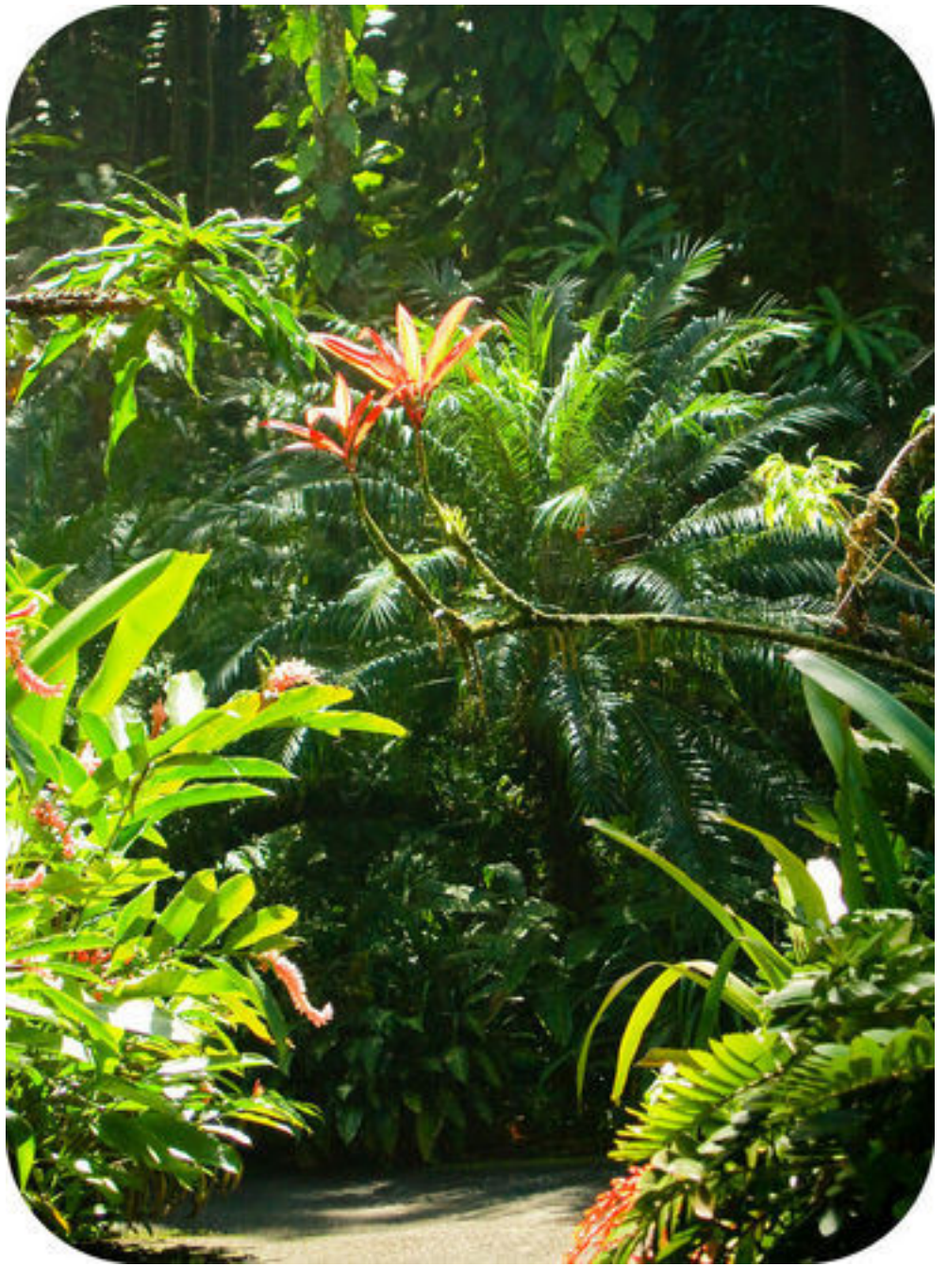


Figure 15.11

Wet, warm tropical areas have the most 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.

Lesson Summary

- Mechanical weathering breaks rocks into smaller pieces without changing their composition.
- Ice wedging and abrasion are two important processes of mechanical weathering.
- Chemical weathering breaks down rocks by forming new minerals that are stable at the Earth's surface.
- Water, carbon dioxide, and oxygen are important agents of chemical weathering.
- Different types of rocks weather at different rates. More resistant types of rocks will remain longer.

Review Questions

1. What are the four forces of erosion and which is responsible for the most erosion?
2. Name two types of mechanical weathering. Explain how each works to break apart rock.
3. What are three agents of chemical weathering? Give an example of each.
4. What type of climate would likely produce the greatest degree of weathering? Explain.
5. What causes differential weathering in a rock?
6. Would a smooth even surface weather faster than an uneven, broken surface?
7. What type of rocks would be best suited to making monuments?

Points to Consider

- What other types of surfaces are affected by weathering other than rock?
- What might the surface of the Earth look like if there was no weathering? Think about the Moon or other planets.
- Do you think that you would be alive today if water did not dissolve elements?
- Would the same composition of rock weather the same way in three very different climates?

Soils

Lesson Objectives

- Discuss why soil is an important resource.
- Describe how soil forms from existing rocks.
- Describe the different textures and components of soil.
- Draw and describe a soil profile.

Vocabulary

- A horizon
- B horizon
- C horizon
- E horizon
- eluviation
- hardpan
- humus
- inorganic
- leaching
- loam
- O horizon
- parent material
- permeable
- residual soil
- soil
- soil horizon
- soil profile
- solum
- subsoil
- topsoil
- transported soil

Introduction

Without mechanical and chemical weathering working to break down rock, there would not be any soil on Earth. It is unlikely that humans or most other creatures would be able to live on Earth without soil. Wood, paper, cotton, medicines, and even pure water need soil. So soil is a precious resource that must be carefully managed and cared for. Although soil is a renewable resource, its renewal takes a lot of time. Soil is one of our most indespensable resources and is taken for granted by many of us. Soil has accurately been called "the bridge between life and the inanimate world." All life--the entire biosphere--owes its existence to a dozen or so elements that must ultimately come from Earth's crust.

Soil

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. When Earth id viewed as a system, soil is referred to as an interface--a common boundary where different parts of a system interact. Within the soil layer, important reactions between solid rock, liquid water, air, and living things take place. **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.

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** below).



Figure 15.12

Peat is so rich in organic material, it can be burned for energy.

Soil is an ecosystem unto itself. In the spaces of soil, there are thousands or even millions of living organisms. Those organisms could be anything from earthworms, ants, bacteria, or fungi (**Figure** below).



Figure 15.13

Earthworms and insects are important residents of soils.

Soil gradually evolves to a state of equilibrium, or balance, with the environment. Soil is dynamic and sensitive to almost every aspect of its surroundings. Thus, when environmental changes occur--in climate, vegetation cover, or animal (including human) activity--the soil responds, Any such change produces a gradual alteration of soil characteristics until a new balance is reached. Although thinly distributed over the land surface, soil functions as a fundamental interface, providing an excellent example of the integration among many parts of the Earth system.

Soil Horizons and Profiles

It is important to realize that soil-forming processes operate from the surface downward. Thus variations in composition, texture, structure, and color gradually evolve at varying depths. These vertical differences, which usually become more pronounced as time passes, divide the soil into zones or layers known as

horizons . If you were to gig a trench in soil, you would see that its walls are layered. Such a vertical section through all of the soil horizons constitutes the **soil profile** .

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** below).



Figure 15.15

Soil is an important resource. Each soil horizon is distinctly visible in this photograph.

The figure **below** presents an idealized view of a well-developed soil profile in which five horizons are identified. From the surface downward, they are designated as O, A, E, B ,and C respectively. These five horizons are common to soils in temperate regions. The characteristics and extent of development of horizons vary in different environments. Thus, different localities exhibit soil profiles that can contrast greatly with one another.

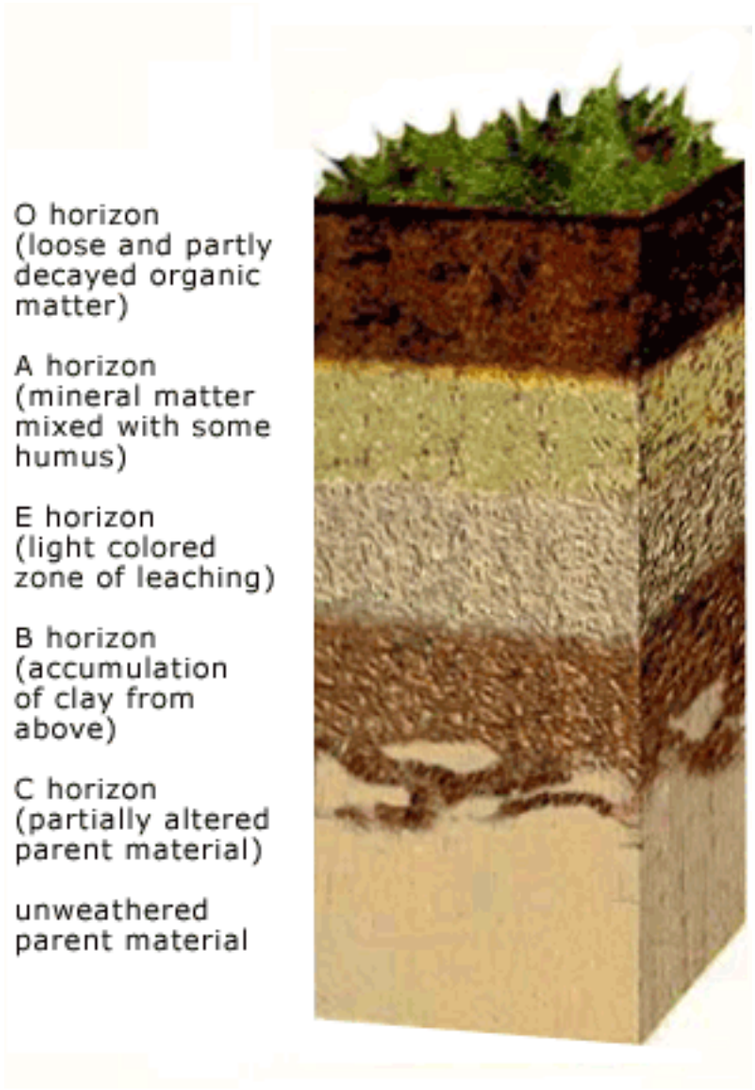


Figure 15.17

O Horizon

The **O horizon** consists largely of organic material. This is in contrast to the layers beneath it, which consists mainly of mineral matter. The upper portion of the O horizon is primarily plant litter such as loose leaves and other organic debris that are still recognizable. By contrast, the lower portion of the O horizon is made up of partly decomposed organic matter (humus) in which plant structures can no longer be identified. The O horizon is filled with microscopic life, including bacteria, fungi, algae, and insects. All of these organisms contribute oxygen, carbon dioxide, and organic acids to the developing soil.

Topsoil

Underlying the organic-rich O horizon is the **A horizon.** This zone is largely mineral matter, yet biological activity is high and humus is generally present--up to 30 percent in some instances. Together the O and A horizons make up what is commonly called **topsoil** . Below the A horizon, the E horizon is a light-colored layer that contains little organic material. As water percolates downward through this zone, finer particles are carried away. This washing-out of the fine soil components is termed **eluviation** . Water percolating downward also dissolves soluable inorganic soil components and carries them to deeper zones. This depletion of soluable materials from the upper soil is termed **leaching** .

Subsoil

Immediately below the E horizon is the **B horizon,** or **subsoil** . Much of the material removed from the E horizon by eluviation is deposited in the B horizon, which is often referred to as the zone of accumulation. The accumulation of the fine clay particles enhances water retention in the subsoil. However, in extreme cases clay accumulation can form a very compact and impermeable layer called hardpan. The O, A, E, and B horizons together constitute the **solum** , or "true soil." It is in the solum that the soil-forming processes are active and that living roots and other plant and animal life are largely confined.

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.

Characteristics of Soil

1. 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. 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.
- 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.

2. Rock Type

The original rock (parent material) 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. Parent material may be the underlying bedrock, or it can be a layer of unconsolidated deposits, as in a stream valley. 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.

The nature of the parent material influences soils in two ways. First, the type of parent material affects the rate of weathering and

thus the rate of soil formation. (Consider the weathering of granite versus limestone.) Also, because unconsolidated deposits are already partly weathered and provide more surface area for chemical weathering, soil development on such material usually progresses more rapidly. Second, the chemical makeup of parent material affects soil fertility. This influences the character of the natural vegetation the soil can support.

3. Slope/topography

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. On steep slopes, soils are often poorly developed. In such situations little water can soak in, and as a result, soil moisture may be insufficient for vigorous plant growth

4. 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. Soil does not form overnight. In fact, soil formation can take thousands, and in some cases even millions of years. A newly exposed surface will have very little if any soil, while old surfaces will often have much deeper soils.

How many years does it take for a soil to form? Soil scientists have measured the age of many soils and have a wide range of rates of soil formation. A one-meter thick soil developed from loess in southern Wisconsin in 8000 years, while a one-meter thick soil in tropical Africa took 75,000 years to form. An average global soil formation rate has been calculated to be 178 years per cm.

Often it is easier to think about soil formation in terms of how rapid specific horizons develop. In general it takes less time for surface horizons to develop than subsoil horizons. A soil is said to have reached a "steady state" when its individual horizons and properties change little over long periods of time. Often this rate of change is too slow to be seen in our lifetime.

In General the following happens with time for a soil:

- thicker horizons that sink deeper into the parent material
- increased iron accumulation making the soils redder
- increased clay content
- increased acidity (soils with lower pH)
- leaching of nutrients so soils are less fertile.

In the USA the oldest soils occur on the terraces and alluvial fans of the Sierra Nevada Mountains in California and the desert soils of Arizona and New Mexico. In these areas silica or calcium carbonate may accumulate in the soil to the extent that the soil becomes cemented or indurated into a hardpan. This hardpan can not be broken with hand tools and if the upper surface erodes away the cycle of soil development begins again. The Californian soil is estimated to be 750,000 years old. The oldest soils in the world occur in Australia and Africa where the landscapes have been stable for million of years.

5. 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.

Soil Texture and Composition

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.

- 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** below).



Figure 15.18

A loam field.

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** below). 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, and at the right corner it would be silt. Soils in the lower middle with less than 50% clay are loams.

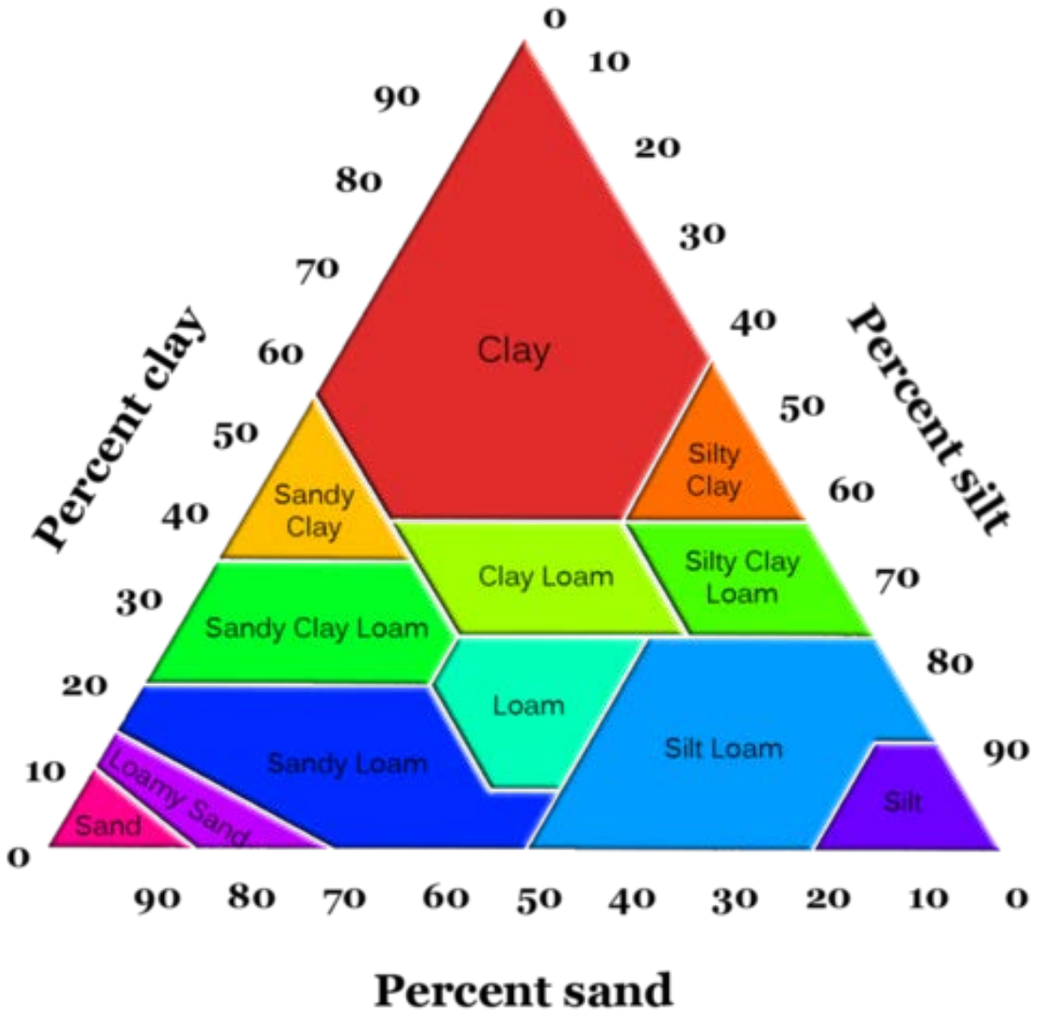


Figure 15.19

Soil types by particle size.

Using the chart as a guide, what is the composition of a sandy clay loam?

Soil Conservation

Soil is only a renewable resource if it is carefully managed. 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.

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. In many areas of the world, the rate of soil erosion is many times greater than the rate at which it is forming. Soils can also be contaminated if too much salt accumulates in the soil or where pollutants sink into the ground. There are many practices that can protect and preserve soil resources. 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 onto water and nutrients (**Figure** below). 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.



Figure 15.20

Organic material can be added to soil to help increase its fertility.

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** below). No-till or low-tillage farming helps to keep soil in place by disturbing the ground as little as possible when planting.



Figure 15.21

Steep slopes can be terraced to make level planting areas and decrease surface water runoff and erosion.

Lesson Summary

•Soil is an important resource. Life on Earth could not exist as it does today without soil.
•The type of soil that forms depends mostly on climate and, to a lesser extent, on the original parent rock material and other factors.
•Soil texture and composition, plus the amount of organic material in a soil, determine a soil's qualities and fertility.
•Given enough time, rock is weathered to produce a layered soil, called a soil profile.
•Each type of climate can ultimately produce a unique type of soil.

Review Questions

1.Why is soil sometimes described as a living resource?
2.Name two factors that influence soil formation and explain how they do so.
3.Which region of a soil profile reacts the most?
4.Is the soil in your backyard most likely a residual soil or a transported soil? How could you check?
5.Name several advantages to adding humus to the soil.
6.What are three soil horizons? Describe the characteristics of each.
7.Where would you choose to buy land for a farm if you wanted fertile soil and did not want to have to irrigate your crops?

Further Reading / Supplemental Links

•The University of British Columbia has a collection of images that illustrate various aspects of soils: See here for more info.

Points to Consider

- Why is soil such an important resource?
- Would soil mature faster from unaltered bedrock or from transported materials?
- If soil erosion is happening at a greater rate than new soil can form, what will eventually happen to the soil in that region?
- Do you think there are pollutants that could not easily be removed from soil?

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Erosion and Deposition by

Erosion and Deposition by Gravity

Lesson Objectives

- Describe the ways that material can move downhill by gravity.
- Discuss the factors that increase the likelihood of landslides.
- Describe the different types of gravity-driven movement of rock and soil.
- Describe ways to prevent and be aware of potential landslides or mudflows.

Vocabulary

- avalanche
- creep
- landslide
- mass movement
- mass wasting
- mudflow
- slump
- talus slope

Introduction

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.

Types of Movement Caused by Gravity

Movements caused by gravity are together referred to as **mass wasting** or **mass movement** . 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** (**Figure** below). Sometimes as one rock falls, it hits another rock, which hits another rock, and begins a landslide.



Figure 15.22

Pieces of rock regularly fall to the base of cliffs to form talus slopes.

Landslides and Avalanches

Landslides and **avalanches** are the most dramatic, sudden, and dangerous examples of earth materials moved by gravity. Landslides are sudden falls of rock, whereas avalanches are sudden falls of snow.

- A video of a snow avalanche is seen here: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/2Avalanches.mov

When large amounts of rock suddenly break loose from a cliff or mountainside, they move quickly and with tremendous force (**Figure** below). Air trapped under the falling rocks acts as a cushion that keeps the rock from slowing down. Landslides and avalanches can move as fast as 200 to 300 km/hour.

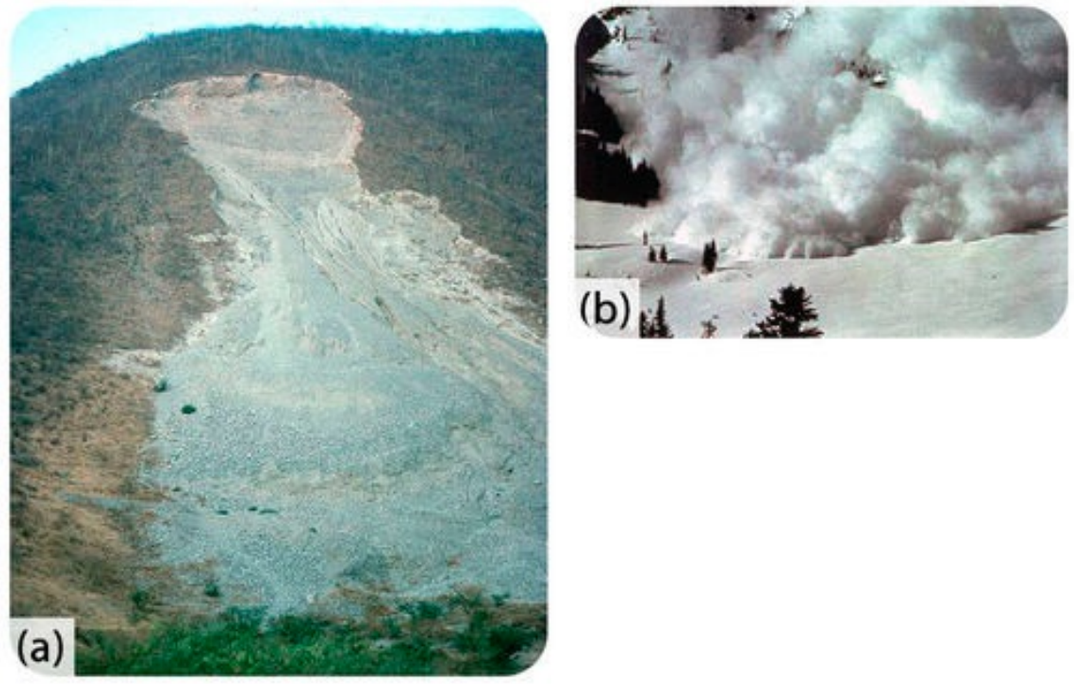


Figure 15.23

(a) Landslides are called rock slides by geologists. (b) A snow avalanche moves quickly down slope, burying everything in its path.

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 (**Figure** below).



Figure 15.24

The 1958 landslide into Lituya Bay, Alaska, created a 524m tsunami that knocked down trees at elevations higher than the Empire State Building (light gray).

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. 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.

•Rapid downslope movement of material is seen in this video: http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/dflows.mov .

KQED: Landslide Detectives

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. Learn more at: http://science.kqed.org/quest/video/landslide-detectives/



Click on the image above for more content

Mudflows and Lahars

Added water creates natural hazards produced by gravity (**Figure** below). 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.



Figure 15.25

The white areas on green hillsides mark scars from numerous mudflows.

•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** below). 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.



Figure 15.26

A lahar is a mudflow that forms from volcanic ash and debris.

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** below). 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 15.27

Slump material moves as a whole unit, leaving behind a crescent shaped scar.

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** below). Tilted telephone or power company poles are also signs of creep.



Figure 15.28

Trees with curved trunks are often signs that the hillside is slowly creeping downhill.

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.

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 (**Figure** below).

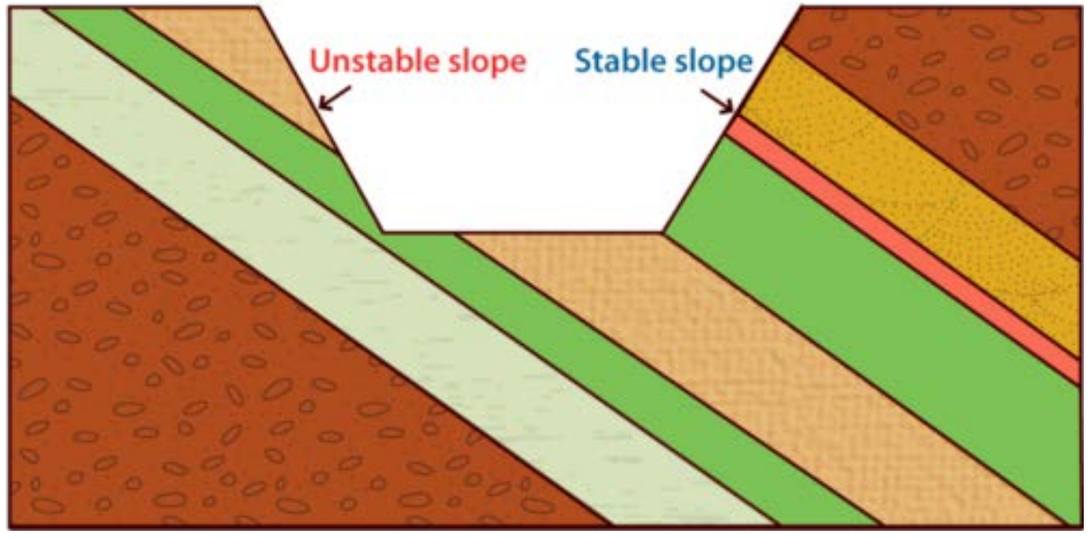


Figure 15.29

The slope of underlying materials must be considered when making road cuts.

•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** below). Trees 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 15.30

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. 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.

Lesson Summary

- Gravity moves earth materials from higher elevations to lower elevations.
- Landslides, avalanches, and mudflows are examples of dangerous erosion by gravity.
- Slump and creep move material slowly downslope.
- Plants, retaining walls, and good drainage are ways to help prevent landslides.

Review Questions

1.Describe three ways that gravity moves materials.
2.What natural events and human actions can trigger a landslide or avalanche?
3.What makes landslides and avalanches move at such great speeds?
4.Compare and contrast a mudflow and a lahar.
5.Name two ways that soil can move slowly down a slope.
6.What can people do to help prevent landslides or mudflows?

Points to Consider

•Why might someone build a home on top of land where a landslide has happened before?
•What factors make it likely or unlikely that a landslide could happen in your area?
•What new technologies might help people to know when a landslide will occur?

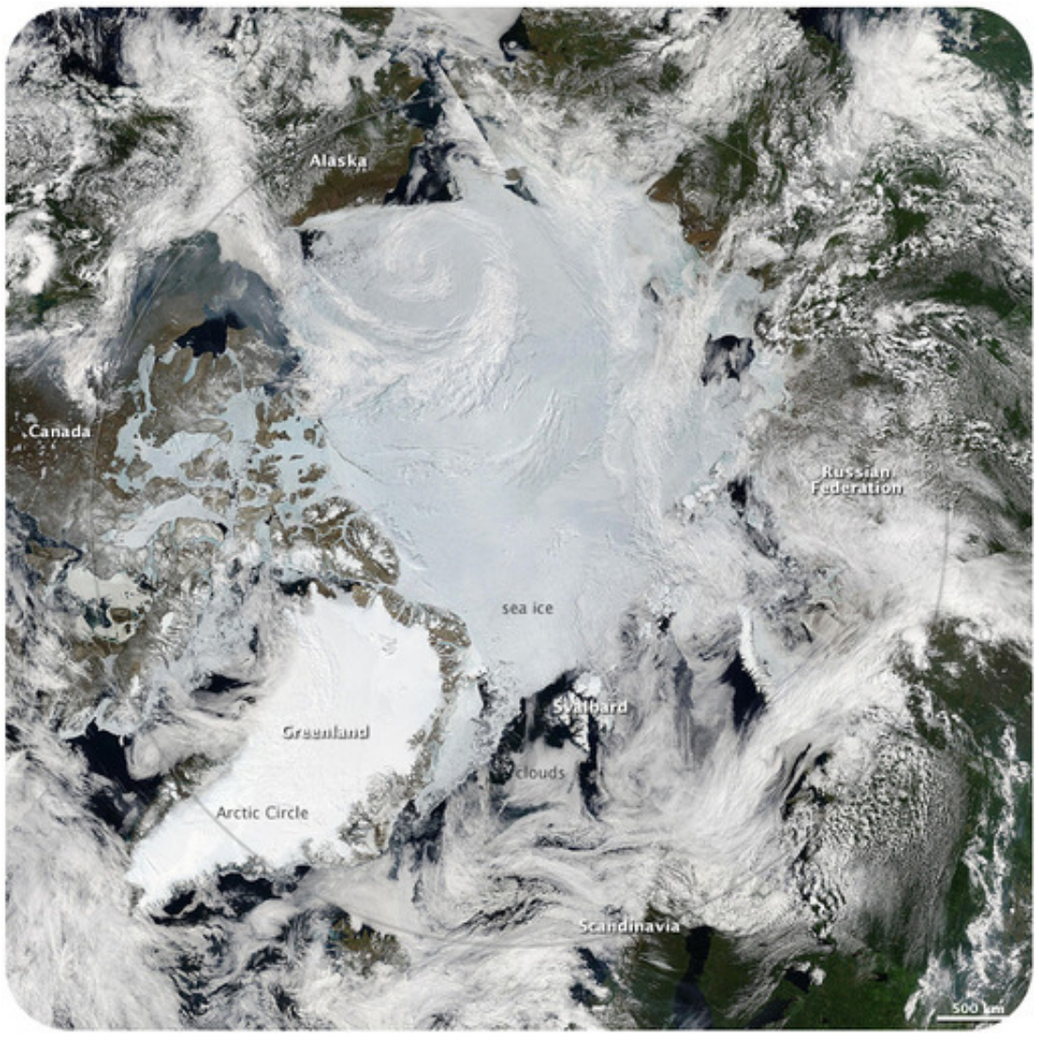
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Ch. 13: Earth's Fresh Water



This unusual view of the world is oriented on the Arctic around summer solstice, June 2010, when the region is bathed in daylight 24 hours a day. The Arctic Circle is marked by a faint circle in the image.

Water appears in several forms in this image: as solid ice, liquid water, and atmospheric gases. Greenland has the highest albedo (that is, it appears the brightest) because it is covered with an ice cap. Sea ice, found west and north of Greenland, appears as a pale gray-blue. Clouds are water vapor and appear throughout the area. Through the clouds, oceans, and possibly even lakes – liquid water – is visible.

Courtesy of Jeff Schmaltz/NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=44524. Public Domain.

Section 1

The Water Cycle

The Water Cycle

Lesson Objectives

- Describe how water is distributed on Earth.
- Describe what powers the water cycle and how water moves through this cycle.

Vocabulary

- condensation
- evaporation
- evapotransiration
- fresh water
- groundwater
- hydrologic (water) cycle
- infiltration
- precipitation
- reservoir
- residence time
- runoff
- sublimation
- transpiration
- water vapor

Introduction

Water is simply two atoms of hydrogen and one atom of oxygen bonded together. 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.

Distribution of Earth's Water

Earth's oceans contain 97% of the planet's water, so just 3% is fresh water, water with low concentrations of salts (**Figure** below). Most **fresh water** is trapped as ice in the vast glaciers and ice sheets of Greenland. 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** .

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?

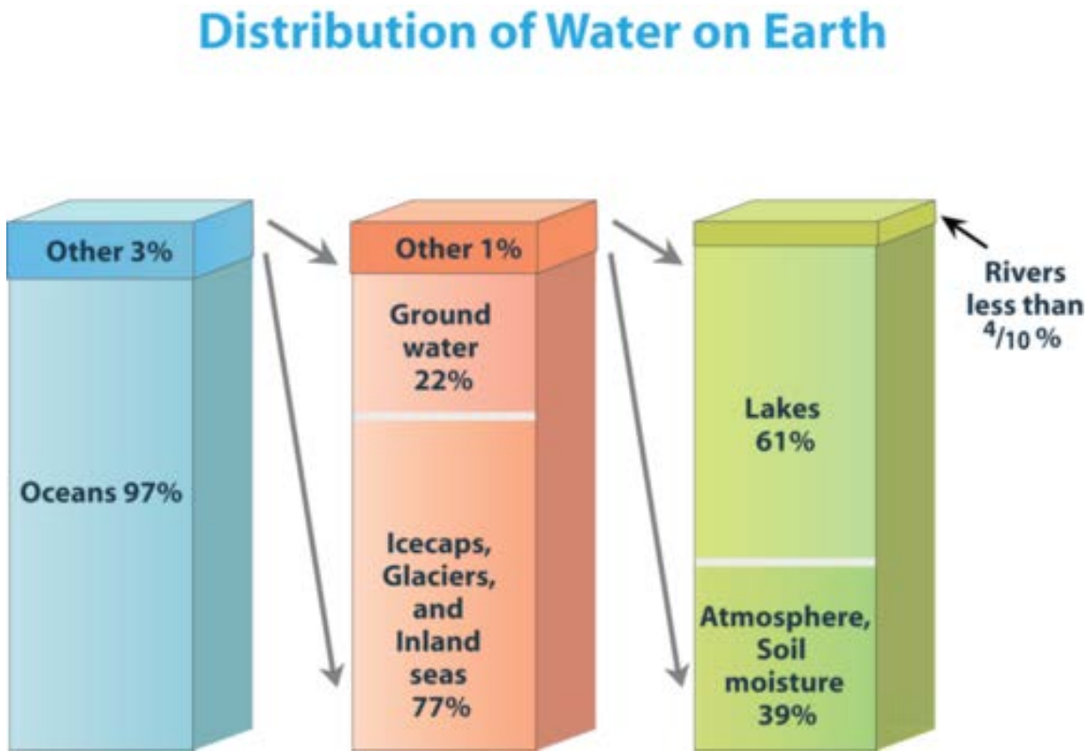


Figure 16.1

The distribution of Earth's water.

The Hydrologic Cycle

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 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?

Three States of Water

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** below).



Figure 16.2

(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.

The Water Cycle

Because Earth's water is present in all three states, it can get into a variety of environments around the planet. The movement of water around Earth's surface is the **hydrologic (water) cycle** (**Figure** below).

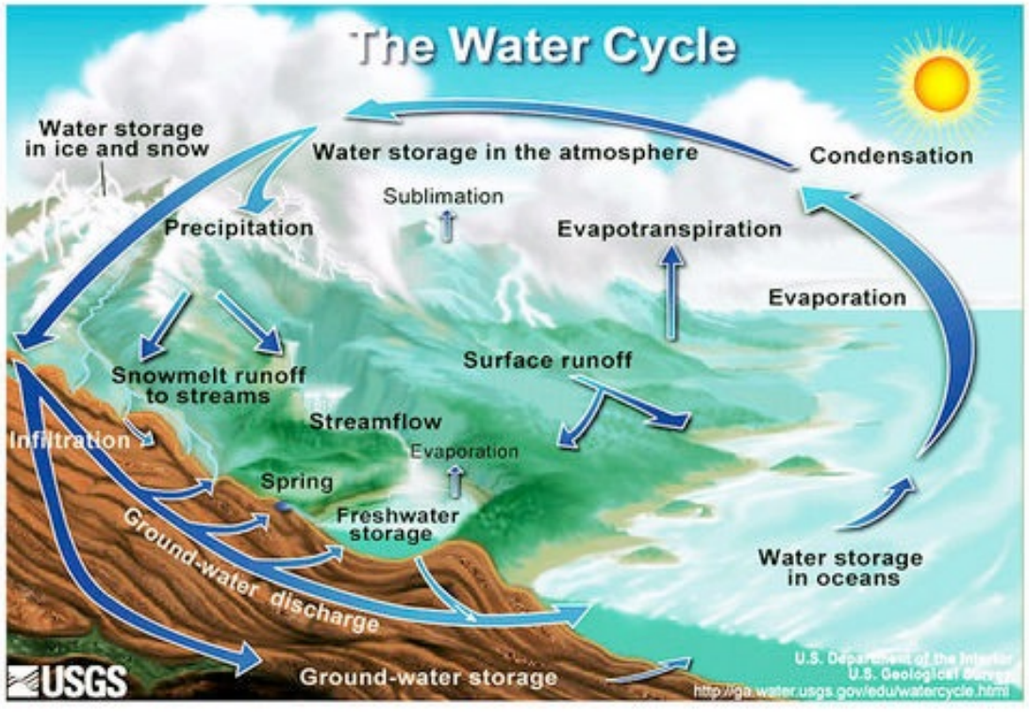


Figure 16.3

Because it is a cycle, the water cycle has no beginning and no end.

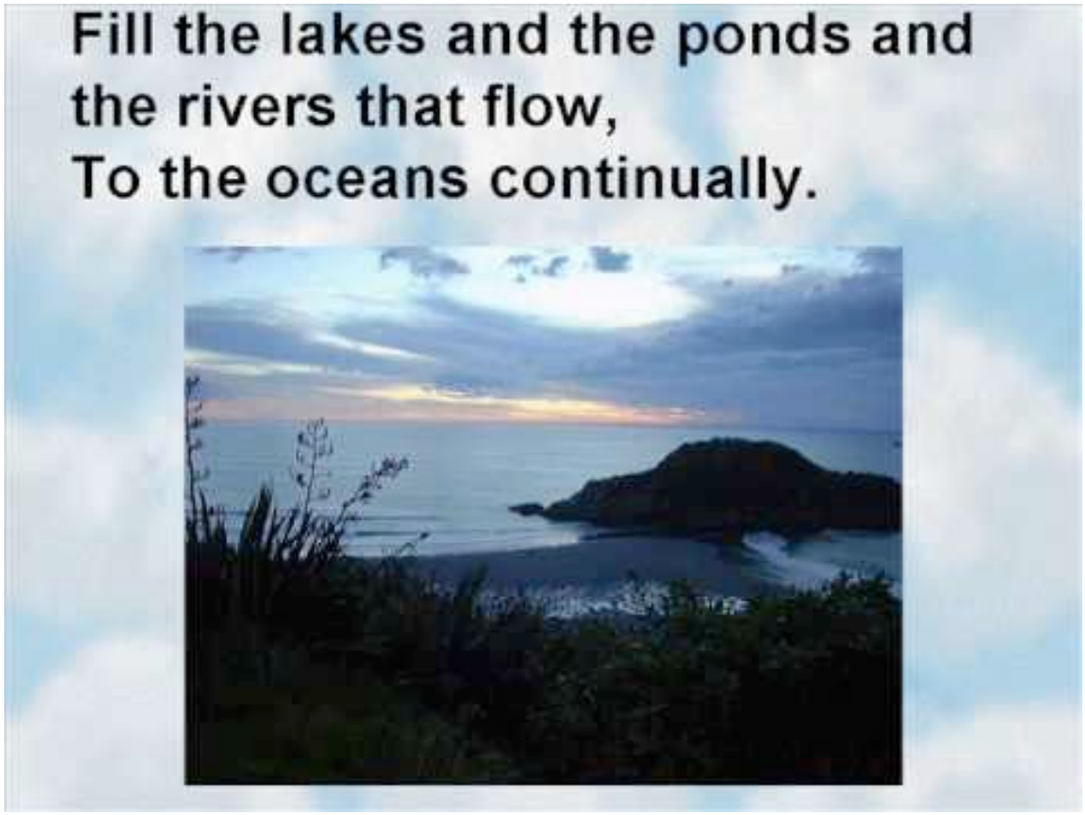
The Sun, many millions of kilometers away, provides the energy that drives the water cycle. Our nearest star directly impacts the water cycle by supplying the energy needed for evaporation.

Most of Earth's water is stored in the oceans where it can remain for hundreds or thousands of years. The oceans are discussed in detail in the chapter Earth's Oceans.

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&feature=related (2:38).



Click on the image above for more content

This animation shows the annual cycle of monthly mean precipitation around the world: http://en.wikipedia.org/wiki/File:MeanMonthlyP.gif

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 sublimating 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.

A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water(**Figure** below). Water trapped in soil is important for plants to grow.

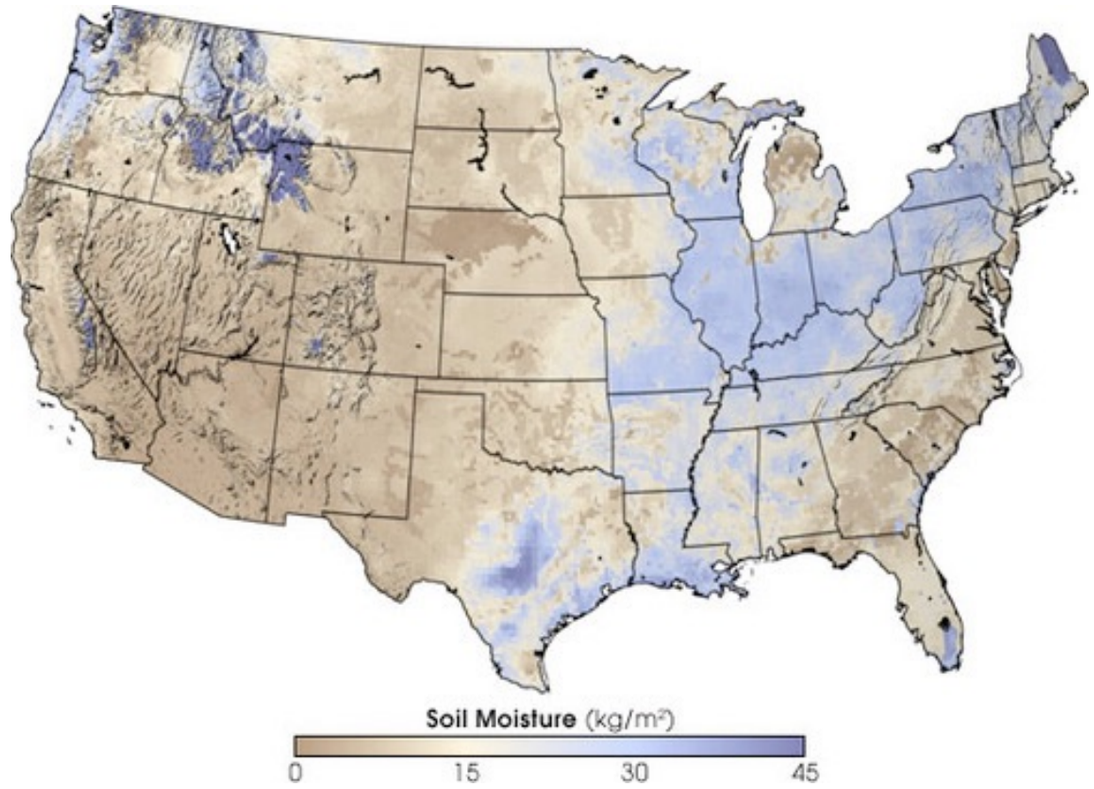


Figure 16.4

The moisture content of soil in the United States varies greatly.

Water may seep through dirt and rock below the soil 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.

Plants and animals depend on water to live and 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** below), a process known as **transpiration** .

Transpiration is the release of water vapor to the atmosphere by plants. **Evapotranspiration** is the combined effect of transpiration and evaporation. It is the rapid cycling of water vapor into the atmosphere by evaporation from Earth's surface or transpiration from plant leaves.

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

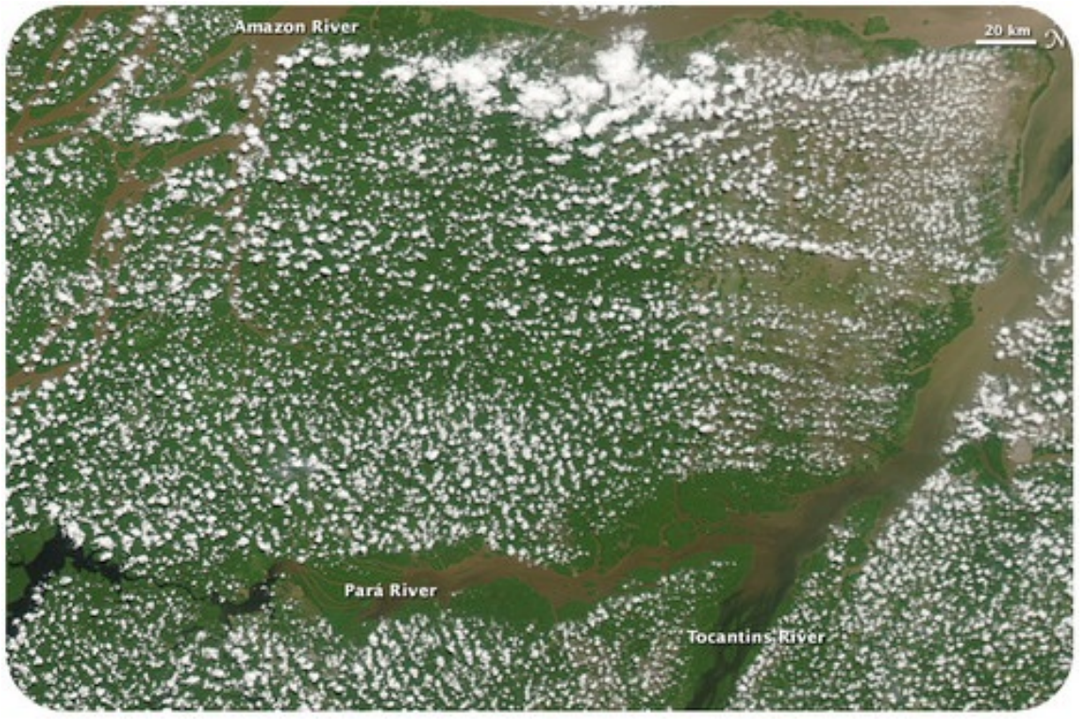


Figure 16.5

Clouds form above the Amazon Rainforest even in the dry season because of moisture from plant transpiration.

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** below).



Figure 16.6

The Pont du Gard aqueduct in France was constructed during the Roman Empire.

Use	United States	Global
Agriculture	34%	70%
Domestic (drinking, bathing)	12%	10%
Industry	5%	20%
Power plant cooling	49%	small

Table 1.1 above displays water use in the United States and globally (Estimated Use of Water in the United States in 2005, USGS).

It is important to note that water 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.

KQED: Tracking Raindrops

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. Learn more at: http://www.kqed.org/quest/television/tracking-raindrops



Click on the image above for more content

Lesson Summary

- Although Earth's surface is mostly water covered, only 3% is fresh water.
- Water on Earth is found in all three phases: solid, liquid, and gas.
- Water travels between phases and reservoirs as part of the hydrologic (water) cycle.
- The major processes of the water cycle include evaporation, transpiration, condensation, precipitation, and return to the oceans via runoff and groundwater supplies.

Review Questions

1. About what percent of the Earth's water is fresh water?

2. About what percent of all of Earth's water is found in groundwater, streams, lakes, and rivers?

3. In what states does water appear on Earth and on other planets?

4. What powers the water cycle? How?

5. In which of the states of matter would water be at 130 ◦C? At 45 ◦C?

6. Define the words condensation and evaporation.

7. Give a detailed summary of the water cycle.

8. What is transpiration? How is it like evaporation?

9. Why is the atmosphere so important to the water cycle?

10. If the sun grew much stronger in intensity, how would the water cycle be affected?

Further Reading / Supplemental Links

Thorough and updated information on the water cycle from NASA: http://earthobservatory.nasa.gov/Features/Water/

An introduction to life in fresh water: http://www.freshwaterlife.org/

The US Geological Survey website has lots of information about fresh water: http://www.usgs.gov/

Points to Consider

•How does precipitation affect the topography of the Earth?
•What natural disasters are caused by the water cycle?
•How might building dams disrupt the natural water cycle?
•As Earth's temperature warms, how might the water cycle be altered?

Section 2

Types of Surface Water

Types of Surface Water

Lesson Objectives

- Compare streams and rivers and their importance.
- Describe what ponds and lakes are, and why they are important.
- Explain why wetlands are significant in the water cycle, and describe their biodiversity.
- Describe the causes of floods and their effects.

Vocabulary

- brackish
- confluence
- continental divide
- divide
- drainage basin/watershed
- estuary
- flood
- lake
- levee
- limnology
- marsh
- mouth
- pond
- pool
- river system
- stream
- swamp
- tributary
- watershed/drainage basin
- wetland

Introduction

Fresh water in streams, ponds, and lakes is an extremely important part of the water cycle if only because of its importance to living creatures. Along with wetlands, these fresh water regions contain a tremendous variety of organisms.

Streams and Rivers

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 might all be lumped together as 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 and were described in the Erosion and Deposition chapter.

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** below). A river and all of its tributaries is called a **river system.**

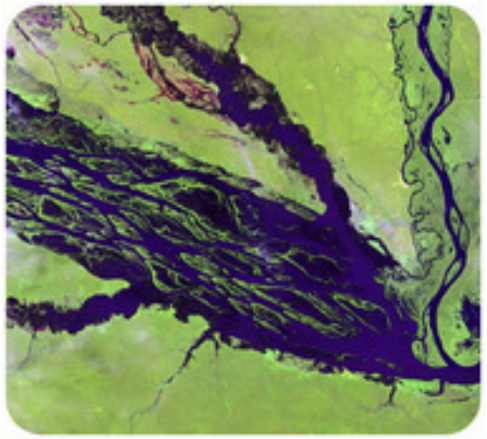


Figure 16.7

The largest band of blue, from left to right across the image, is the Rio Negro in Brazil. The other streams are tributaries of that river. Their confluence is near the bottom right.

A stream may create a **pool** where water slows and becomes deeper (**Figure** below).



Figure 16.8

A stream pool in Maui.

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** below).



Figure 16.9

The Parana River drains South America and enters the Atlantic Ocean.

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 (**Figure** below).



Figure 16.10

The Klamath River enters the Pacific at Redwood National Park.

Rivers

Rivers are the largest types of stream, moving large amounts of water from higher to lower elevations (**Figure** below). The Amazon River, the world's river with the greatest flow, has a flow rate of nearly 220,000 cubic meters per second!



Figure 16.11

The famous Horseshoe Falls at Niagara Falls drops over 1,800 cubic meters of water per second, down a cliff nearly 50 meters (170 feet) in height. The falls are fed by Lake Erie and the Niagara River.

People have used rivers since the beginning of civilization as a source of water, food, transportation, defense, power, recreation, and waste disposal.

Divides

The **drainage basin,** or **watershed** , of a river includes all the land that drains into the river either directly or through its tributaries. A **divide** is a topographically high area that separates a landscape into different water basins (**Figure** below). 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** .

The major divide of the United States, called the Continental Divide, is located in the Rocky Mountains. Rain falling east of the Continental Divide eventually flows into the Atlantic Ocean. Rain falling west of it flows into the Pacific Ocean.

The largest single drainage basin in the United States is the Mississippi River system. Its western divide is the Continental Divide. Its eastern divide is in the Appalachian Mountains. The drainage basin between these two divides covers a land area of about 4.76 million square kilometers.



Figure 16.12

(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?

Ponds and Lakes

Ponds and lakes are bordered by hills or low rises, so that the water is blocked from flowing directly downhill. **Ponds** are small bodies of fresh water that usually have no outlet (**Figure** don't purge me) ; ponds are often are fed by underground springs.



Figure 16.13

Ponds are small, enclosed bodies of water.

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.

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** below). 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.

Lakes form in a variety of different ways: in depressions carved by glaciers, in calderas (**Figure** below), and along tectonic faults, to name a few. Subglacial lakes are even found below a frozen ice cap.

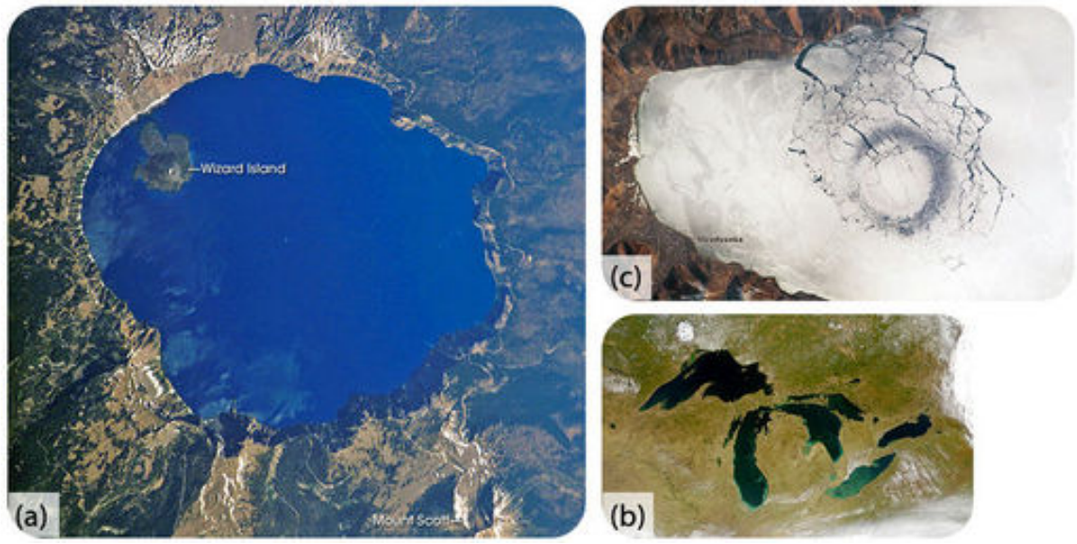


Figure 16.14

(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.

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** below).

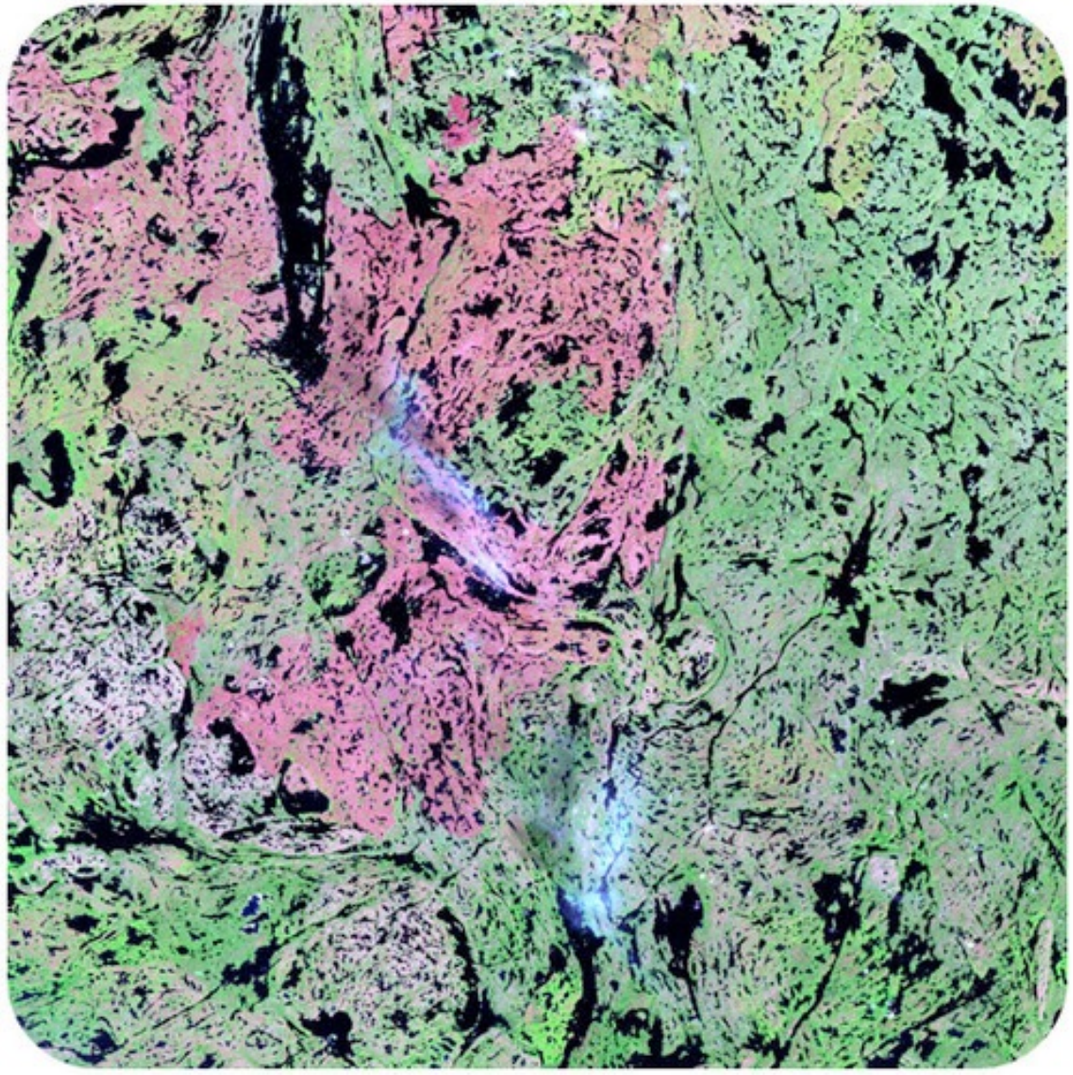


Figure 16.15

Lakes near Yellowknife were carved by glaciers during the last Ice Age.

Limnology is the study of bodies of fresh water and the organisms that live there. The ecosystem of a lake is divided into three distinct sections (**Figure** below):

1. The surface (littoral) zone is the sloped area closest to the edge of the water.

2. The open-water zone (also the photic or limnetic zone) has abundant sunlight.

3. The deep-water zone (also 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.

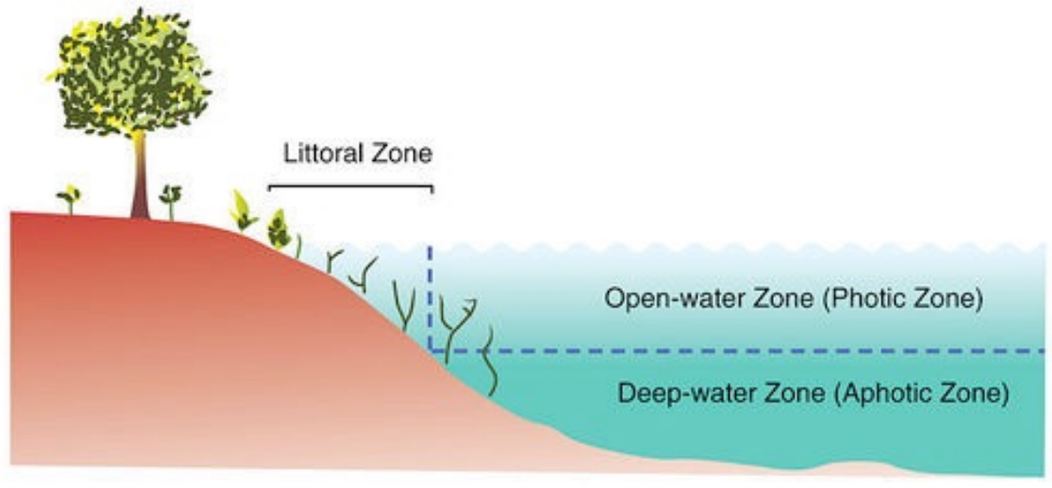


Figure 16.16

The three primary zones of a lake are the littoral, open-water, and deep-water zones.

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, or if their outlets grow because of erosion. When the climate of an area changes, lakes can either expand or shrink (**Figure** below). Lakes may disappear if precipitation significantly diminishes.



Figure 16.17

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.

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 amounts and quality of water present within them.

Types of Wetlands

Marshes are shallow wetlands around lakes, streams, or the ocean where grasses and reeds are common, but trees are not (**Figure** below). Frogs, turtles, muskrats, and many varieties of birds are at home in marshes.



Figure 16.18

A marsh is a treeless wetland.

A **swamp** is a wetland with lush trees and vines found in a low-lying area beside slow-moving rivers (**Figure** below). 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 16.19

A swamp is characterized by trees in still water.

In an estuary, salt water from the sea mixes with fresh water from a stream or river (**Figure** below). These semi-enclosed areas are home to plants and animals that can tolerate the sharp changes in salt content that the constant motion and mixing of waters creates. Estuaries contain **brackish** water, water that has more salt than fresh water but less than sea water. Because of the rapid changes in salt content, estuaries have many different habitats for plants and animals and extremely high biodiversity.



Figure 16.20

Chesapeake Bay, surrounded by Maryland and Virginia, is the largest estuary in the United States.

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.

Floods

Floods are a natural part of the water cycle, but they can be terrifying forces of destruction. Put most simply, a flood is an overflow of water in one place. Floods can occur for a variety of reasons, and their effects can be minimized in several different ways. Perhaps unsurprisingly, floods tend to affect low-lying areas most severely.

"Floods 101" is a National Geographic video found in Environment Video, Natural Disasters, Landslides, and more: http://video.nationalgeographic.com/video/player/environment/

Causes of Floods

Floods usually occur when precipitation falls more quickly than that 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** below and below).

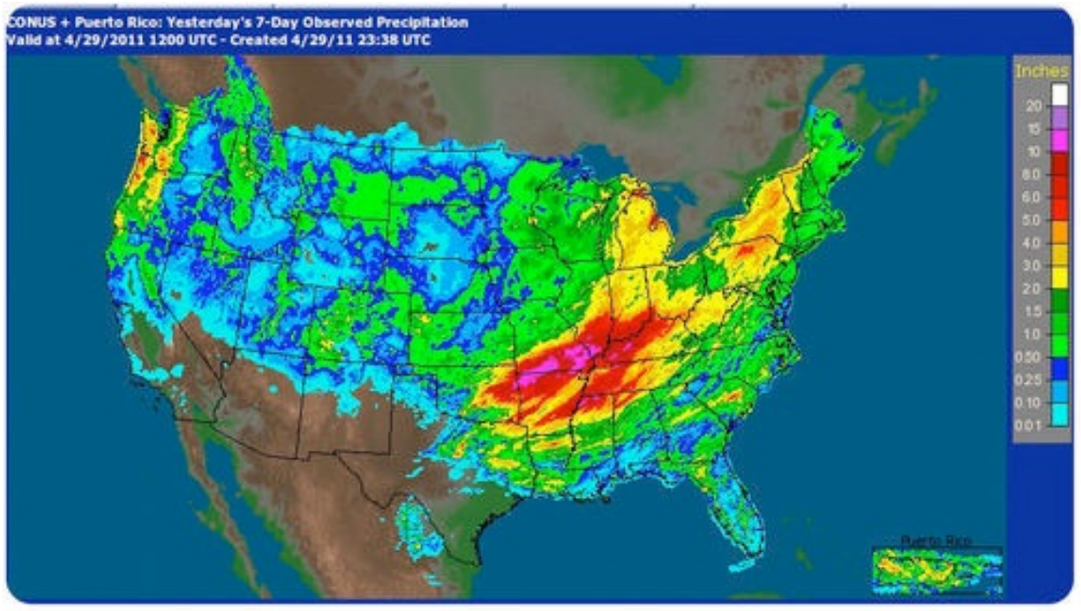


Figure 16.21

This maps shows the accumulated rainfall across the U.S. in the days from April 22 to April 29, 2011.



Figure 16.22

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.

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period (**Figure** below). A flash flood may do its damage miles from where the rain actually falls if the water travels far down a dry streambed so that the flash flood occurs far from the location of the original storm.



Figure 16.23

A 2004 flash flood in England devastated two villages when 3-1/2 inches of rain fell in 60 minutes.

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 to hit 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.

When a dam breaks along a reservoir, flooding can be catastrophic. High water levels have also caused small dams to break, wreaking havoc downstream.

People try to protect areas that might flood with dams, and dams are usually very effective. 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 and 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 crops.

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.

Lesson Summary

- Streams return water to the oceans.
- Stream headwaters are at higher elevations where snow melts or where there are springs.
- Tributaries join together as a river flows to its mouth at lower elevations.
- A river may eventually form a delta with an estuary where it meets the ocean.
- Water temporarily resides in ponds and lakes, which are mostly fresh water.
- Flooding is part of the natural cycle of rivers, enriching floodplains with nutrients, but flooding may destroy crops and settlements.

Review Questions

1. Where do streams originate?

2. Compare and contrast streams and rivers.

3. What is an advantage and disadvantage of living in floodplains?

4. Compare and contrast ponds and lakes.

5. What are wetlands and what is the value of wetlands?

6. Consider an animal common in swamps and an animal common in rivers. What natural adaptations do they each have to live in their habitat?

7. Deserts get little rain so why are they in danger of flash floods?

Points to Consider

•What types of streams have you seen in your area?
•Why are bodies of water never really permanent?
•Is it possible that your home could be flooded? What would you do if it were flooded?

Section 3

Streams and Rivers

Streams and Rivers

Lesson Objectives

- Describe how surface streams produce erosion.
- Describe the types of deposits left behind by streams.
- Describe landforms that are produced as ground water flows.
- Describe the characteristics of streams and rivers.

Vocabulary

- alluvial fan
- base level
- bed load
- capacity
- channel
- column
- competence
- delta
- discharge
- dissolved load
- distributaries
- floodplain
- gradient
- groundwater
- headwaters
- meander
- natural levee
- saltation
- stream piracy
- suspended load
- velocity

Introduction

Streams – any running water from a rivulet to a raging river -- complete the hydrologic cycle by returning precipitation that falls on land to the oceans (**Figure** below). Some of this water moves over the surface and some moves through the ground as **groundwater.** Flowing water does the work of both erosion and deposition.

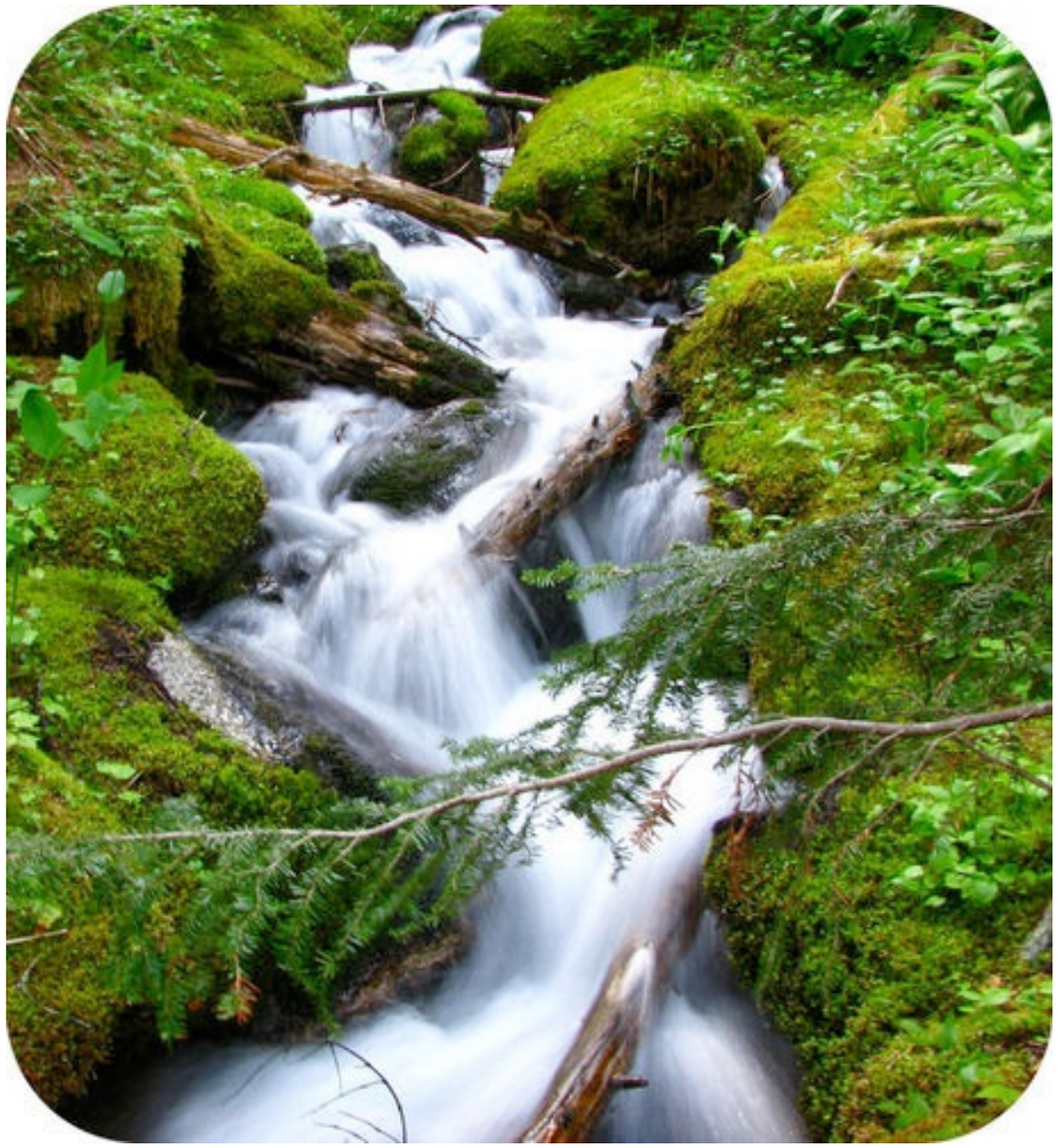


Figure 16.24

As streams flow towards the ocean, they carry weathered materials.

Characteristics of Steams and Rivers

The ability of a stream or river to erode and transport sediment is affected by many factors. These factors, which are interconnected, include the velocity and stream flow of water, the streams gradient, its discharge, and the shape of its channel.

Velocity

The velocity of water in a stream or river is the distance that water travels in a given amount of time. The velocity of the water in a river is related to the amount of energy that the water has. A fast moving river can erode materials more quickly and can carry larger particles than a slow-moving river. Many factors affect a river's velocity, including the steepness of the slope, the amount of water traveling downstream, and the shape of the path through which water travels.

Gradient

The steepness of then slope of anstream or river is called then gradient. A river's gradient varies along its course. A river may plunge down steep hills or mountains near its source. There its gradient is very large. By the time a river approaches sea level, it may be traveling across a plain that slopes very gradually, so its gradient is very small.



Figure 16.25

GRADIENT: The picture above shows a gentle gradient.



Figure 16.26

GRADIENT: The picture above shows a steep gradient.

Discharge

The discharge of a stream or river is the amount, or volume, of water that passes a certain point in a given amount of time. Discharge is not content over the length of a river. In many rivers, discharge increases downstream because tributaries continually add more water. In rivers that flow into deserts, discharge may decrease downstream.

Discharge is not constant year-round. During times of increased precipitation or at times when snow is melting, more water runs

into rivers. The velocity of the water also increases. Rivers become wider and deeper and may even flood their banks.

Channel

The path which the water flows in a stream or river is called its channel. The size and shape of a channel affect the velocity of water. The channel of a shallow, winding stream with many boulders has a great deal of surface area in contact with water flowing through it. Friction slows the water down. By contrast, a straight channel that is wide and deep has less surface area in contact with the water so the water's velocity is greater.

Erosion and Deposition by Streams

Erosion by Streams

Of all the agents of erosion, running water is the most effective. Gravity draws surface water downhill, eroding soil and rock materials along the way. These materials are deposited when a stream or river no longer has enough energy to transport them.

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. The eroded rock and soil materials that are transported downstream by a river are called its **load.** Sediments are carried as:

1.**Dissolved load** : Dissolved load is composed of ions in solution. These ions are usually carried in the water all the way to the ocean. Common minerals carried in solution by rivers include dissolved calcium, magnesium, and bicarbonate. Most of a river's solution load comes from groundwater seeping into a river.

2.**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** below). 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. Competence is a measure that describes the maximum size of the particles a stream can carry.

3.**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.

A video of bedload transport is found here: https://www.classzone.com/books/earth_science/terc/content/visualizations/es1303/es1303page01.cfm?chapter_no=visualization



Figure 16.27

Rivers carry sand, silt and clay as suspended load. During flood stage, the suspended load greatly increases as stream velocity increases.

Competence and Capacity

Two measures are used to describe the ability of a stream to transport materials. As stated above **competence** is a measure that describes the maximum size of the particles a stream can carry. **Capacity** is a measure of the total amount of sediment a stream can carry. The competence and capacity of a stream depend on the stream's velocity and discharge. Because the velocity and discharge of a given stream are not constant, the competence and capacity of a stream are not constant. Competence and capacity vary along a stream and change throughout the year.

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** below). The stream moves fast and does lots of work eroding the stream bed.



Figure 16.28

This stream begins as snow melt from the mountains.

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** below).



Figure 16.29

(a) At a meander, a stream actively erodes its outer banks and deposits material along the inside curves. This causes these meanders to migrate laterally over time. (b) This stream has deposited larger materials such as gravel and pebbles along the inside curve of a meander. (c) This image is a topographic map. The San Juan River eroded the land surface as the Colorado Plateau uplifted. The river's meanders were preserved as a feature called incised meanders.

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** below).

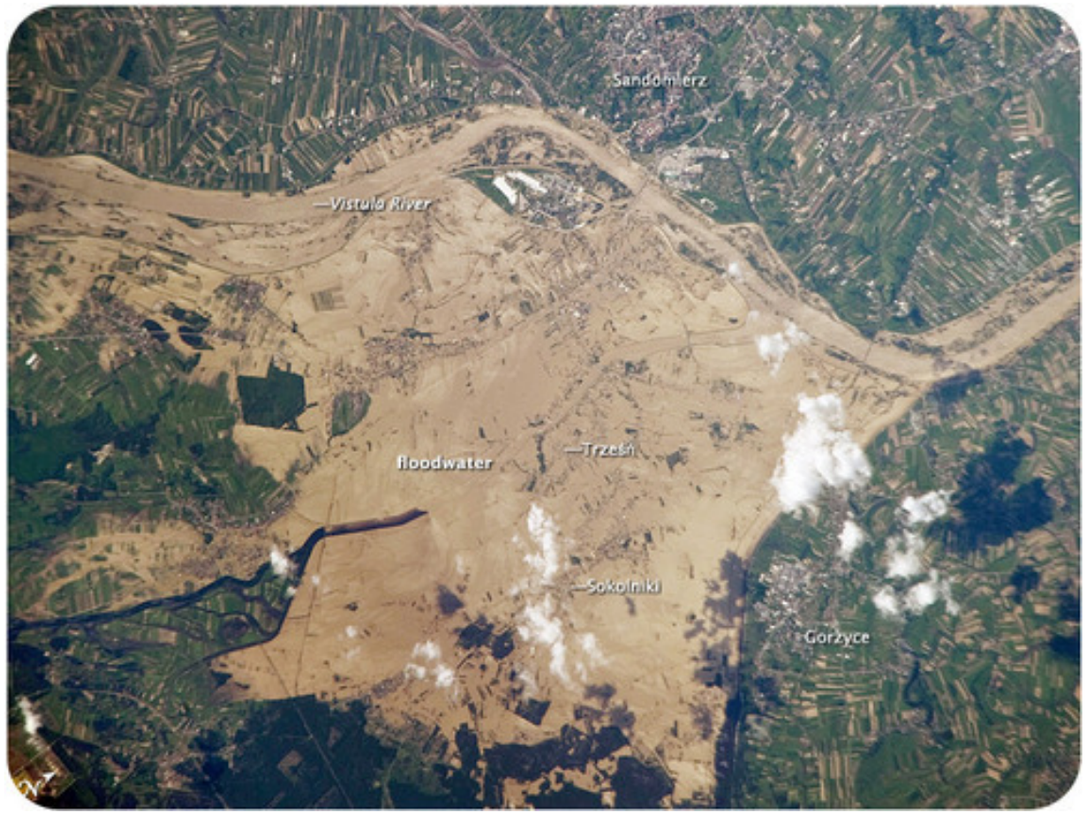


Figure 16.30

The Vistula River in Poland flows onto its floodplain.

Most youthful river valleys are V-shaped. Such valleys are found in regions where there is enough rain to erode the sides of the valley. As the river cuts its way downward into its channel, the upper valley walls are widened into a V-shape by erosion. A stream cannot erode its bed to a level any lower than the level of the largest body of water into which it flows. This is called the **basel level.** 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. Ultimate base level is the ocean.

The headward erosion that brings about the formation of a river valley is an important factor in a process called **stream piracy or** stream capture. Picture two rivers separated by a divide. Through headward erosion, one of the rivers wears through the divide and captures the headwaters of the other river. The first river grows larger and extends its drainage basin at the expense of the captured river. Geologists think that stream piracy has been an important factor in the early growth of many great river systems.

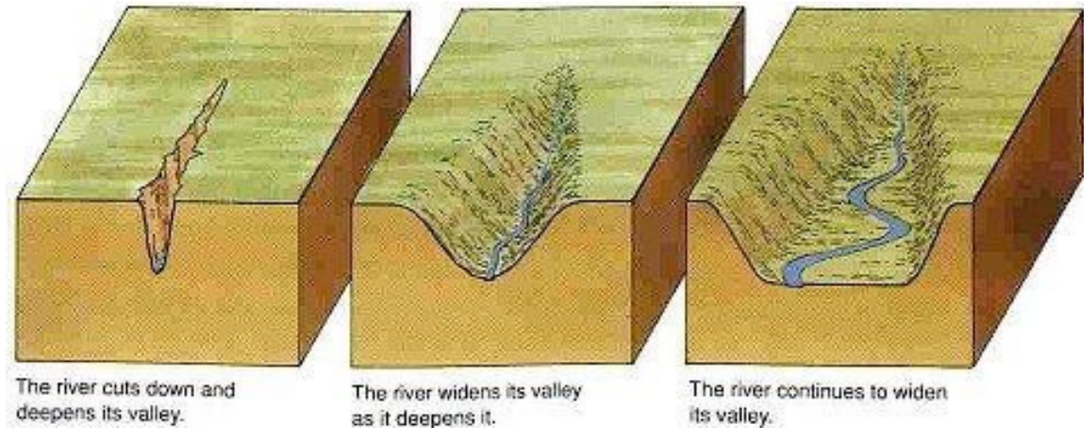


Figure 16.31

V-shaped Valley Formation

Stream Deposition

As a stream gets closer to base level, 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, described in the Earth's Minerals chapter, 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** below).

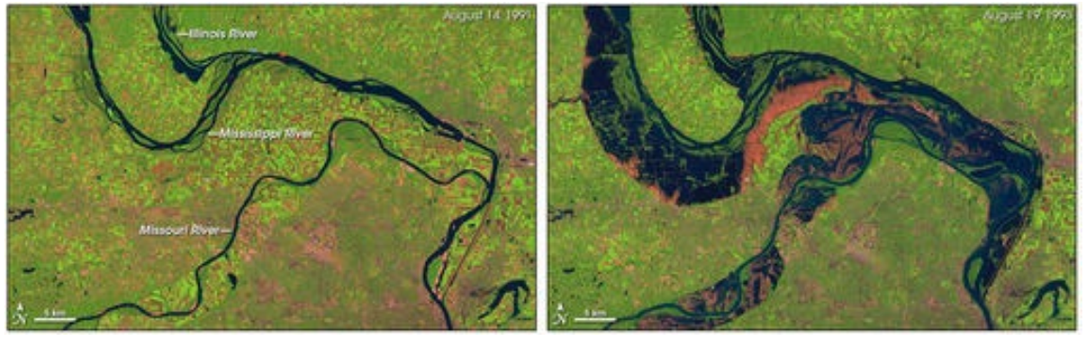


Figure 16.32

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.

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** (**Figure** below).

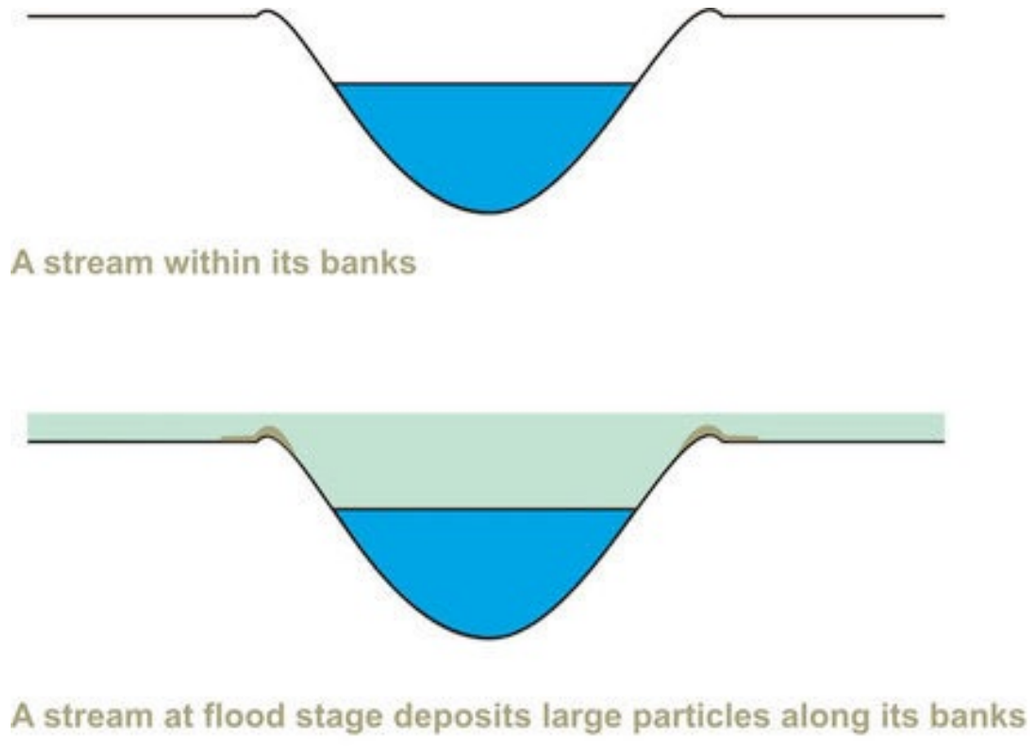


Figure 16.33

After many floods, a stream builds natural levees along its banks.

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** below). River water comes almost to a standstill at a

delta where most of a river's sediment is dropped. As long as the amount of sediment supplied by the river is larger than the amount that can be taken away by currents, the deposit grows. A river flowing over its delta splits into branches called **distributaries** . The distributaries are responsible for the delta's shape. Their smaller channels bring sediment to the front of the delta. Delta formation is a delicate balance between erosion and deposition. Human use of rivers and deltas can cause a decrease in deposition, which leaves a delta more susceptible to wave and current erosion.



Figure 16.34

(a) The Nile River delta has a classic triangular shape, like the capital Greek letter delta. (b) Sediment in the Yellow River delta. The main stream channel splits into many smaller distributaries.

If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops (**Figure** below). When the stream reaches the land, the stream's velocity decreases greatly. As a result, the stream drops a large part of its sediment load. Alluvial fans generally form in arid regions. An alluvial fan differs from a delta in several ways. First, the deposit is formed on land, not in water. Second, the sediments are coarse sands and gravels rather than fine silt and clay. Third, its surface is sloping, not flat like a delta.



Figure 16.35

An alluvial fan in Iran. The mountains are in the lower right corner of the photograph.

Lesson Summary

- Streams erode the land as they move from higher elevations to the sea.
- Eroded materials can be carried in a river as dissolved load, suspended load, or bed load.
- A river erodes deeply when it is far from its base level, the place where it enters standing water.
- Streams form bends, called meanders. Broad, flat areas are known as floodplains.

•A delta or an alluvial fan might form where the stream drops its sediment load.
•Caves form underground as ground water gradually dissolves away rock.

Review Questions

1.Define the three kinds of load that make up the particles a stream carries.
2.What is a stream's gradient? What effect does it have on the work of a stream?
3.How do streams erode their beds?
4.How does a stream produce a wide, flat floodplain?
5.What type of gradient would a river have when it is actively eroding its stream bed?
6.When would a river form an alluvial fan and when will it form a delta? Describe the characteristics of each type of deposit.

Points to Consider

•Would a stream at high elevations erode more than a stream at lower elevations?
•How would Earth's surface look without streams?
•Would a flash flood along a normally dry river valley be a dangerous event?
•Do you think caves could form in your neighborhood?

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Ch. 14: Earth's Groundwater

Lesson Objectives

- Define groundwater.
- Explain the location, use, and importance of aquifers.
- Define springs.
- Describe how wells work and why they are important.

Vocabulary

- aquifer
- artesian formation
- capillary action
- capillary fringe
- fissures
- impermeable
- permeability
- porosity
- sinkhole
- spring
- subsidence
- stalactite
- stalagmite
- travertine
- water table
- well
- zone of aeration
- zone of saturation

Introduction

Although this may seem surprising, water beneath the ground is commonplace. Usually groundwater travels slowly and silently beneath the surface, but in some locations it bubbles to the surface at springs. The products of erosion and deposition by groundwater were described in the Erosion and Deposition chapter.

Groundwater

Groundwater is the largest reservoir of liquid fresh water on Earth and is found 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 a 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 from where the aquifer is located; for example, it may be in a mountain area.

The amount of water that is available to enter groundwater in a region 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.

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.

Aquifers

Features of an Aquifer

To be a good aquifer, the rock in the aquifer must have good:

- **porosity** : small spaces between grains. The amount of water that soil or rock can hold depends upon the amount of space, or pore space, between the grains of material. Porosity is the percent of a material's volume that is pore space.
- **permeability** : connections between pores. Permeability is the rate at which water or other liquids pass through pore spaces of a rock.

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

Porosity depends upon a number of factors. One factor is particle shape. Materials consisting of rounded particles have a lot of poor space--picture the spaces between marbles in a jar. Materials consisting of flat or angular particles have less poor space because the particles fit together more tightly.

Another factor affecting porosity is sorting. The amount of poor space is greatest in materials made up of particles that are all the same size. Such materials are said to be well-sorted. For example, the porosity of deposits of well sorted, rounded particles of sand with little or no cement between the grains may be more than 40 percent. When a material is poorly sorted, as in a mixture of gravel and sand, small particles fill the spaces between the large particles, reducing the total porosity.
Porosity does not describe how easily water can flow through a material. Permeability describes flow ability. In general, permeability increases with grain size because large-grained materials have larger pore spaces. Water passes easily through materials with large pore spaces, such as sand grains and gravel. It passes slowly through finer materials, such as silt. A material that water cannot pass through is called impermeable. Clays and shales, which are very fine-grained, are usually impermeable.
It is possible for material to be highly porous but not at all permeable. For example, pumice has many pores, but the pores are not connected. Thus, water cannot pass through pumice. On the other hand, a nonporous rock such as granite, may become permeable if cracks develop in the rock, because the cracks transmit the water.

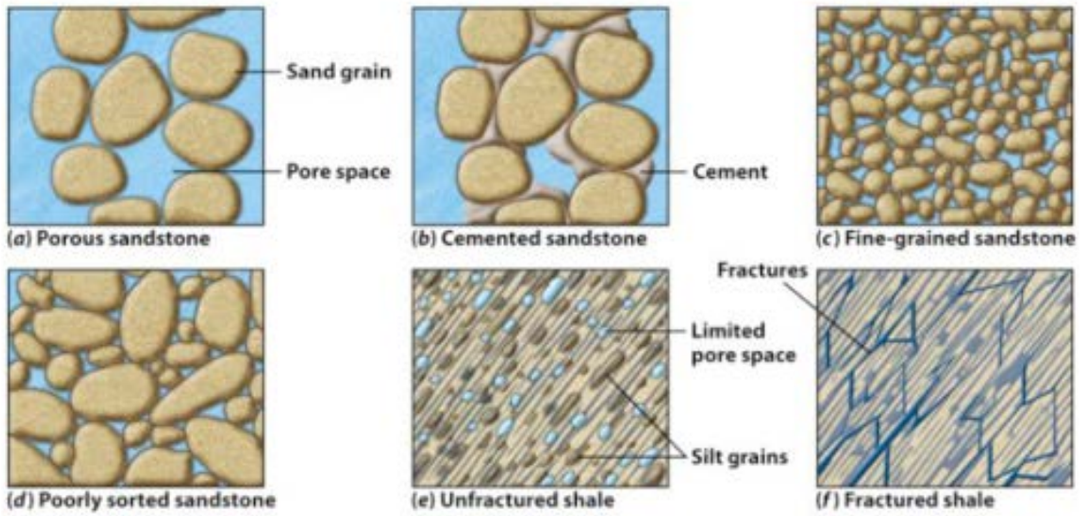


Figure 17.1

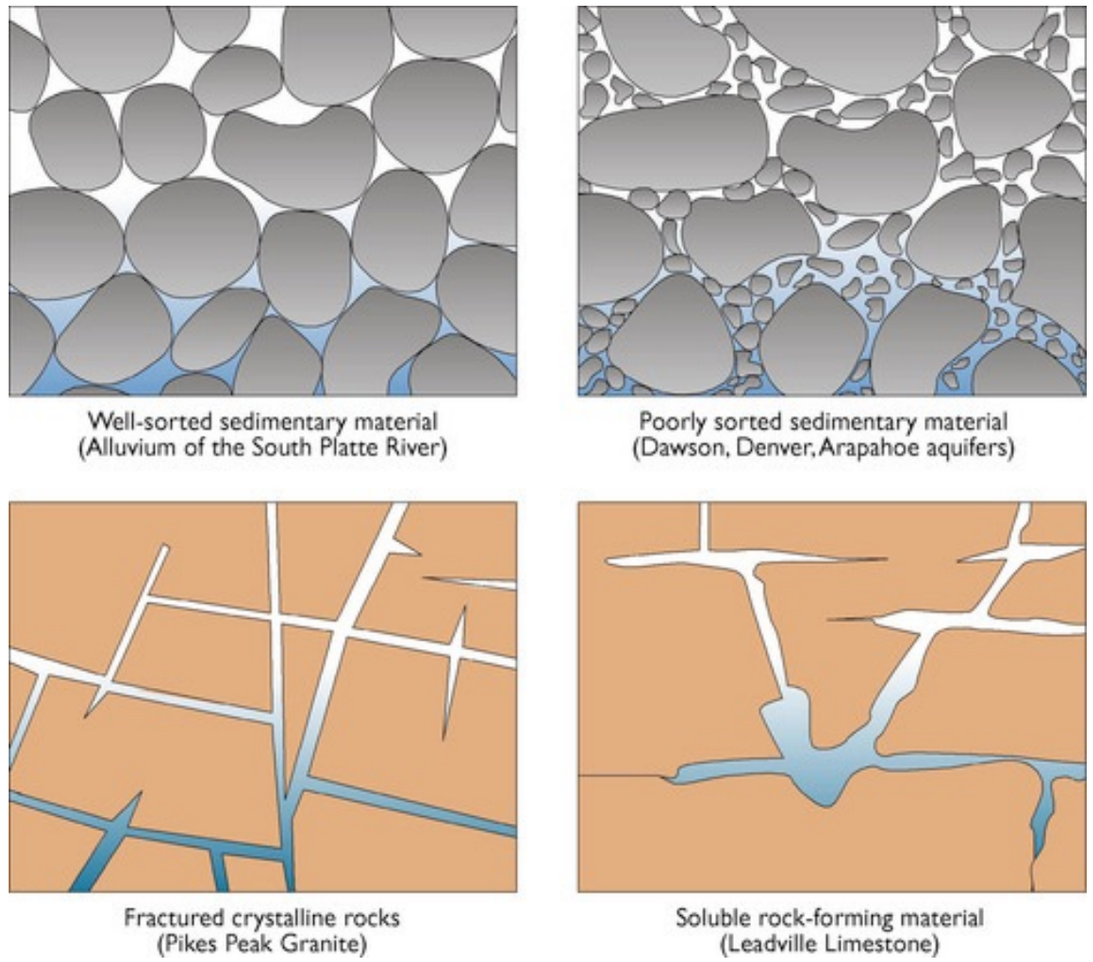


Figure 17.2

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** below). This impermeable rock layer forms the base of the aquifer. The upper surface where the groundwater reaches is the **water table** .

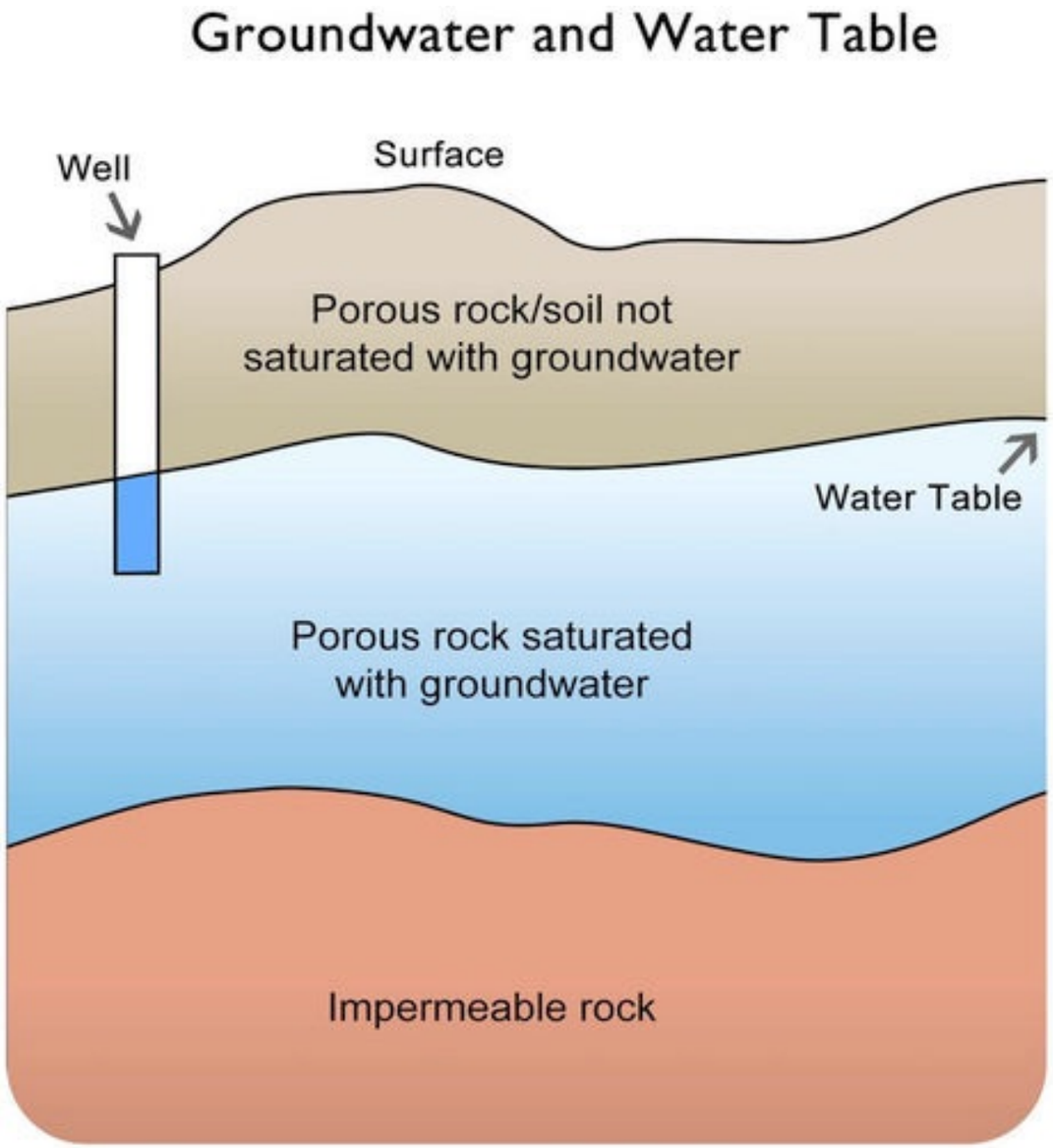


Figure 17.3

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?

In wet regions, streams are fed by groundwater; the surface of the stream is the top of the water table (**Figure** below). 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.

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.

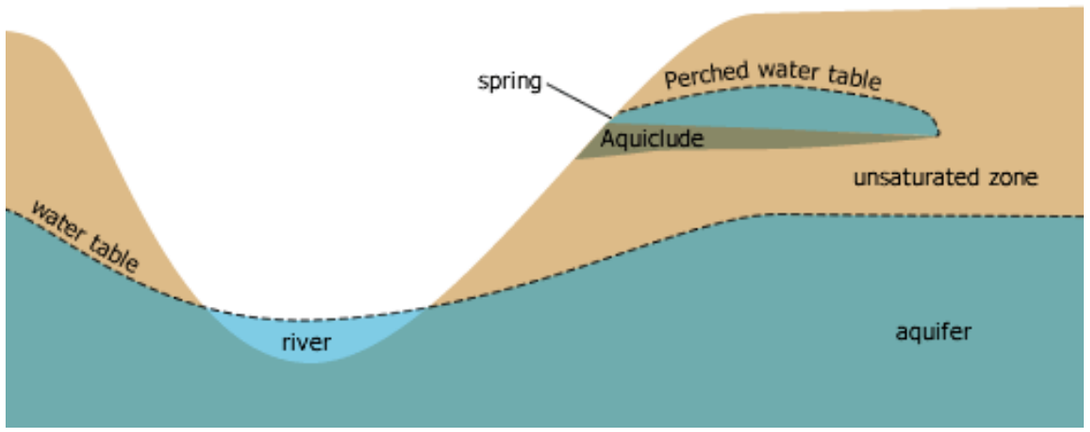


Figure 17.4

The top of the stream is the top of the water table. The stream feeds the aquifer.

The part of the ground where all pore spaces are filled is called the **zone of saturation** . The upper surface of the zone of saturation is called the **water table** . Between the water table and the surface, there is a section of the ground that can still hold some water. This section is called the **zone of aeration** because air can enter this region. It includes three parts. Just above the water table is the **capillary fringe** , where water rises because the water molecules are attracted to the soil particles. This interaction between the water and the soil is called **capillary action** . A familiar example of capillary action occurs when a paper towel is dipped in water. Just as water rises into the towel, water rises into the soil just above the water table. Above the capillary fringe is a section of soil where rainwater drains downward to the capillary fringe and to the zone of saturation below. The soil here is generally drier than the soil below and the soil above except during and shortly after rainfall. The third section of soil lies just below the soil surface. The soil here contains more organic material, which helps it hold water. A film of water may stick to the grains of topsoil in this upper section unless it evaporates or is absorb light by plant roots.

The water tables distance from the surface depends upon many factors. These include the amount of rainfall, the amount of time that passes between rains, the season, the slope of the ground surface, the thickness of the soil, and the climate. Humans can also affect the water table by drilling wells.

One of the most interesting, but extremely atypical types of aquifers is found in Florida. Although aquifers are very rarely underground rivers, in Florida water has dissolved the limestone so that streams travel underground and above ground (**Figure** below).

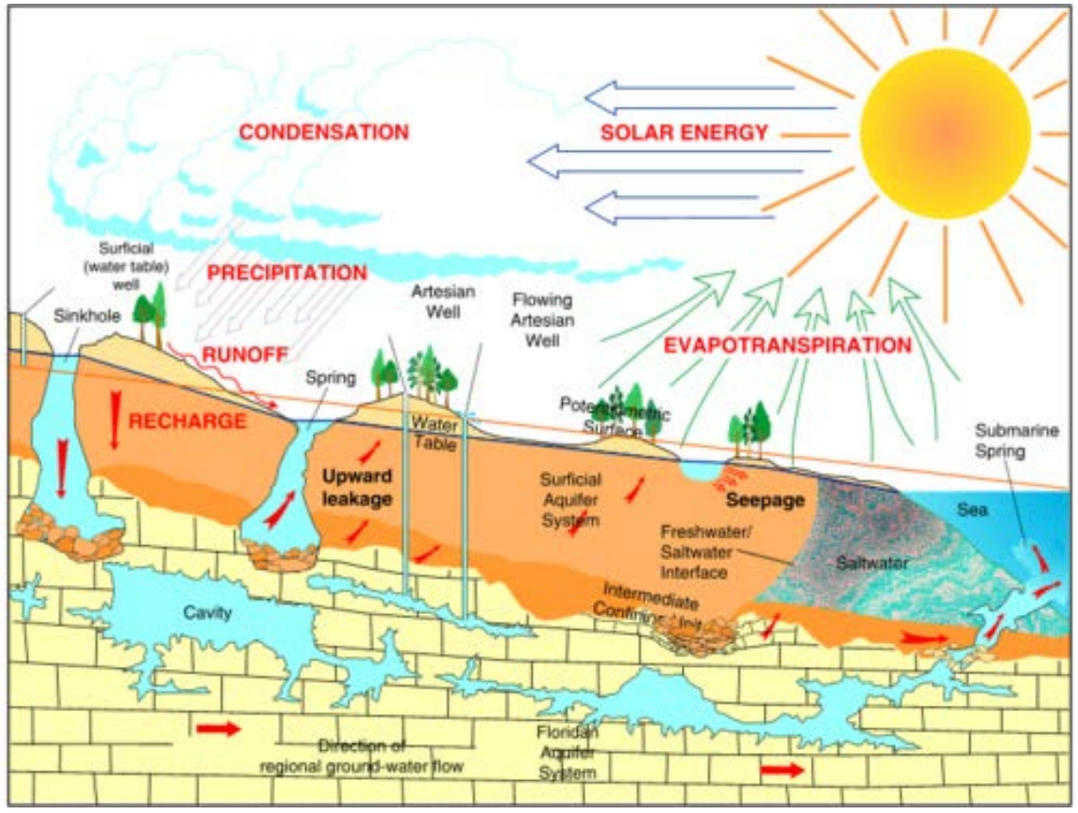


Figure 17.5

In Florida, groundwater is sometimes not underground.

Artesian Formations

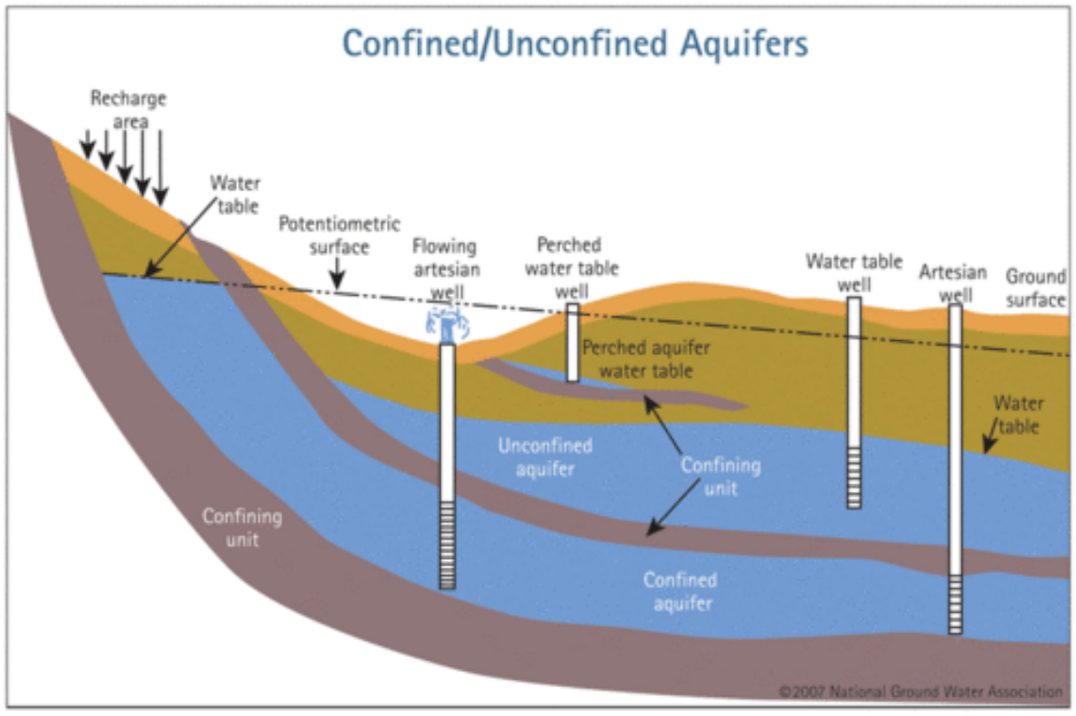


Figure 17.6

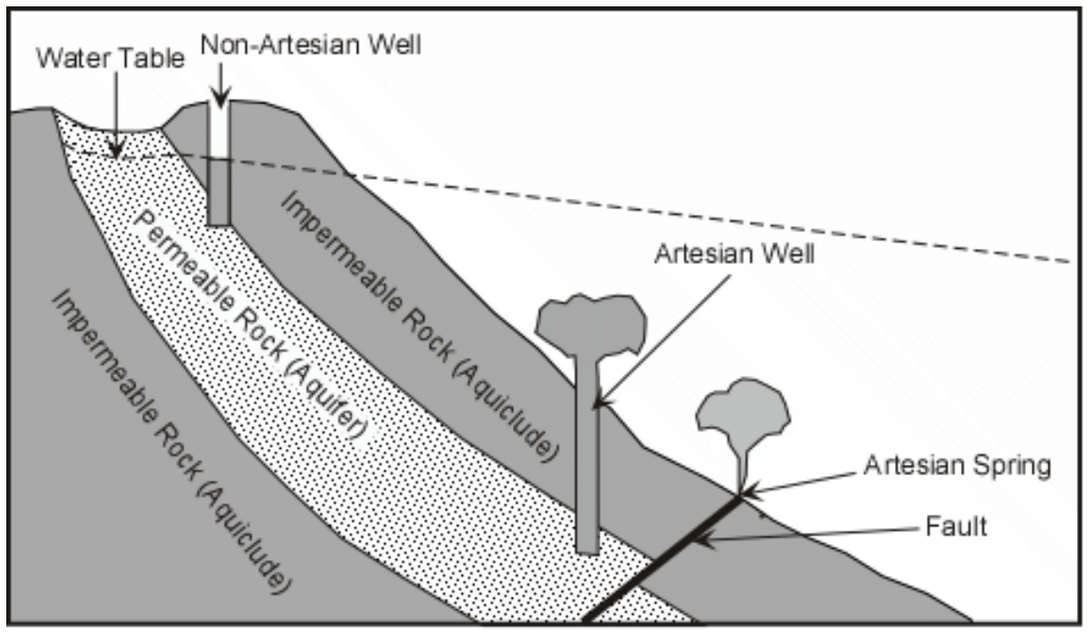


Figure 17.7

The permeable layers of rock and sediment that store and carry groundwater in enough quantity to supply wells are the aquifers. The upper level of an aquifer that supplies an ordinary well is the water table. The best aquifers are uncemented sand and gravel, followed by porous sandstones.

Sometimes and aquifer dips underground between impermeable rock layers. A sandwich of permeable and impermeable rocks is formed. This arrangement is called an **artesian formation** . The upper impermeable layer of an artesian formation, usually shale, is called cap rock. Rain that enters the aquifer is trapped between the rock and the impermeable rock layer below. Gravity moves the water downward in the dipping aquifer. The water is pushed along by the weight of all the water above and behind it.
Great quantities of water may enter the aquifers of artesian formations. Like the water in a great sloping pipe, the water in the aquifer is under pressure. When the well is drilled, the pressure causes the water to rise up in the well. The water may even spout into the air if the water pressure is great enough Wells drilled into artesian formations are called artesian wells.
Artesian formations may be broken by cracks in the cap rock called **fissures** . Artesian springs, or fissure springs, rise through these cracks. Such a spring may form a desert oasis.

Groundwater Use

Groundwater is an extremely important water source for people. Groundwater is a renewable resource and its use is sustainable when the water pumped from the aquifer is replenished. It is important for anyone who intends to dig a well to know how deep beneath the surface the water table is. Because groundwater involves interaction between the Earth and the water, the study of groundwater is called hydrogeology.

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.

The Ogallala Aquifer supplies about one-third of the irrigation water in the United States (**Figure** below). The aquifer is found from 30 to 100 meters deep over about 440,000 square kilometers! The water in the aquifer is mostly from the last ice age.

The Ogallala Aquifer is widely used by people for municipal and agricultural needs.

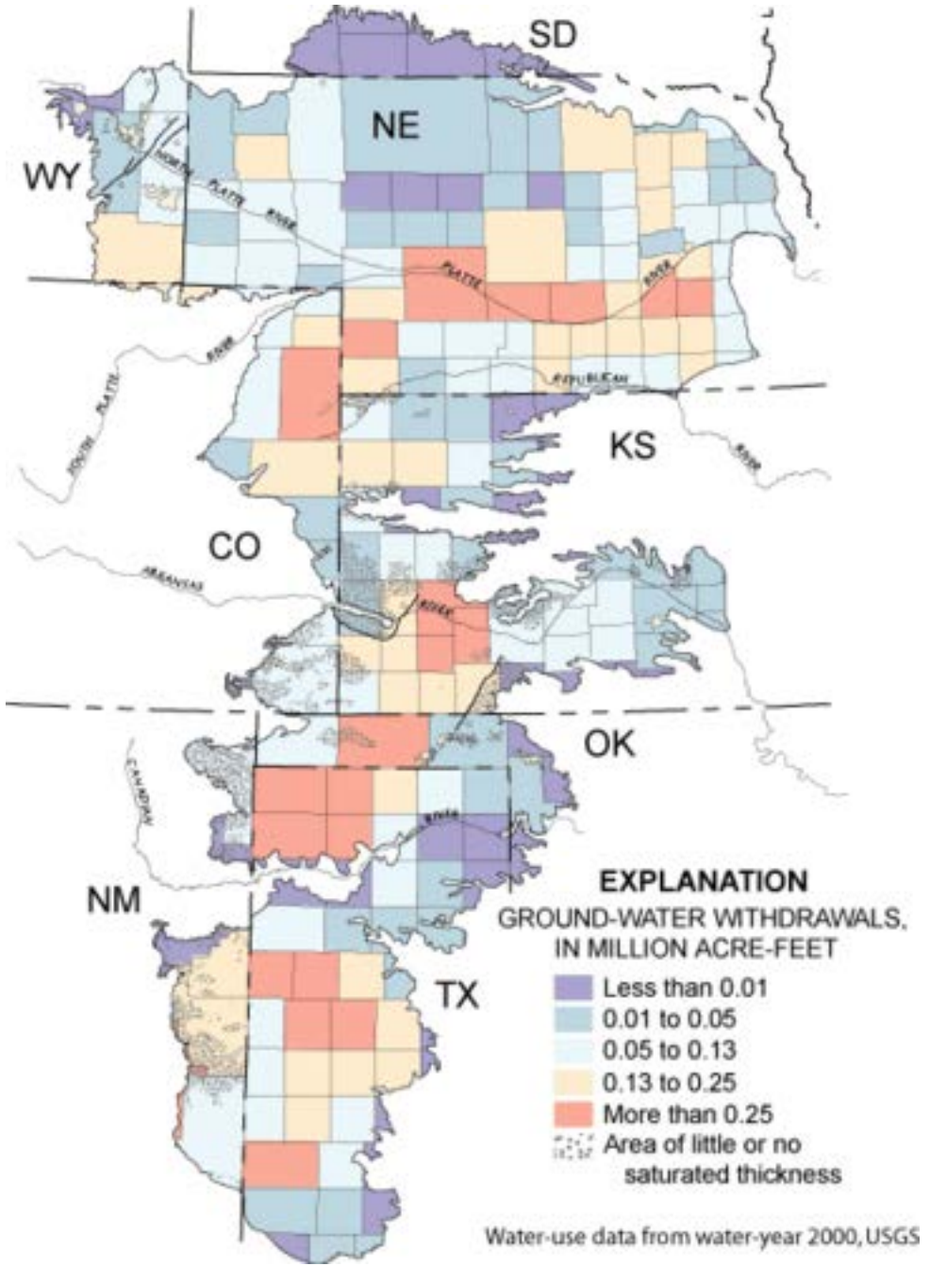


Figure 17.8

The Ogallala Aquifer is found beneath eight states and is heavily used.

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** below).



Figure 17.9

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.

Lowering the water table may cause the ground surface to sink. **Subsidence** may occur beneath houses and other structures (**Figure** below).



Figure 17.10

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.

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.

Springs

Groundwater meets the surface in a stream, as shown above, or a **spring** (**Figure** below). A spring may be constant, or may only flow at certain times of year.

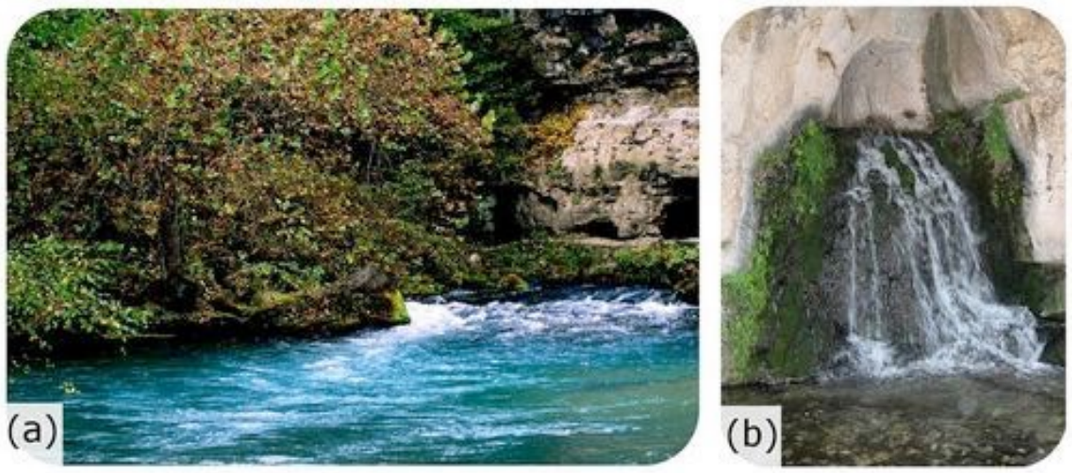


Figure 17.11

(a) Big Spring in Missouri lets out 12,000 liters of water per second. (b) Other springs are just tiny outlets like this one.

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 (**Figure** below).

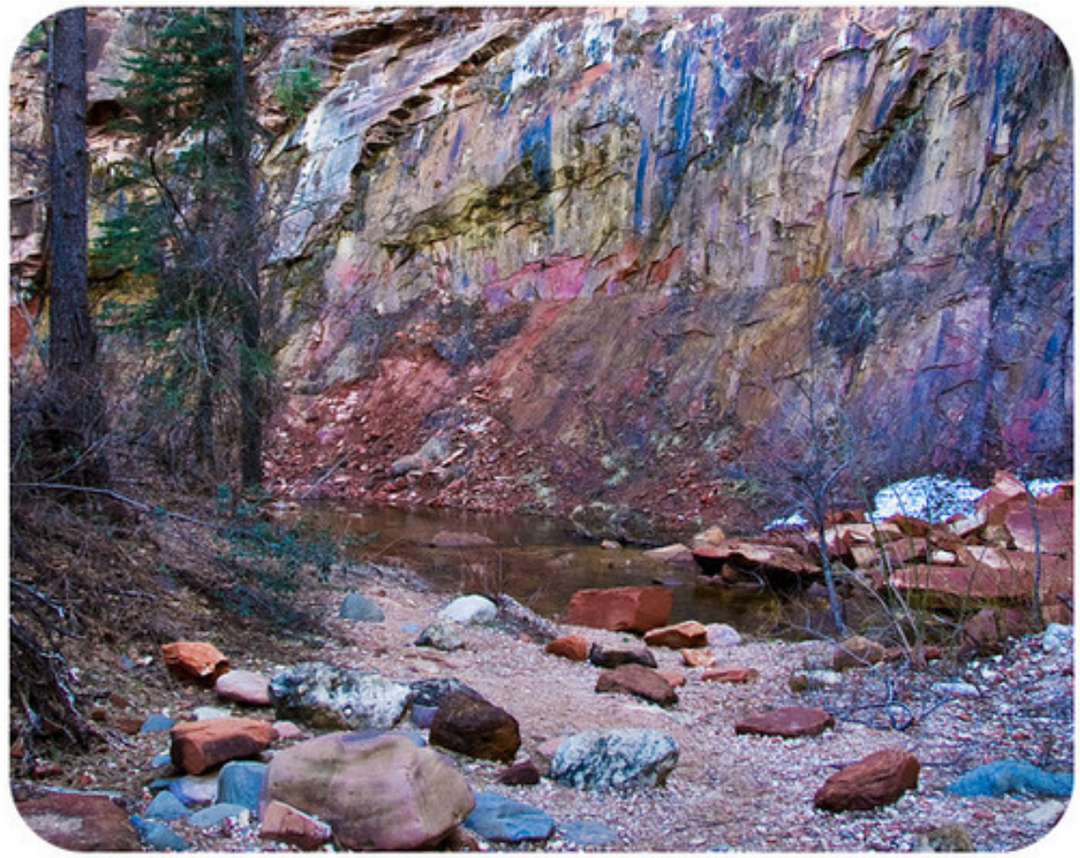


Figure 17.12

In the dry Arizona desert, Oak Creek and many other streams are spring fed.

Wells

A **well** is created by digging or drilling to reach groundwater. 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 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** below).



Figure 17.13

An old-fashioned well that uses a bucket drawn up by hand.

Ground Water Erosion and Deposition

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 **ground water.**



Figure 17.15

When water sinks into the ground, it becomes ground water.

Ground water is a strong erosional force, as it works to dissolve away solid rock (**Figure** above). Carbonic acid is especially good at dissolving the rock limestone.

Cave Formation

Working slowly over many years, ground water travels along small cracks. The water dissolves and carries away the solid rock gradually enlarging the cracks. Eventually a cave may form (**Figure** below).



Figure 17.17

Caverns many football fields long and as high as many meters tall form where ground water erodes away rock.

Ground water carries the dissolved minerals in solution. The minerals may then be deposited, for example, as **stalagmites** or **stalactites** (**Figure** below).



Figure 17.19

(a) 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. (b) 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. Caves also produce a beautiful rock, formed from calcium carbonate, **travertine** . Ground water saturated with calcium carbonate precipitates as the mineral calcite or aragonite. Mineral springs that produce travertine can be hot, warm or even cold (**Figure** below).



Figure 17.21

Travertine is a beautiful form of limestone.

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

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** below).



Figure 17.23

This sinkhole formed in Florida.

Lesson Summary

- Groundwater is the largest reservoir of fresh water.
- The water table is the top of an aquifer below which is water and above is rock or soil mixed with air.
- Aquifers are underground areas of sediment or rock that hold groundwater.
- An aquifer needs good porosity and permeability.
- Where groundwater intersects the ground surface, a spring can form.
- People dig or drill wells to access groundwater.

Review Questions

1. What is groundwater?

2. What is the water table?

3. What are aquifers and why are they so important?

4. Replenishing an aquifer is important because it makes the aquifer a resource that can last a long time. What do you think are ways to keep the amount of water used and the amount of water replenished the same?

5. How does a well work?

6. Since groundwater is largely unseen from the surface, how might you monitor how humans are affecting the amount of groundwater in an aquifer?

Further Reading / Supplemental Links

Earth's water distribution video, University of Waikato, New Zealand http://www.sciencelearn.org.nz/contexts/h2o_on_the_go/sci_media/video/earth_s_water_distribution

Points to Consider

- Is water from a river or from a well more likely to be clean to drink?
- Why is overuse of groundwater a big concern?
- What policies might people put in place to conserve water levels in lakes and aquifers?

Opening image courtesy of Jeff Schmaltz/NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=44524 . Public Domain.

14.2 Long Island's Groundwater

Long Island Groundwater

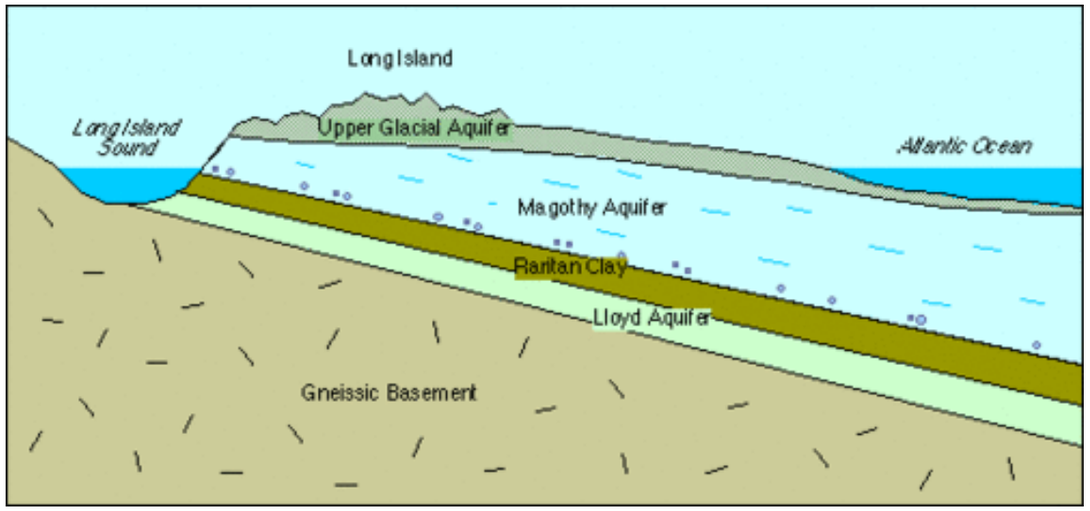


Figure 17.24

In sequence from shallowest to deepest, the LI aquifers are: the **Upper Glacial** , the **Magothy** and the **Lloyd** Aquifers. A minor aquifer, the **Jameco** , lies beneath the Upper Glacial, along the western south shore of Long Island. All of the aquifers slope downward toward the southern portion of the island. This causes the deepest parts of the aquifers and the groundwater system to reside along the southern shore of Long Island, and extends out into the subsurface material beneath the ocean floor.

The aquifer formations beneath Long Island were deposited at different times in the area's geologic history. The deepest aquifer layer, the Lloyd, rests on a bed of consolidated bedrock, primarily

igneous and metamorphic. The bedrock was laid down in the Precambrian Era, making it older than 600 million years. The sand deposits of the Lloyd Aquifer were laid down in the Cretaceous Period, about 80-100 million years ago. The sand and gravel of the Magothy aquifer was deposited in the upper Cretaceous Period, about 50-80 million years ago. The youngest aquifer formation, the Upper Glacial, was laid down during the last ice age, 10-15 million years ago. It contains course sands, pebbles, rocks and occasionally boulders, carried to Long Island and left behind by the glaciers. The water table, or the top of the groundwater system, is found in the Upper Glacial aquifer.

A thick deposit of clay (100-200 feet thick) called the Raritan Clay exists between the Magothy and Lloyd aquifers. The Lloyd sands and the clay bed above it are together known as the Raritan Formation. The Lloyd aquifer is found along the north shore of Long Island at depths averaging 200-300 feet. Along the southern shoreline the Lloyd aquifer is approximately 1,500 feet below the land surface. Along the south shore a second clay bed separates the Upper Glacial aquifer from the Jameco aquifer. It is called the Gardiners Clay. Clay units have very low permeability and act as aquitards, minimizing water exchange between the layers

All Long Island aquifers receive their fresh water from precipitation. Long Island receives, on average, about 44 inches of precipitation a year. Of this, about half of the precipitation, or approximately 22 inches of rain, percolates into the ground and is recharged into the groundwater system. The remaining precipitation is either evaporated, taken up by plants, or runs off into creeks, bays and estuaries. In areas where the water table and the ground surface meet, streams, ponds and wetlands are formed. In an undisturbed natural setting, (e.g., before human activities) all of Long Island's groundwater would ultimately reach the coast where the groundwater would mix with and the ocean. Due to human activity, this process has been significantly changed so that not all water in the groundwater system is returned to the ocean.

Today, groundwater is withdrawn from the system constantly. Over 138 billion gallons of water is taken each year from beneath Nassau and Suffolk Counties. In coastal areas, as water is drawn up for use, less groundwater is available to be discharged into the estuaries. The resulting loss of water and pressure allows saltwater from the ocean to flow into the aquifer, causing the groundwater to become saline, resulting in a condition called **"saltwater intrusion"** .

New water from precipitation is constantly recharging, or replenishing, the aquifers. Unfortunately, as water recharges the system, it can easily carry contaminants with it into the groundwater. Since it is the shallowest and closest to most sources of contamination, the Upper Glacial aquifer is the most heavily contaminated of the three. The next most seriously contaminated aquifer is the Magothy, which is the layer below the Upper Glacial. The Magothy aquifer supplies over 90% of the water used in Nassau County and about 50% of all water used in Suffolk County.

Although water can flow from one aquifer to another, groundwater on Long Island generally travels in a easterly direction. This horizontal movement offers some protection for deeper aquifers, however pollutants can still contamination aquifers below the Upper Glacial.

Citizen's Campaign: http://www.citizenscampaign.org/campaigns/long-island-groundwater.asp

Stonybrook Study: http://www.eserc.stonybrook.edu/cen514/info/LI/Groundwater.pdf

Hofstra University Study: http://people.hofstra.edu/j_b_bennington/121notes/pdfs/LI_%20aquifers.pdf

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1.CK-12 Foundation - Geoff Ruth and Hana Zavadska. . CC-BY-NC-SA 3.0
2.CK-12 Foundation. . CC-BY-NC-SA 3.0
3.Courtesy of US Geological Survey. http://en.wikipedia.org/wiki/File:Florida_groundwater_cycle.gif . Public Domain
4.Courtesy of the US Geological Survey. http://ne.water.usgs.gov/ogw/hpwlms/physsett.html . Public Domain
5.Courtesy of NASA/GSFC/METI/ERSDAC/JAROS and US/Japan ASTER Science Team. http://earthobservatory.nasa.gov/IOTD/view.php?id=5772 . Public Domain
6.US Geological Survey. http://en.wikipedia.org/wiki/File:Gwsanjoaquin.jpg . Public Domain
7.(a) Jerry Miller [Flickr: jmiller713]; (b) [Flickr: Boobelle]. (a) https://secure.flickr.com/photos/20303862@N00/2163081172/; (b) https://secure.flickr.com/photos/barbaraainscough/2999677017/ . (a) CC-BY-NC 2.0; (b) CC-BY-NC 2.0
8.Miles Orchinik. http://miles-home.smugmug.com/Nature/Oak-Creek-Canyon/8327482_xovM6#545648420_hYeBP . Used with permission
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Ch. 15: Glaciers

Lesson Objectives

•Discuss the different erosional features formed by alpine glaciers.
•Describe the processes by which glaciers change the underlying rocks.
•Discuss the particles deposited by glaciers as they advance and recede.
•Describe the landforms created by glacial deposits.

Vocabulary

•alpine (valley) glacier
•arête
•basal slip
•cirque
•continental glacier
•crevasses
•drumlins
•end moraine
•erratics
•eskers
•firn
•glacial erratic
•glacial striations
•glacial till
•glaciers
•ground moraine
•hanging valley
•horn
•iceberg
•ice cap
•kames
•kettles
•lateral moraine
•medial moraine
•moraine
•nunataks
•outwash
•outwash plains
•plastic flow
•plucking
•roches moutonnees
•snow line
•stratified drift
•tarn
•terminal moraine
•varve

Introduction

Glaciers cover about 10% of the land surface near Earth's poles and they are also found in high mountains. During the Ice Ages, glaciers covered as much as 30% of Earth. Around 600 to 800 million years ago, geologists think that almost all of the Earth was covered in snow and ice. Scientists use the evidence of erosion and deposition left by glaciers to do a kind of detective work to figure out where the ice once was.

Formation of Glaciers

Glaciers are solid ice that move extremely slowly along the land surface (**Figure** below). Glaciers form in areas that are always covered by snow. In such areas, more snow class than melts each year, as a result of snow build up from previous years. Climates cold enough to cause such conditions may be found in any part of the world. Air temperatures drop as you climb high above sea level and as you travel further from the equator.

Even in equatorial areas, however, a layer of permanent snow may exist on high mountains at high elevation. Further from the equator, the elevation need not be so high for a layer of permanent snow to exist. In the polar areas, permanent snow maybe found even at sea level. The lowest elevation at which the layer of permanent snow occurs in summer is called the **snow line** . If a mountain is completely covered with snow in winter but without snow in summer, it has no snow line.

In general, the snow line occurs at lower and lower elevations as the latitude approach the poles. The snow line also changes according to total yearly snowfall and the amount of solar exposure. Thus, the elevation of the snow line is not the same for all places at a given latitude.

How Glaciers Form

Except for bear rock cliffs, a mountain above the snow line is always buried in snow. Great basins below the highest peaks are filled with snow that can be hundreds of meters thick. In these huge snowfields, buried snow becomes compressed and recrystallizes into a rough, granular ice material called **firn.**

Firn resembles the ice of a packed snowball. It is not fluffy, such as new fallen snow, nor is it as hard as solid ice. The granules of firn start out no larger than grains of sand. As the layer of firn thickens, the firm's crystals may grow as large as kernels of corn. Within a layer of firn, the weight of the material at the top compresses the firn below turning that firn into solid ice. Under the weight of the overlying snow and firn, the ice begins to flow downward and outward. This moving mass of snow and ice is a glacier.

Types of Glaciers

Glacial ice erodes and shapes the underlying rocks. Glaciers also deposit sediments in characteristic landforms. The two types of glaciers are:

- **Continental glaciers** are large ice sheets that cover relatively flat ground. These glaciers flow outward from where the greatest amount of snow and ice accumulate.
- **Alpine** or **valley glaciers** flow downhill through mountains along existing valleys. They move within valley walls.

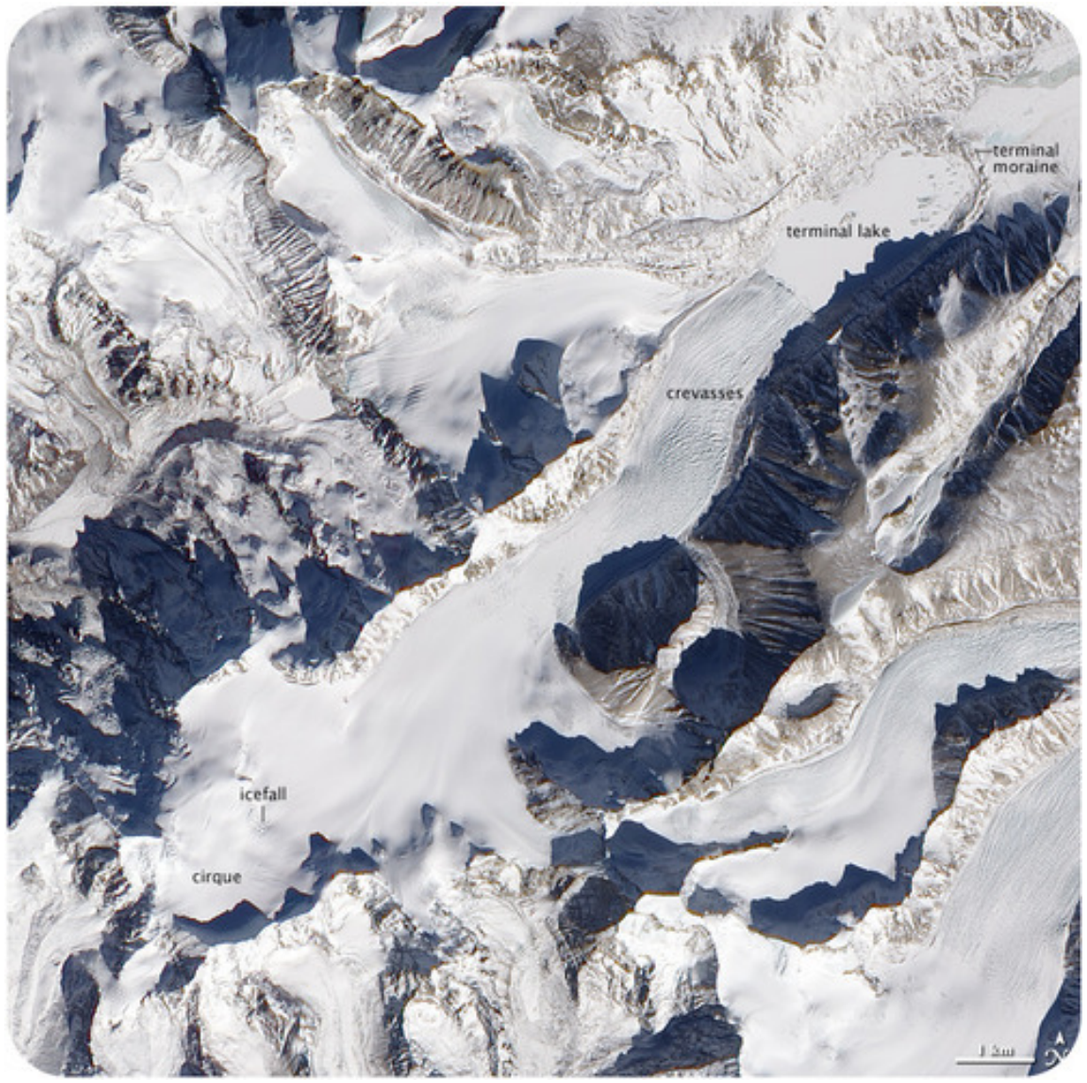


Figure 18.1

A satellite image of glaciers in the Himalaya with some features labeled.

Valley Glaciers

Many mountain ranges in the world have peeks and valleys high enough so that snowfall there exceeds snowmelt. The snow builds up and changes to ice as it accumulates in the valleys of such mountain ranges. The ice stays within valley walls, forming a large river of ice and snow, which moves slowly downhill under the influence of gravity. This long, slow-moving, wedge shaped stream of ice is a valley glacier. Valley glaciers are also known as *alpine glaciers* , after the Alps in south-central Europe.

Valley glaciers form in regions where mountains are high enough to be in the colder part of the Earth's atmosphere. Valley glaciers even formed in equatorial regions where mountains are located at high elevations. Valley glaciers exist on all continents except Australia.
Valley glaciers very in size. Small valley glaciers may be less than 2 km long. Large valley glaciers may be over 100 km long and hundreds of meter thick. Some of the world's largest valley glaciers are in southern Alaska. The world's tallest mountains, the Himalayas, also had very large valley glaciers.

Continental Glaciers

Over the inland areas of polar regions, the climate is so cold that all precipitation falls as snow. Even in the summer, the air is never warm enough to melt all the snow. In places such as Greenland and Antarctica, snow has been falling, for thousands of years, building up and changing to ice. Landmasses such as these are almost entirely covered by thick masses of ice that leaves only the highest mountain peaks uncovered. The ices is thousands of meters thick and moves outward from its center in all directions to lower elevations. In some places the ice reaches the sea, where great chunks break off and float away as **icebergs.** This moving mass of ice is a continental glacier.

Continental glaciers are roughly circular or oval in shape. The Greenland glacier is about 1,700,000 km^2 in area and up to 3 km thick in places. The Antarctic glacier covers an even larger

landmass, with an area of about 13,700,000 km^2. This land area is greater than the combined areas of the United States and Mexico. In some places, the Antarctic glacier is over 4 km thick. Along the coast the ice may descend to more than 2 km below sea level. Inland, mountain peaks called *nunataks* project through the ice. A glacier that is less than 50,000 km^2 in area is sometimes called and **ice cap** . Iceland, Baffin Island, Spitsbergen, and other large islands of the Arctic Ocean have ice caps.

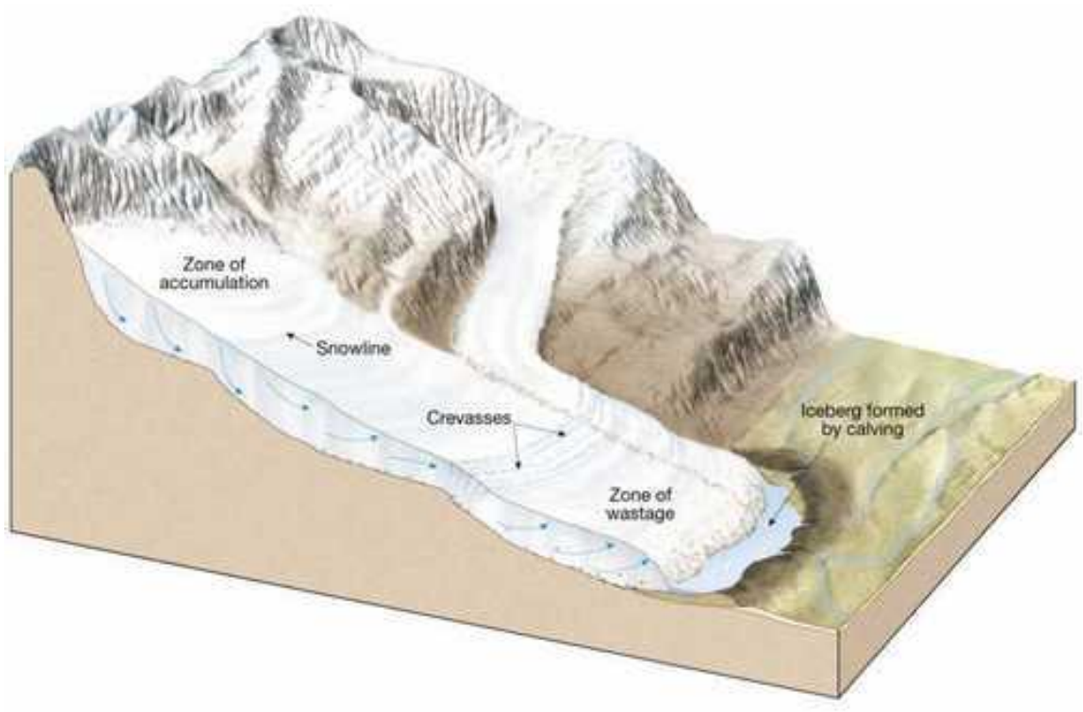


Figure 18.2

Glacial Profile

Glacial Erosion

Glaciers erode the underlying rock by abrasion and **plucking.** Glacial meltwater seeps into cracks of the underlying rock, the water freezes and pushes pieces of rock outward. The rock is then plucked out and carried away by the flowing ice of the moving glacier (**Figure** below). 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.** These striations help scientists figure out the direction of glacial movement.



Figure 18.3

Glacial striations point the direction a glacier has gone.

Mountain glaciers leave behind unique erosional features. When a glacier cuts through a ‘V’ shaped river valley, the glacier pucks

rocks from the sides and bottom. This widens the valley and steepens the walls, making a ‘U’ shaped valley (**Figure** below).



Figure 18.4

A U shaped valley in Glacier National Park.

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** below).



Figure 18.5

Yosemite Valley is known for waterfalls that plunge from hanging valleys.

Up high on a mountain, where a glacier originates, rocks are pulled away from valley walls. Some of the resulting erosional features are shown: (**Figure** below), and (**Figure** below).

Cirque i s a semicircular basin found at the head of a glacial valley formed by a valley glacier. The cirque is where the valley glacier began. When a change in climate causes a valley glacier to

disappear, the snowfields that once filled the cirque may melt. The cirque may thus fill with water, becoming a *cirque lake* or *tarn*.

Arête is a divide between two cirques that formed next to each other on a peak.

Horn is a pyramid-shaped peak, that forms when three or more cirques cut into the same peak. The Matterhorn, a mountain on the border of Switzerland and Italy, is one such example.

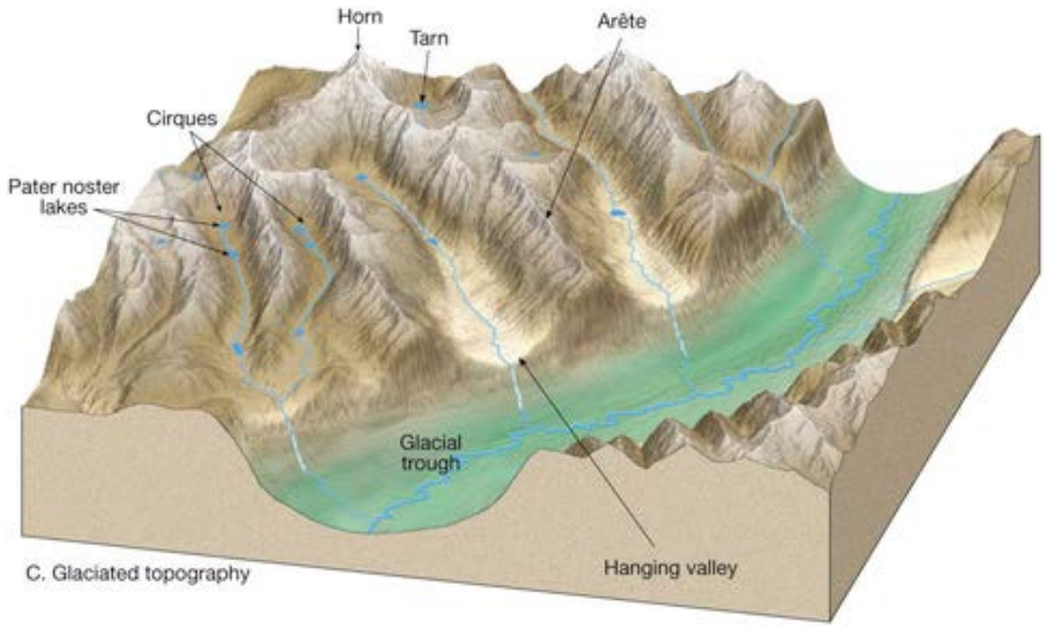


Figure 18.6

Effects of Erosion by a Glacier



Figure 18.7

(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.

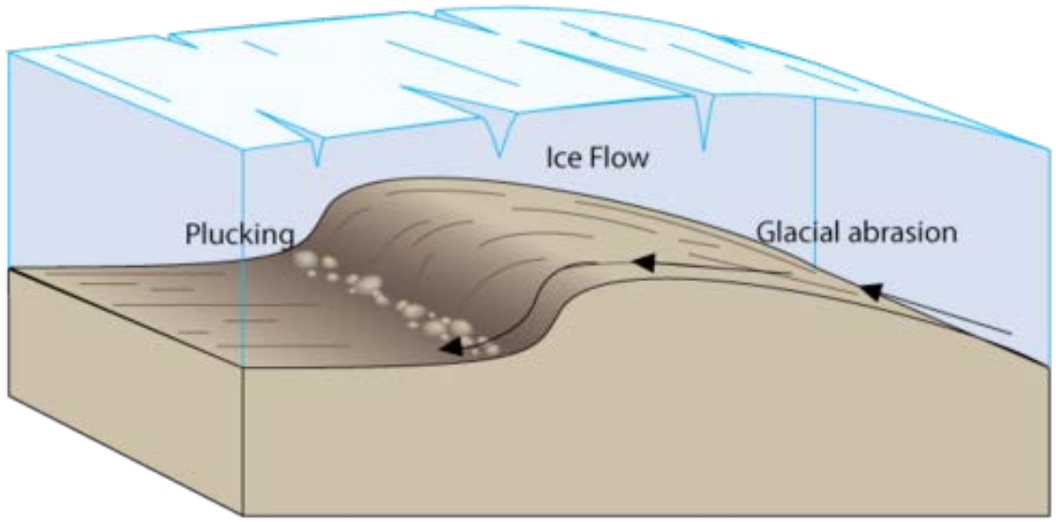


Figure 18.8

A roche moutonée forms where a glacier smooths the uphill side of the bedrock and plucks away rock from the downslope side.

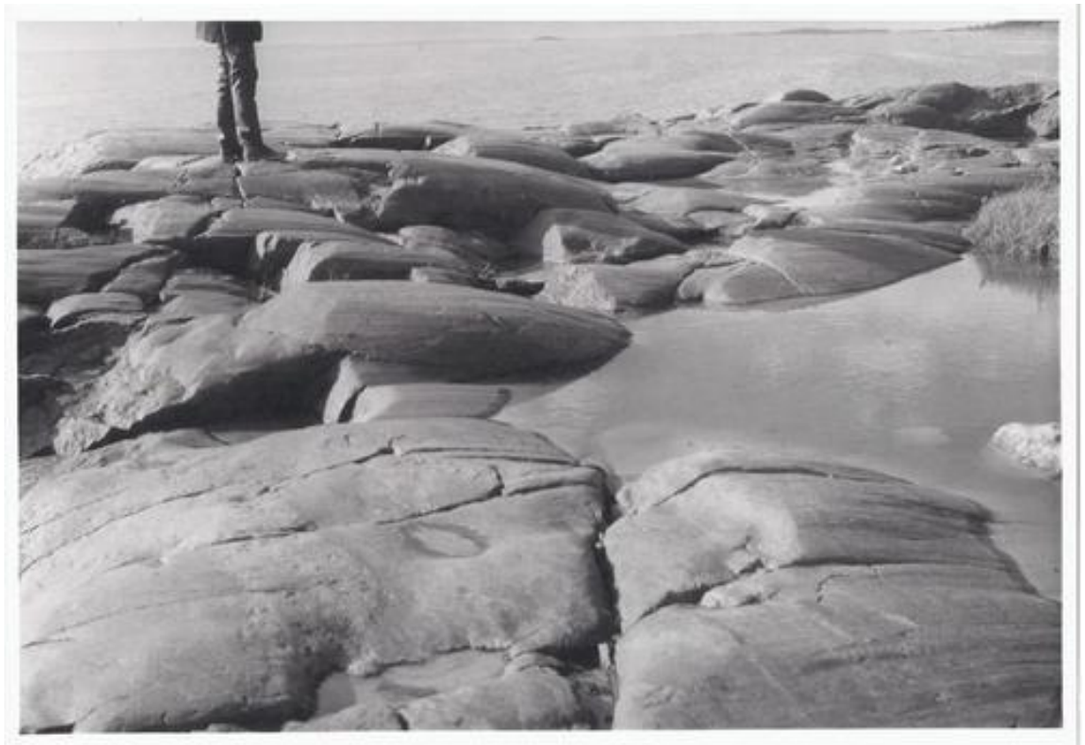


Figure 18.9

Roches Moutonnees

Glacial Movement

How can something as heavy as a glacier move? In fact, because a glacier moves to lower elevations under the influence of gravity, it is the glacier's great weight that enables it to move. As it moves, if you erodes rock materials

Some glaciers move only a few centimeters a day, while others may move several meters a day for weeks or months. Occasionally, glaciers surge forward at even higher rates. Glaciers move more rapidly after winters of heavy snowfall, on steep slopes, and in summer. Friction between glacial ice and the valley floor and walls slows a glacier's movement along its base and sides. For this reason, a typical glacier moves more rapidly at it's surface and at its center.

Basal Slip and Plastic Flow

At the base of some glaciers, the overlying weight causes grains of ice to partially melt and refreeze. The melting produces a great deal of water, which collects underneath the glacier. This water can form a thin layer of its own, or it can mix with sands and gravel, creating a slushy layer. Either type of layer reduces friction thus allowing the huge mass of ice to slide easily under the influence of gravity. This movement at the glaciers base is called **basalt slip.**
While the basal slip generally accounts for the movement at the base of a glacier, it cannot propel the rest of the glacier. In fact, in extremely cold regions, basal slip does not even occur. Most ice in

the interior of a glacier moves downhill through a process called **plastic flow** . In this process, the grains of ice actually deform, or change shape, continuously and permanently under the pressure of the overlying snow and ice. Near the bottom of the glacier, the ice grains are almost flat. Aided by the change in shape, the grains of ice slip past each other to create forward movement.

Like river valley's, glacial valleys have both steep and gentle slopes. When a valley glacier comes to a steep downward slope, great fissures or cracks, called **crevasses** form across the width of the glacier. These cracks form because the ice near the surface of a glacier is rigid. This ice responds to the movement of the ice underneath it by breaking. Crevasses rarely go deeper then about 50 meters, since below this depth there is not enough pressure for plastic flow to occur.

How do scientists study glacial movement? One way is by driving rows of stakes into the ice across a valley and observing the positions of the stakes regularly over time. Geologist also use orbiting satellites to track the movement of glaciers.

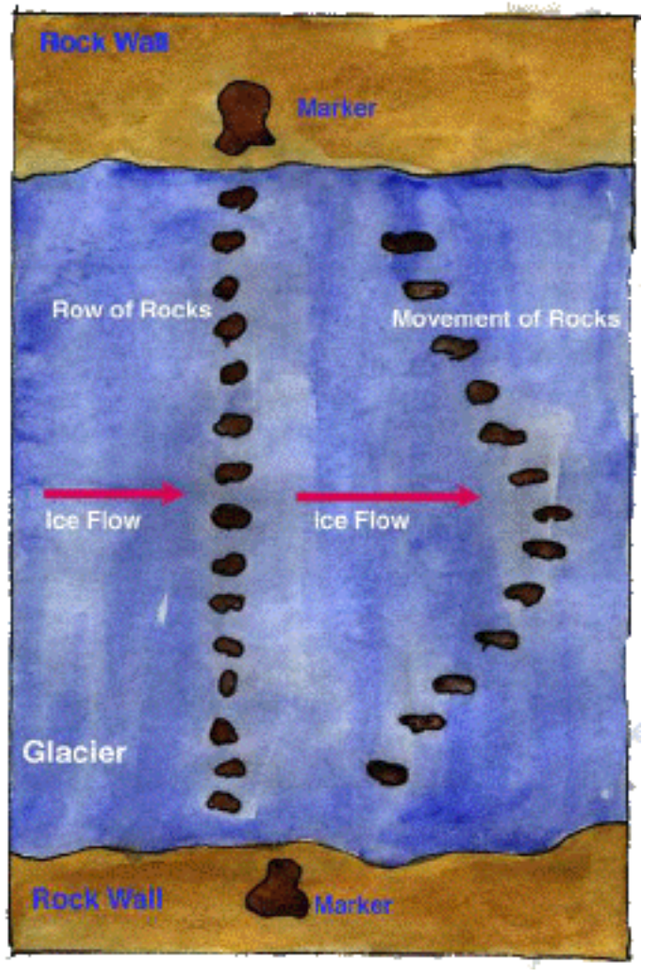


Figure 18.10

This picture shows how the original stakes have advanced furthest at the center due to the lack of friction.

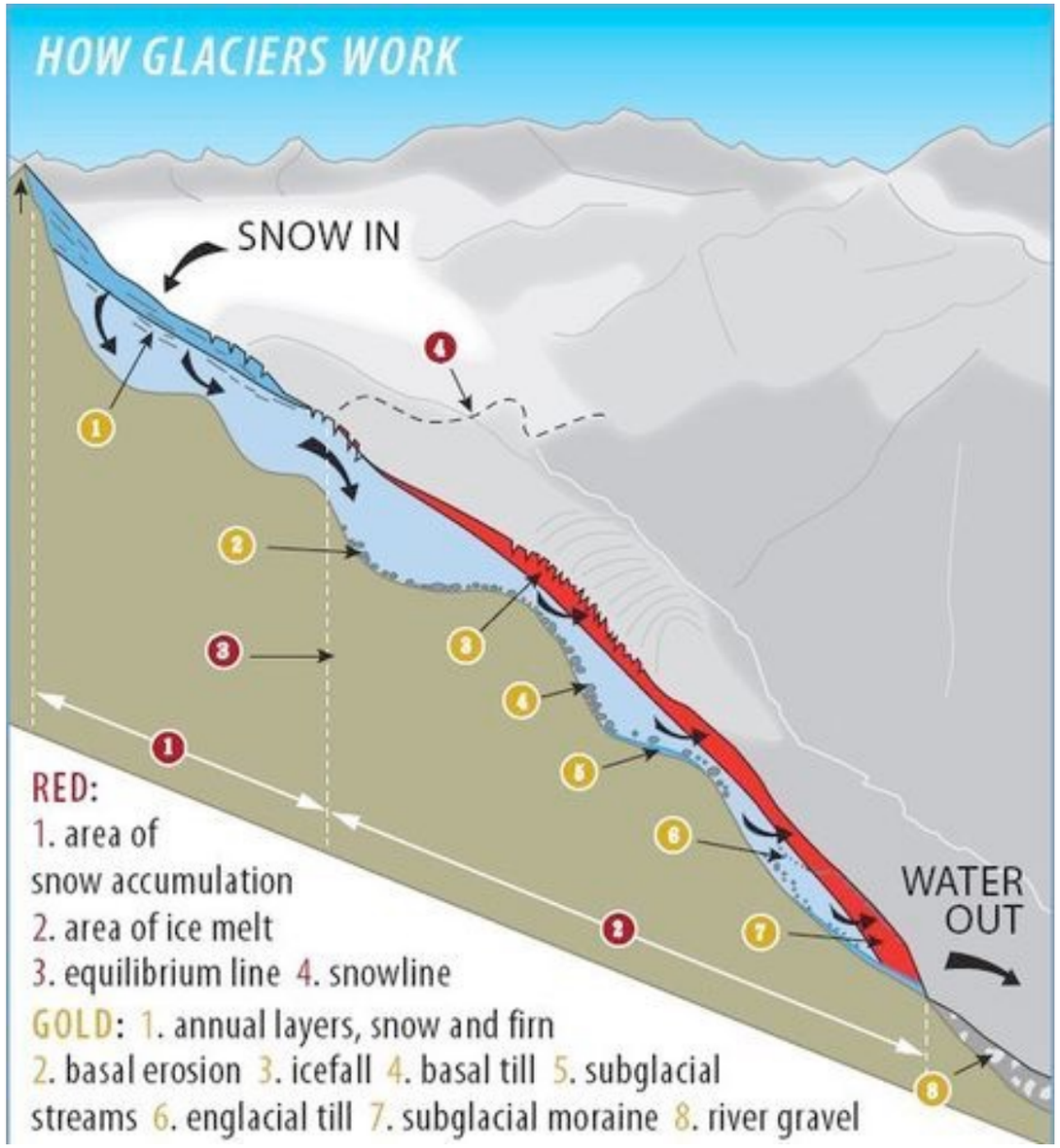


Figure 18.11

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** below). These rocks can be carried for many kilometers for many years.

These rocks with a different rock type or origin from the surrounding bedrock are **glacial erratics** . 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** . Materials deposited by glacial meltwater are called **outwash** . Like all stream deposits, outwash is sorted and stratified.



Figure 18.12

A large boulder dropped by a glacier is a glacial erratic.

Glacial Till, Moraines, and Drumlins

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. 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** below).



Figure 18.13

The long, dark lines are medial and lateral moraines.

- Sediment from underneath the glacier becomes a **ground moraine** after the glacier melts. Ground moraine contributes 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.

Drumlins are long, smooth, canoe shaped hills that are usually found in groups. Drumlins point in the direction of glacial movement. They are thought to form when an advancing glacier runs over an earlier glacial moraine, sweeping it into long strips.

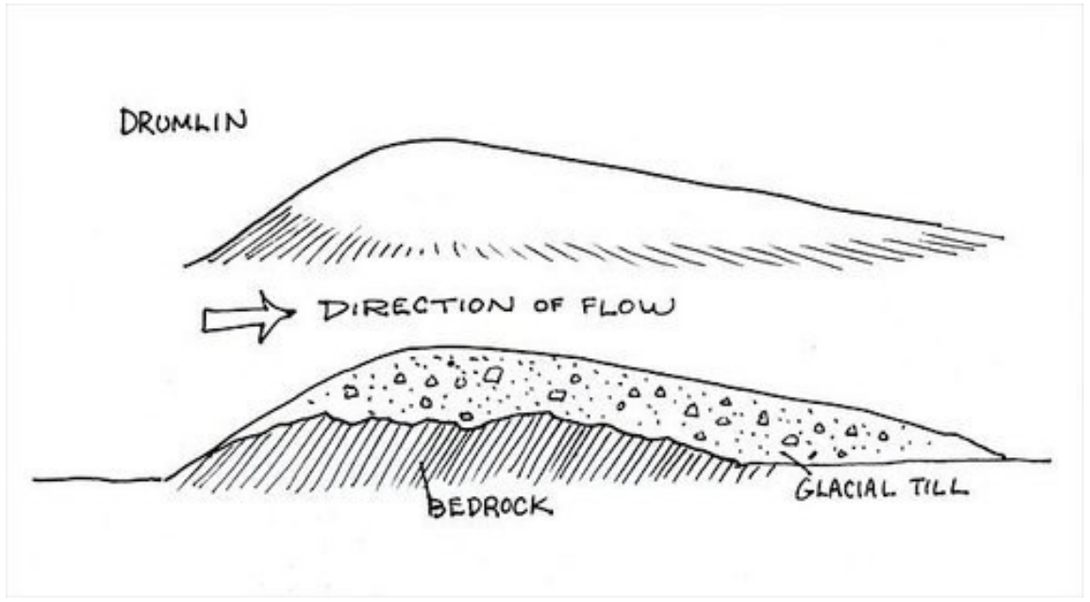


Figure 18.14



Figure 18.15

(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.

While glaciers dump unsorted sediments, glacial meltwater can sort and re-transport the sediments (**Figure** above). As water moves through unsorted glacial till, it leaves behind the larger particles and takes away the smaller bits of sand and silt. (**Figure** below).

Glacial melt water pours out at the ice front in streams filled with rock flour, sand, and gravel. The streams deposit outwash that may extend for many kilometers beyond the terminal moraine. These deposits look like alluvial fans. In front of large glaciers, they overlap and form broad, flat areas called **outwash plains** .
Much of the water of a melting glacier falls to the base of the glacier through crevasses. Subglacial streams are formed that run in tunnels beneath the ice and come out at the ice front. The winding tunnels of these streams become partly filled with roughly stratified sands and gravel. When the glacier melts, these deposits slump down at the sides and form long, winding ridges called **eskers** .
Kames are small, cone shaped hills of stratified sand and gravel. They form when streams flowing across the top of a glacier deposit their sediments at the ice front or in lakes on top of the ice. The sediments pile up as the ice thins. When the ice melts completely, sediments that had been heaped up against it or resting on top of it slump to the ground. Like the sediments in eskers, deltas, and outwash plains, those in Kames are deposited by water, not ice.
Kettles are bowl-shaped hollows found in moraines and outwash plains. Kettles form where buried blocks of ice have been left behind by a retreating glacier. When the ice melts, the water drains, leaving the kettles. This is then called a kettle lake.

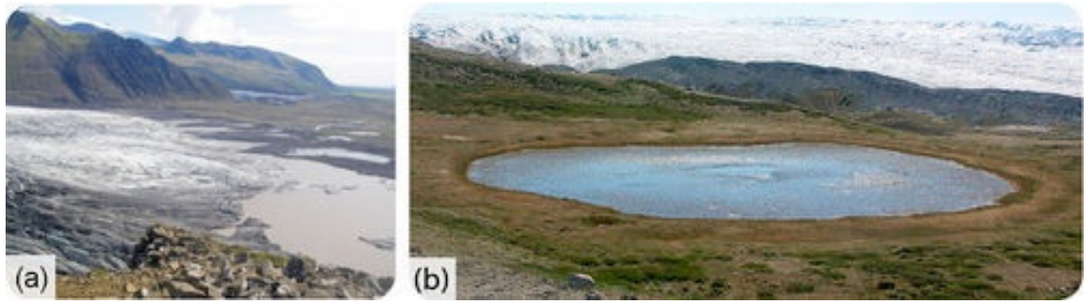


Figure 18.16

(a) A sorted deposit of sand and smaller particles is stratified drift. A broad area of stratified drift from meltwater over broad region is an outwash plain. (b) Kettle lakes form as blocks of ice in glacial till melt.

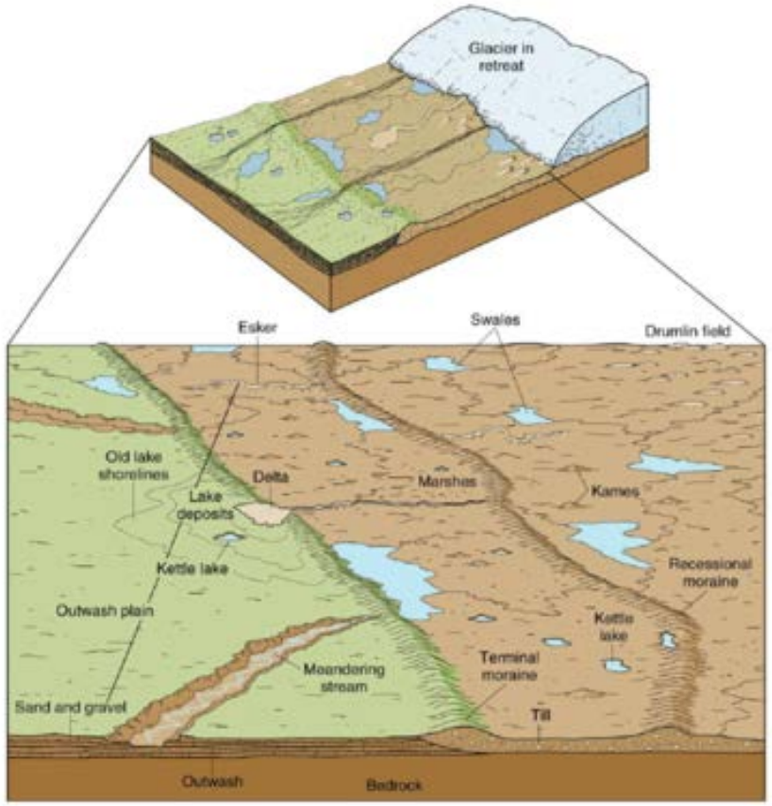


Figure 18.17

Glacial Deposits

> •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 .

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. If during a year, a glacier accumulates more ice than melts away, the glacier advances downhill. If a glacier melts more than it accumulates over a year, it is retreating (**Figure** below).



Figure 18.18

Grinnell Glacier in Glacier National Park has been retreating over the past 70 years.

Lesson Summary

•The movement of ice in the form of glaciers has transformed our mountainous land surfaces with its tremendous power of erosion.
•U-shaped valleys, hanging valleys, cirques, horns, and aretes are features sculpted by ice.
•The eroded material is later deposited as large glacial erratics, in moraines, stratified drift, outwash plains, and drumlins.
•Varves are a very useful yearly deposit that forms in glacial lakes.

Review Questions

1.How much of the Earth's land surface is covered by glaciers today? Where are they found?

2.What are the two types of glaciers and how are they different from each other?
3.What is the shape of a valley that has been eroded by rivers? How does a glacier change that shape and what does it become?
4.What two different features form as smaller side glaciers join the central main glacier?
5.How do glaciers erode the surrounding rocks?
6.Name the erosional features that are formed by glaciers high in the mountains and describe how they form.
7.Describe the different types of moraines formed by glaciers.
8.Describe the difference between glacial till and stratified drift. Give an example of how each type of deposit forms.
9.Name and describe the two asymmetrical hill shaped landforms created by glaciers.

Further Reading / Supplemental Links

- Glacial landforms illustrated: http://www.uwsp.edu/geo/faculty/lemke/alpine_glacial_glossary/glossary.html

Points to Consider

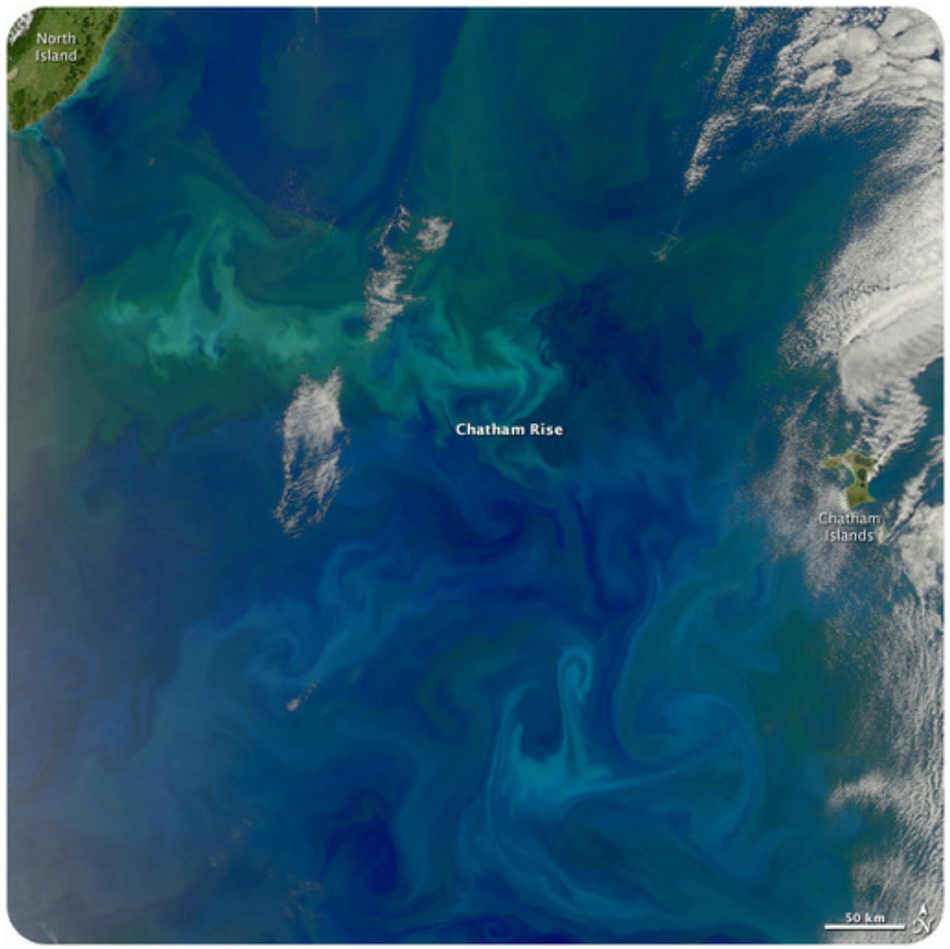
- What features would you look for to determine if glaciers had ever been present?
- If glaciers had never formed, how would soil in Midwestern North America be different?
- Can the process of erosion produce landforms that are beautiful?

References

1.Courtesy of Jesse Allen/NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=43391 . Public Domain
2.Walter Siegmund. https://commons.wikimedia.org/wiki/File:Glacial_striation_21149.JPG . CC-BY 2.5
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9.(a) Pearson Scott Foresman; (b) Brendanconway. (a) http://en.wikipedia.org/wiki/File:Esker_(PSF).png; (b) http://commons.wikimedia.org/wiki/File:Clew_Bay.JPG . (a) Public Domain; (b) Public Domain
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en.wikipedia.org/wiki/File:Kettle-glacial-lake-form-isunngua-greenland.jpg . (a) CC-BY-NC-SA 2.0; (b) Public Domain
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Ch. 16: Earth's Oceans



Phytoplankton bloom in spring when sunlight hits the water. The green color is from chlorophyll, the pigment needed for photosynthesis. The blue color is from the reflective plating around coccolithophores, a type of phytoplankton. The Chatham Rise is an underwater plateau that causes deep water to rise, bringing up nutrients. The feature is located where cold Antarctic currents meet warmer, subtropical water. The mixing of water and the nutrients foster large phytoplankton blooms.

Phytoplankton are the base of the marine food web and so they are food to nearly all other marine organisms. By using carbon dioxide for photosynthesis, phytoplankton help to reduce the buildup of greenhouse gases in the atmosphere.

Courtesy of Norman Kuring/NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=42099. Public Domain.

Introduction to the Oceans

Introduction to the Oceans

Lesson Objectives

- Explain the significance of the oceans.
- Describe the composition of ocean water.
- Define the parts of the water column and oceanic divisions.

Vocabulary

- aphotic zone
- biomass
- intertidal zone
- neritic zone
- oceanic zone
- photic zone
- salinity
- water column

Introduction

As terrestrial creatures, humans think of the importance of the planet's land surfaces. But Earth is mostly a water planet. From space, the dominance of water is obvious (**Figure** below). Most of Earth's water is in the oceans.



Figure 19.1

About 71% of the Earth's surface is covered with water, mostly by the oceans.

Because all of Earth's oceans are somehow connected, should this chapter be titled "Earth's Ocean" or "Earth's Oceans?" Try to decide by the end of the chapter.

An animation will help you see Earth's one, three, four, or five oceans: http://en.wikipedia.org/wiki/File:World_ocean_map.gif .

Significance of the Oceans

Earth would not be the same planet without its oceans.

Moderates Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70 ◦C and others as hot as 55 ◦C, the range is only 125 ◦C. On Mercury temperatures go from -180 ◦C to 430 ◦C, a range of 610 ◦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 the ocean and most precipitation falls on the oceans.

Biologically Rich

The oceans are home to an enormous amount of life. That is, they have tremendous biodiversity (**Figure** below). 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 19.2

A swimming polar bear is a tiny part of the immense biodiversity of the oceans.

Continental Margin

Recall from the Plate Tectonics chapter that 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** below).

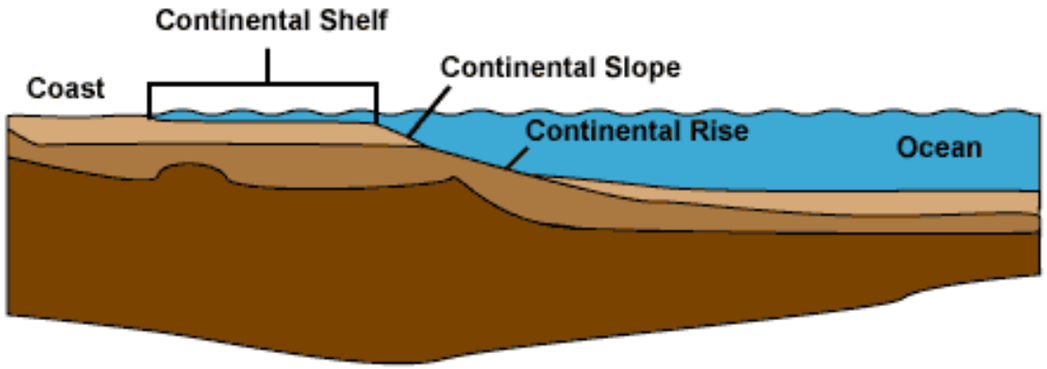


Figure 19.3

The continental margin is divided into the continental shelf, continental slope, and continental rise, based on the steepness of the slope.

Composition of Ocean Water

Remember from the Mineral's chapter that H_2O is a polar molecule so it can dissolve many substances (**Figure** below).

Salts, sugars, acids, bases, and organic molecules can all dissolve in water.

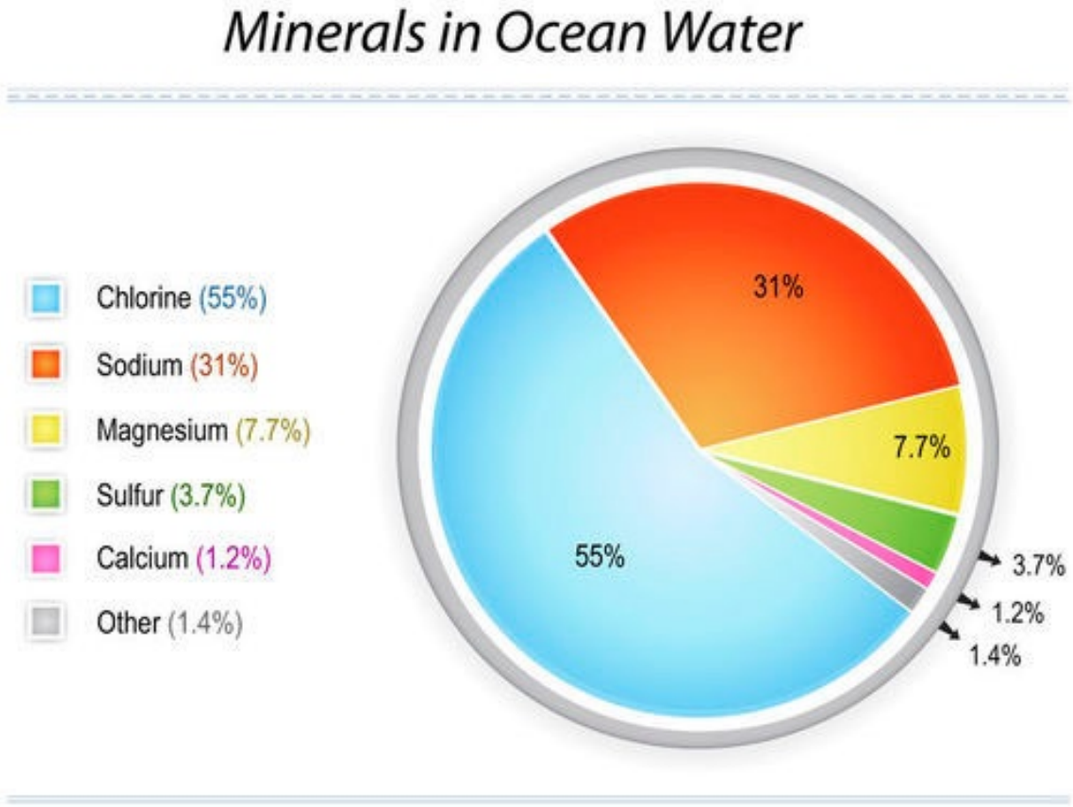


Figure 19.4

Ocean water is composed of many substances, many of them salts such as sodium, magnesium, and calcium chloride.

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** below). Why do you think this water body is called the Dead Sea?



Figure 19.5

The Dead Sea has such high salinity that people can easily float in it.

Interactive ocean maps can show salinity, temperature, nutrients, and other characteristics: http://earthguide.ucsd.edu/earthguide/diagrams/levitus/index.html .

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 Ocean Movements lesson.

The Water Column

In 1960, two men in a specially designed submarine called the Trieste descended into a submarine trench called the Challenger Deep (10,910 meters) (**Figure** below).

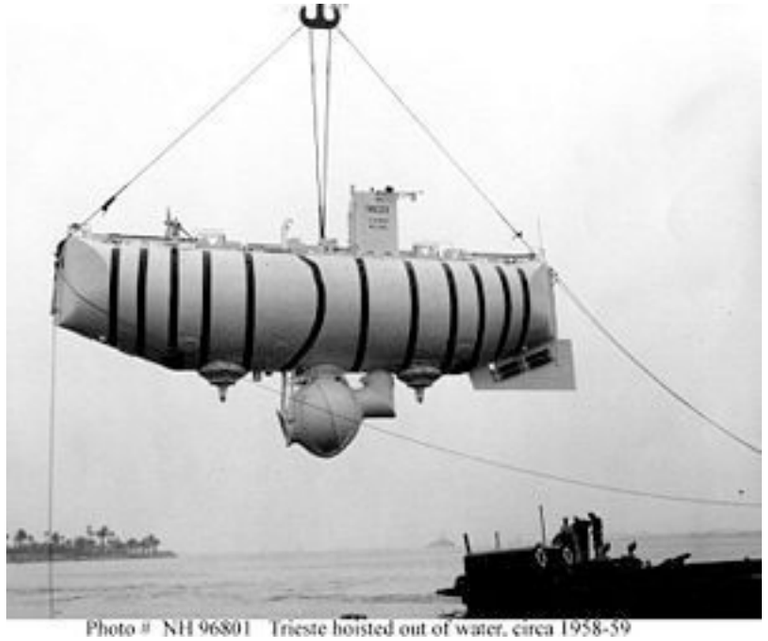


Figure 19.6

The Trieste made a record dive to the Challenger Deep in 1960.

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.

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** below).

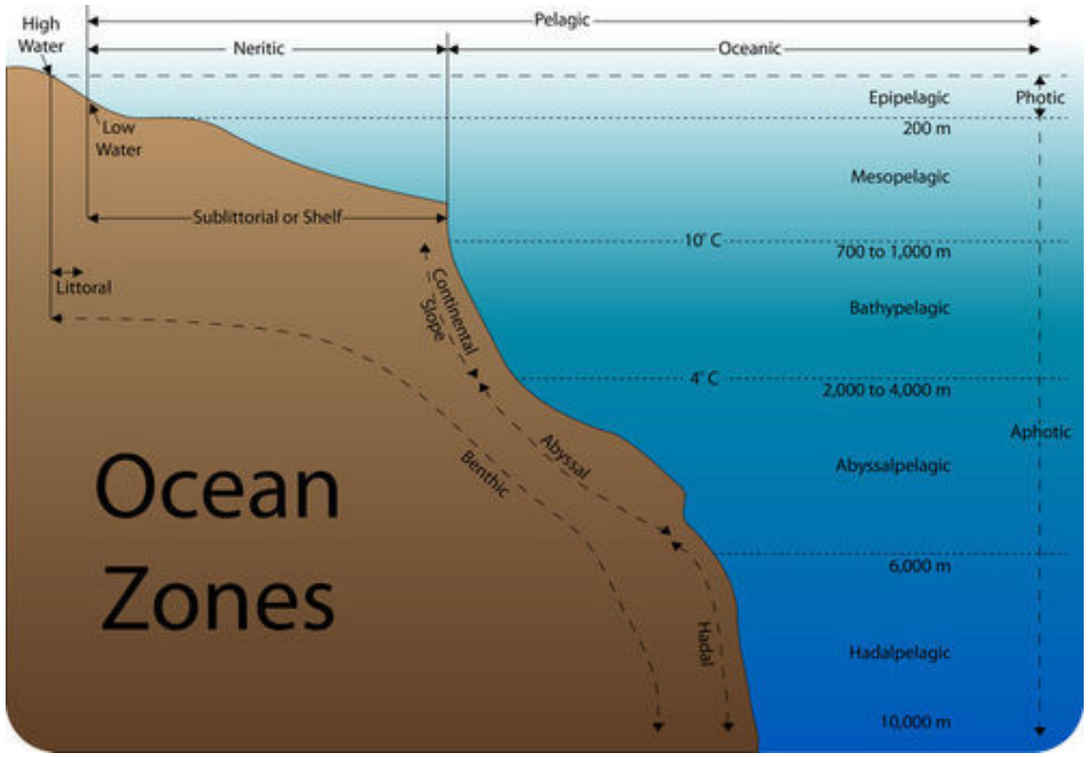


Figure 19.7

Oceanographers divide the ocean into zones both vertically and horizontally.

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** (littoral) **zone** , the region between the high and low tidal marks. This hallmark of the intertidal is change: water is in constant motions in waves, tides, and currents. The land is sometimes under water and sometimes is 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 above).

Lesson Summary

- The oceans help to moderate Earth's temperatures.
- The main elements in seawater are chlorine, sodium, magnesium, sulfate, and calcium.
- The average salinity of the oceans is about 3.5%.
- In seawater, if evaporation is high, salinity is high. If fresh water mixes in, salinity is low.
- In the photic zone there is enough available light for photosynthesis.
- The vast majority of the ocean lies in the aphotic zone, where there is not enough light for photosynthesis.
- The ocean floor averages about 3,790 m but ocean trenches are as deep as 10,910 m.
- The neritic zones are nearshore areas, including the intertidal zone. The oceanic zones are offshore regions of the ocean.

Review Questions

1. What percent of the Earth’s surface is covered by water?

2. How do the oceans help to moderate Earth's temperatures?

3. What is the most common substance that is dissolved in ocean water?

4. Define density. Why is density important to the water column?

5. Compare and contrast the photic and aphotic zones.

6. Briefly describe the types of organisms found in the intertidal, neritic, and oceanic zones.

Points to Consider

- How do water motions such as tides and waves affect living creatures in and near the sea?
- Is it possible to have a river in the middle of the ocean?
- What factors affect the movement of ocean water? How do these factors affect the world’s climate and the ocean’s ecosystem?

Section 2

Ocean Movements

Ocean Movements

Lesson Objectives

- Define waves and explain their formation.
- Describe what causes tides.
- Describe how surface currents form and how they affect the world's climate.
- Describe the causes of deep currents.
- Relate upwelling areas to the food chain.

Vocabulary

- Coriolis effect
- downwelling
- gyre
- high tide
- longshore current
- low tide
- neap tide
- rip current
- spring tide
- storm surge
- surface current
- thermohaline circulation
- tidal range
- tide
- upwelling
- wave

Introduction

Ocean water is constantly in motion: north-south, east-west, alongshore, and vertically. Seawater motions are the result of waves, tides, and currents (**Figure** below). Ocean movements are the consequence of many separate factors: wind, tides, Coriolis effect, water density differences, and the shape of the ocean basins. Water movements and their causes will be discussed in this lesson.



Figure 19.8

Ocean waves transfer energy through the water over great distances.

Waves

Waves have been discussed in previous chapters 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.

Wind Waves

This lesson studies the most familiar waves, those on the ocean's surface. 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 that create 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 starts out in a wave in the middle of the ocean later arrive at the shore?

Water molecules in waves make circles or ellipses (**Figure** below). 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

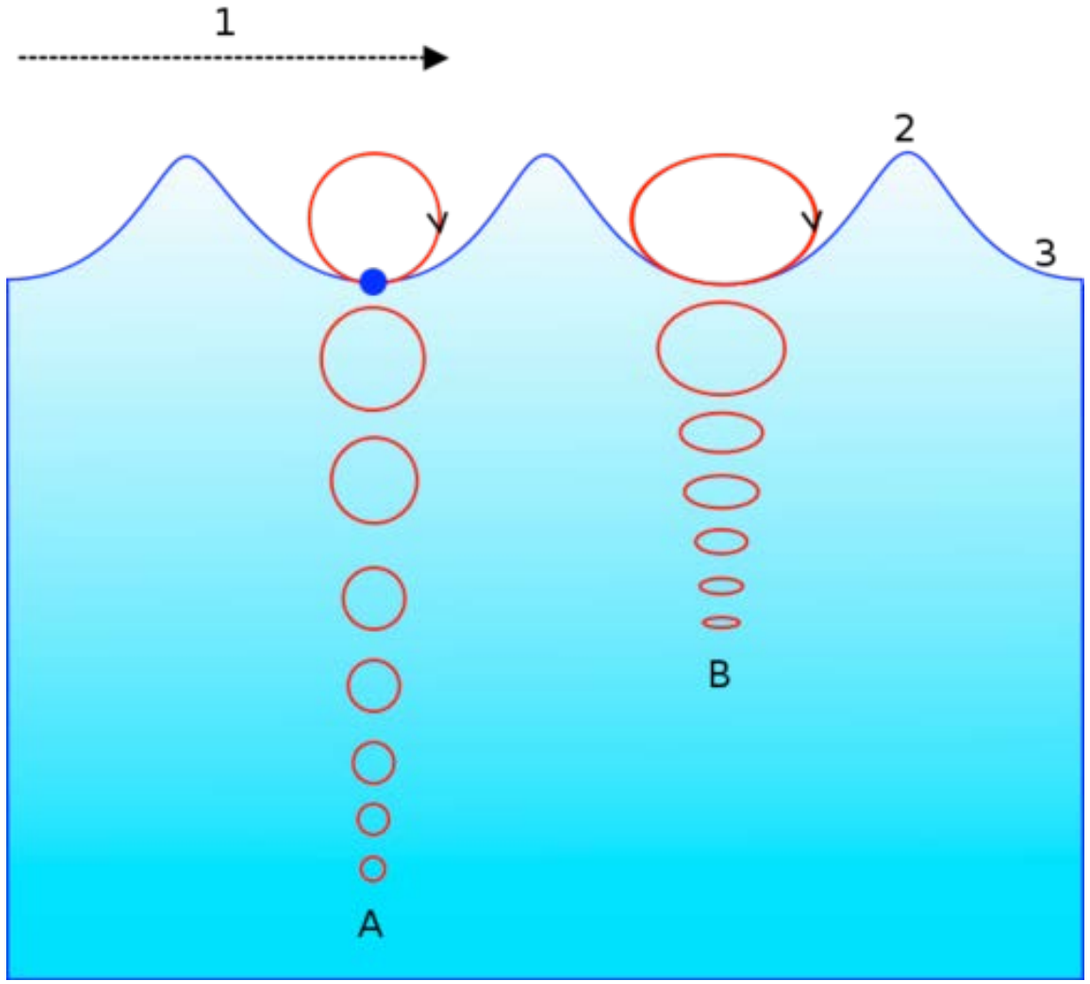


Figure 19.9

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 .

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.

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/

KQED: Science of Big Waves

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 at: http://www.kqed.org/quest/television/science-of-big-waves .



Click on the image above for more content

Tsunami

Tsunami are described in the Earthquakes chapter as damaging waves that result from the sharp jolt to the water from an undersea earthquake. Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami (**Figure** below). Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

Tsunami have small wave heights and long wavelengths so they are usually unnoticed at sea. As the wave rides up the continental shelf the wave height increases.

A video explanation of tsunami is here: http://www.youtube.com/watch?v=StdqGoezNrY

The wave speed of a tsunami is also slowed by friction with the shallower ocean floor, which causes the wavelength to decrease, creating a much taller wave.

Many people caught in a tsunami have no warning of its approach. Since the wavelength is long, a long time can pass between crests or troughs onshore. In 1755 in Lisbon, an offshore earthquake caused a great deal of damage on land. People rushed to the open space of the shore and discovered that the water was flowing seaward fast. The trough of the tsunami wave reached shore first. People who went out onto the open beach were drowned when the crest of the wave reached shore.



Figure 19.10

A wave from the 2004 Boxing Day Tsunami hits the Maldives in the Indian Ocean.

KQED: Science on the SPOT: Watching the Tides

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. Learn more at: http://science.kqed.org/quest/video/scary-tsunamis/ .



Click on the image above for more content

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 primarily cause of tides and the pull of the Sun’s gravity on Earth is the secondary cause (**Figure** below). 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.



Figure 19.11

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.

Daily Tide Patterns

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. The Moon's gravity then pulls the Earth toward it, leaving the water on the opposite side of the planet behind. This creates a second high tide bulge on the opposite side of Earth from the Moon. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides** .

Since so much water is pulled into the two high tides, **low tides** form between the two high tides (**Figure** below). As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides every day.

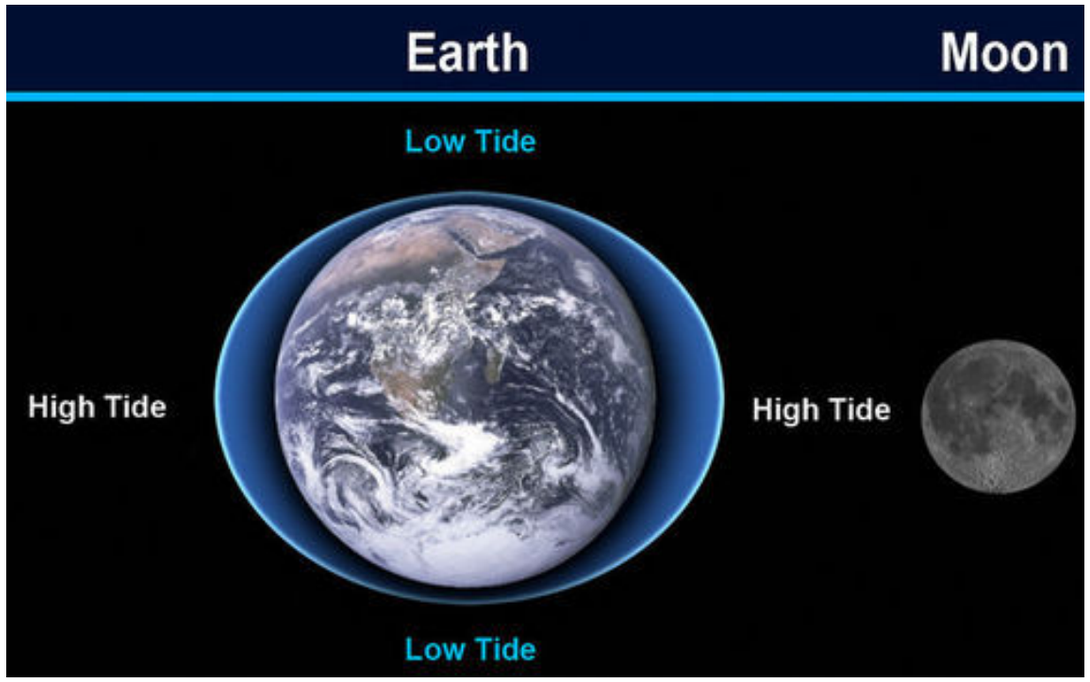


Figure 19.12

The gravitational attraction of the Moon to ocean water creates the high and low tides.

A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html .

The **tidal range** is the difference between the ocean level at high tide and the ocean at low tide (**Figure** below). 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.

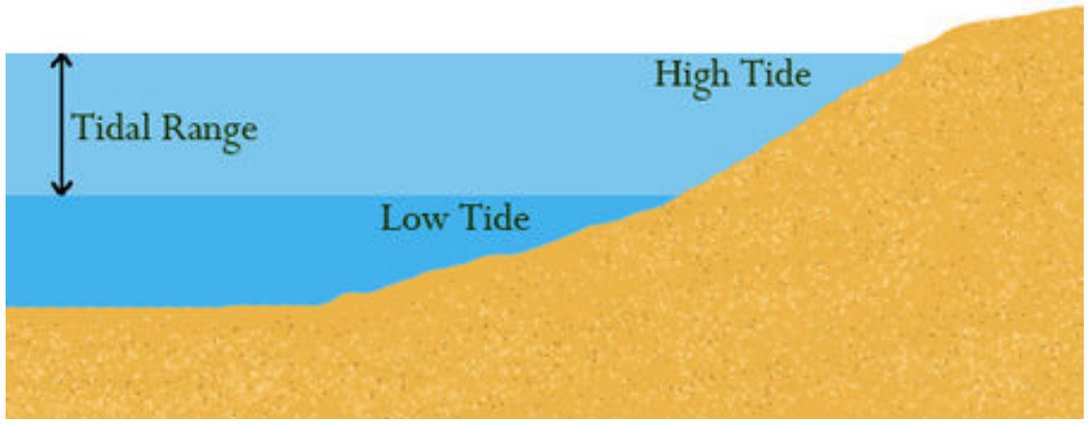


Figure 19.13

The tidal range is the difference between the ocean level at high tide and low tide.

Monthly Tide Patterns

If you look at the diagram of high and low tides in the **Figure** 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 add and the low tides add (**Figure** below). Highs are higher and lows are lower than at other times through the month. 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.

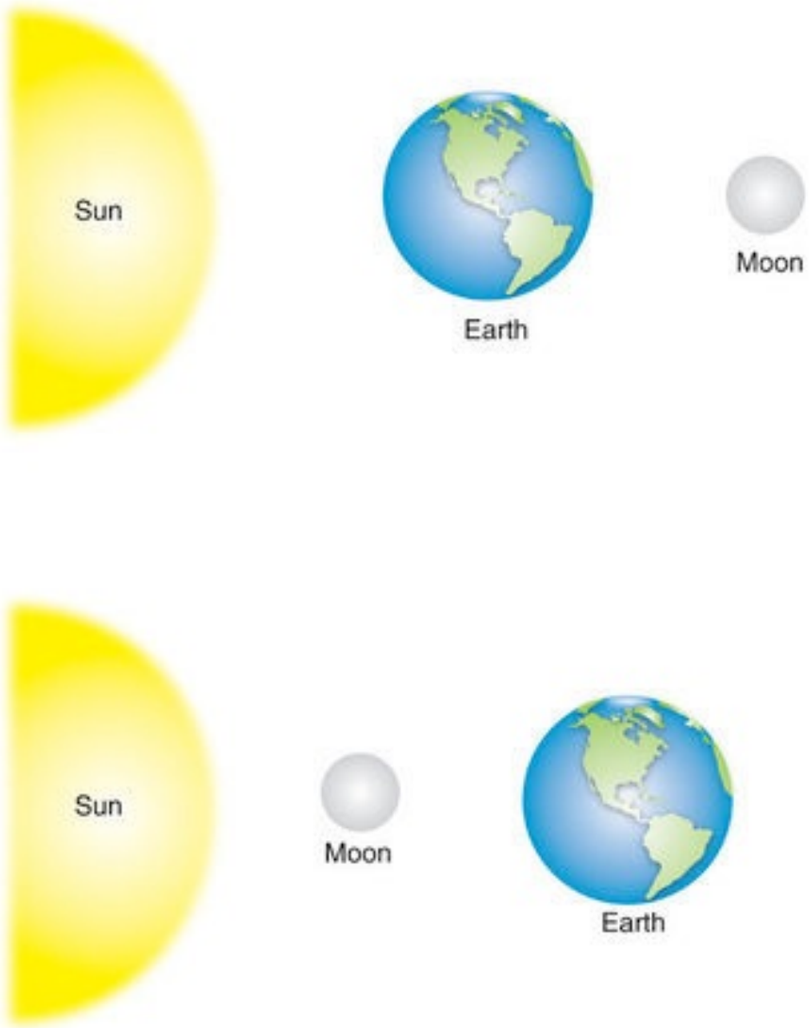


Figure 19.14

Spring tides occur when the tidal bulges from the Moon and Sun are aligned. The Moon is full in this image; in the bottom image the Moon would appear as a new Moon.

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif .

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90 ◦ angle (**Figure** below). 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 relatively small.

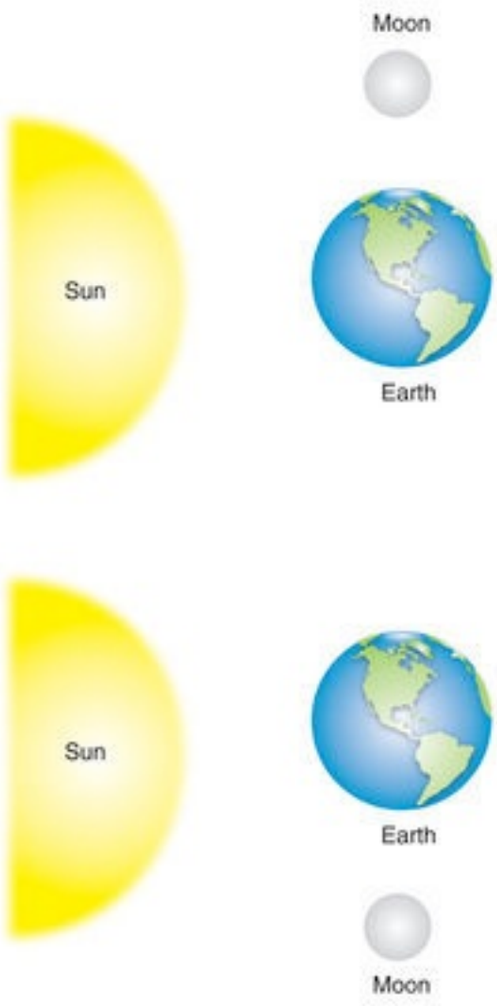


Figure 19.15

Neap tides occur when the Earth, the Sun, and the Moon form a right angle; the Moon is in its first or third quarter.

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html .

High tides occur about twice a day, 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 24 hours and 50 minutes later. 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?

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/focus/ocean/motion/tides1.htm .

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.

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** . The causes of the global wind patterns will be described in detail in the Earth's Atmosphere chapter.

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 ◦N and 30 ◦S
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50 ◦and 60 ◦north and south of the equator and the north and south pole

Earth’s Rotation

Wind is not the only factor that affects ocean currents. The Coriolis effect describes how Earth’s rotation steers winds and surface ocean currents (**Figure** below). 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.

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 19.16

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 (2:04).



Click on the image above for more content

Shape of the Ocean Basins

When a surface current collides with land, the current must change direction. 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.

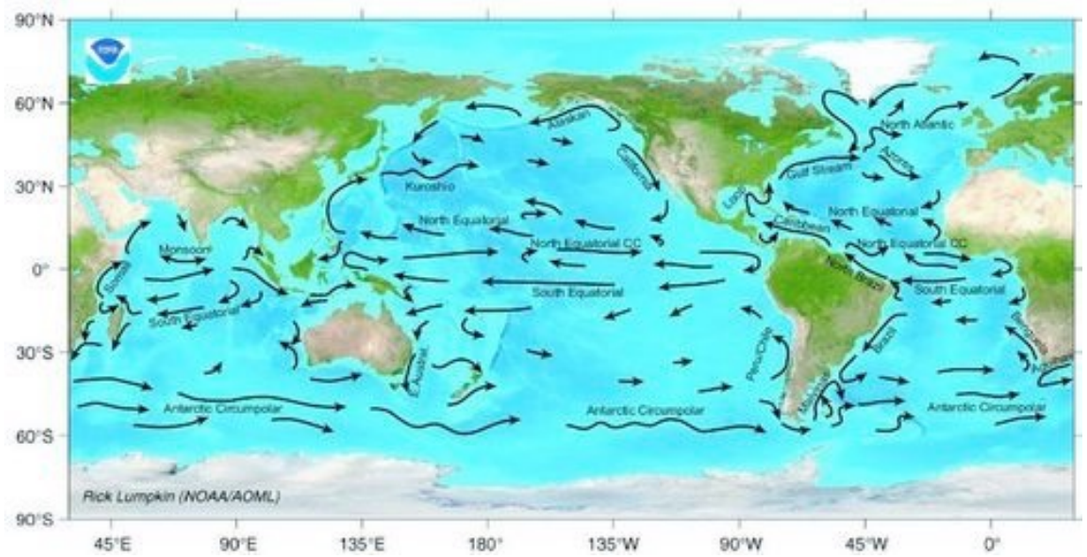


Figure 19.17

The major surface ocean currents.

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (**Figure** below). 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?

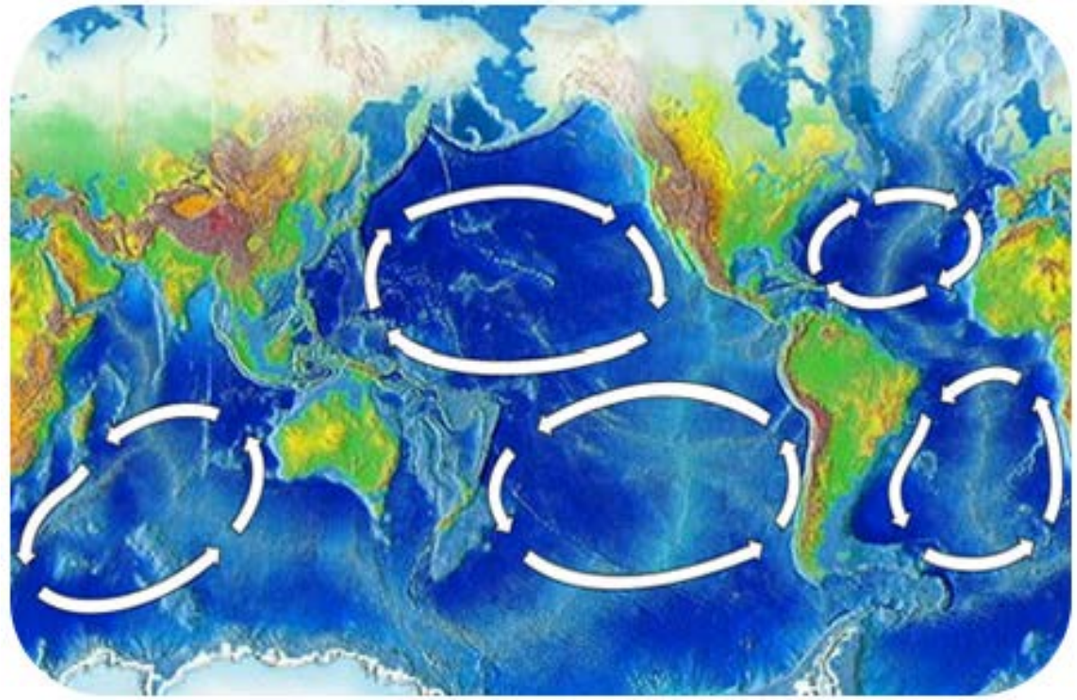


Figure 19.18

The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

This video shows the surface ocean currents set by global wind belts **(5a)** : http://www.youtube.com/watch?v=Hu_Ga0JYFNg (1:20).



Click on the image above for more content

Local Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines (**Figure** below). Two are **longshore currents** and **rip currents** .

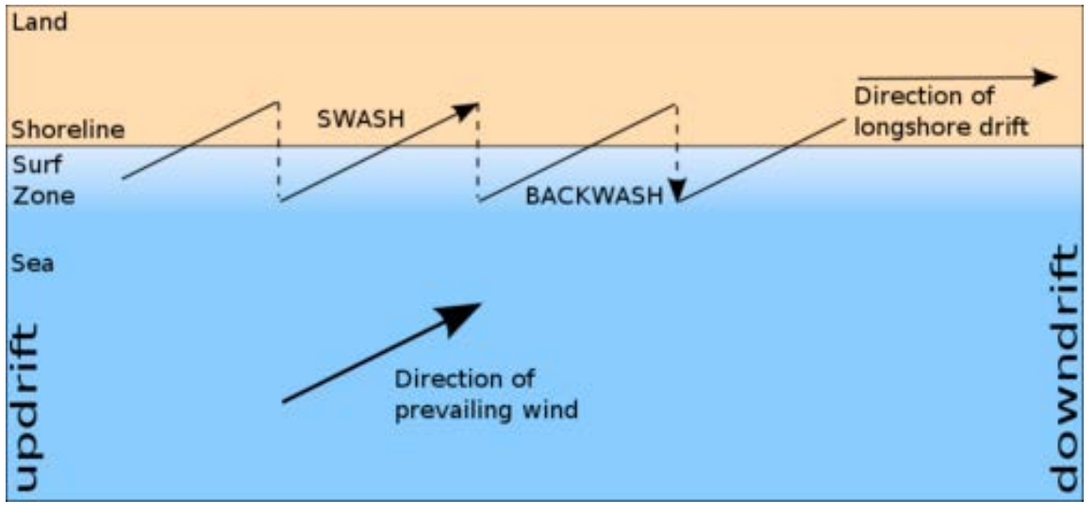


Figure 19.19

Longshore currents move water and sediment parallel to the shore in the direction of the prevailing local winds.

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 .

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 (**Figure** below). 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 ◦C (5 to 11 ◦F). London, U.K., for example, is at the same latitude as Quebec, Canada. However, London's average January temperature is 3.8 ◦C (38 ◦F), while Quebec's is only -12 ◦C (10 ◦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.

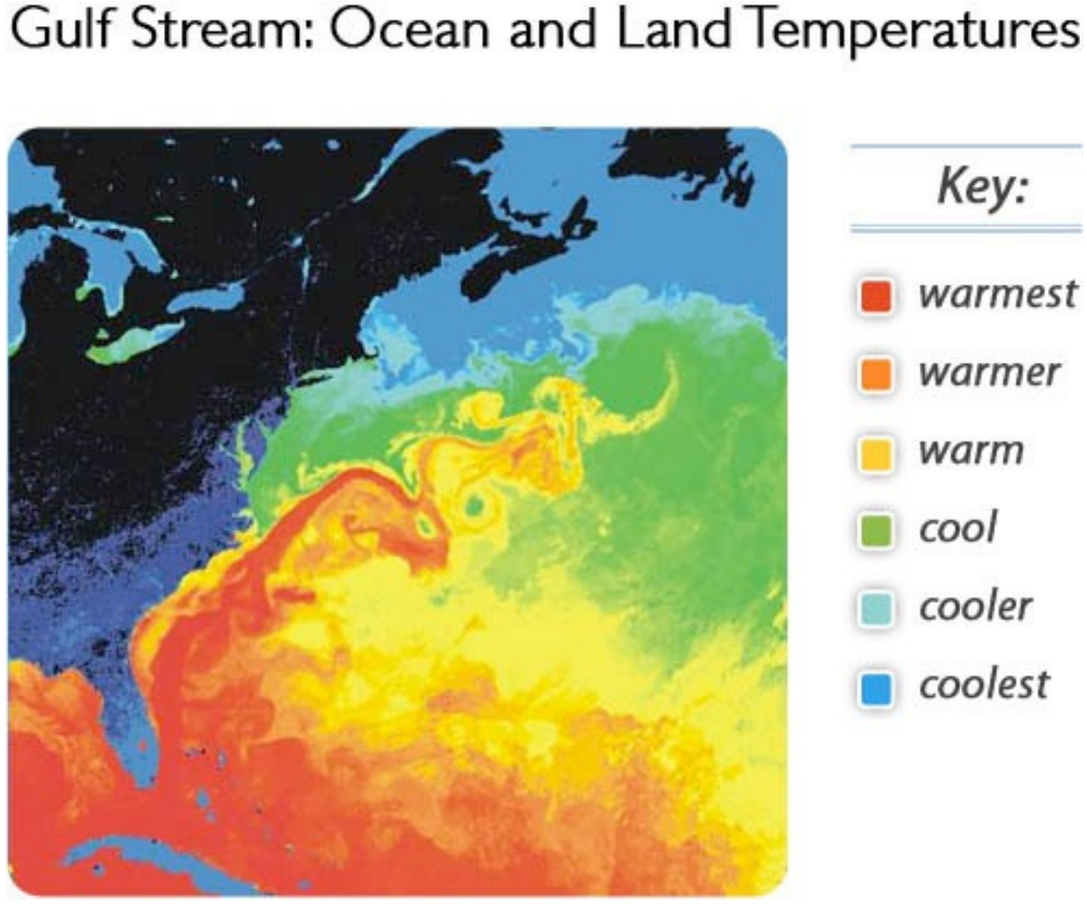


Figure 19.20

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 eastern North America.

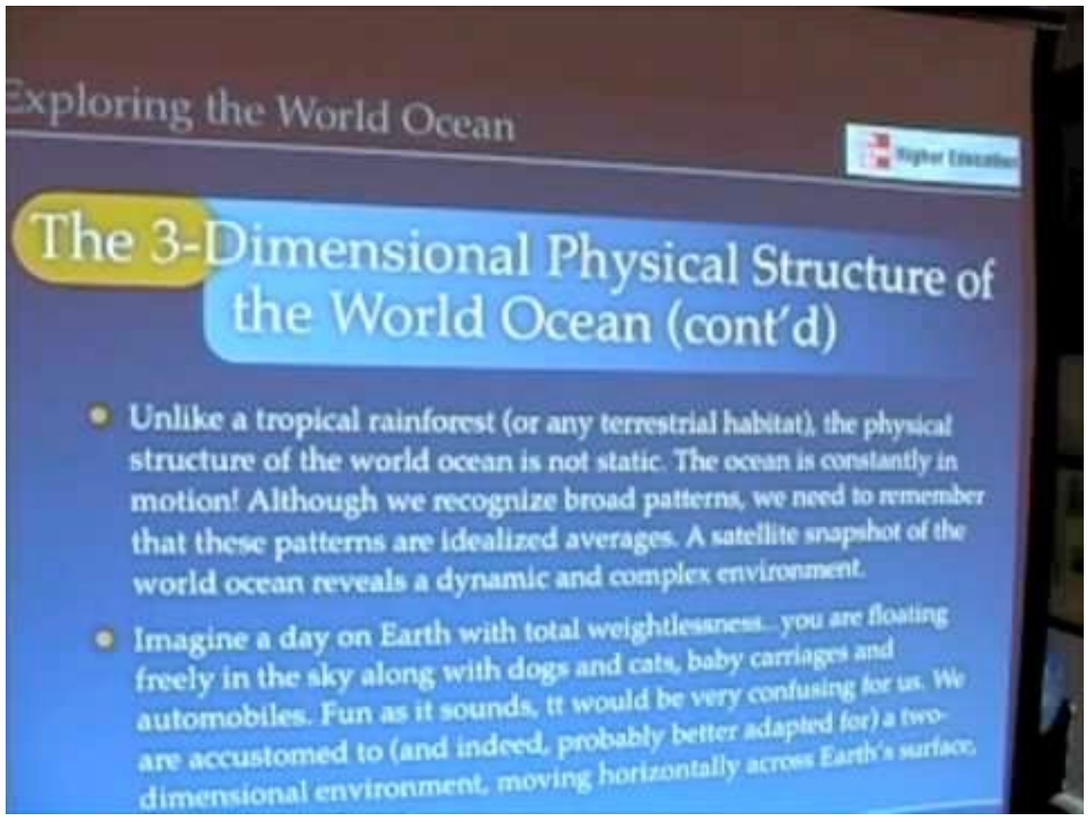
Deep Currents

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.

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).



Click on the image above for more content

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** below). Water also sinks into the deep ocean off of Antarctica.

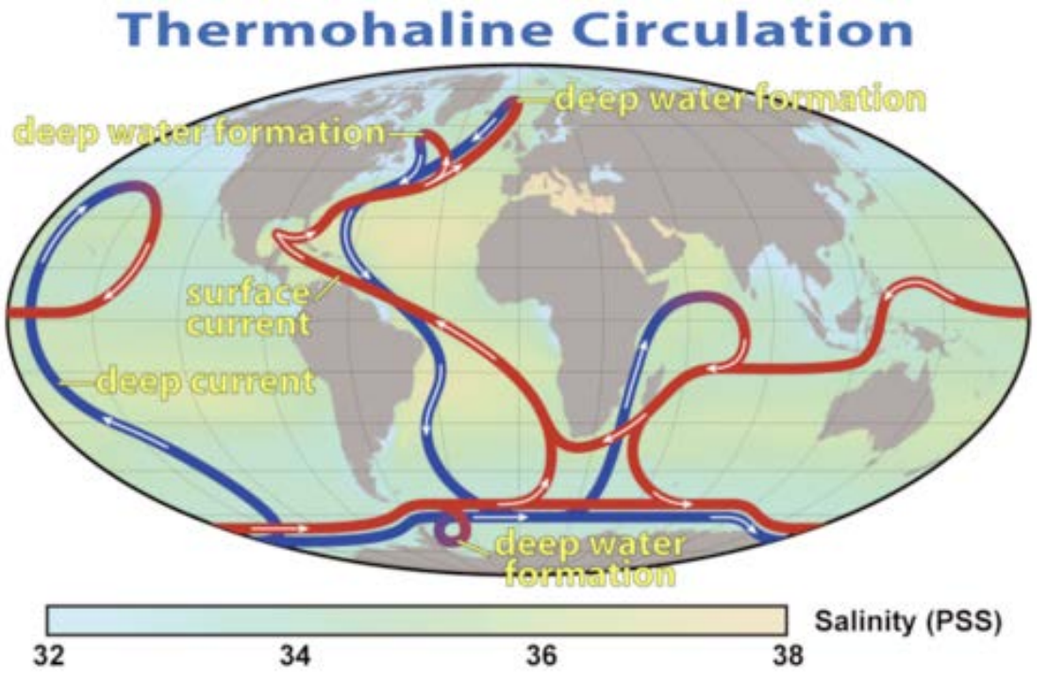


Figure 19.21

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.

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** below).

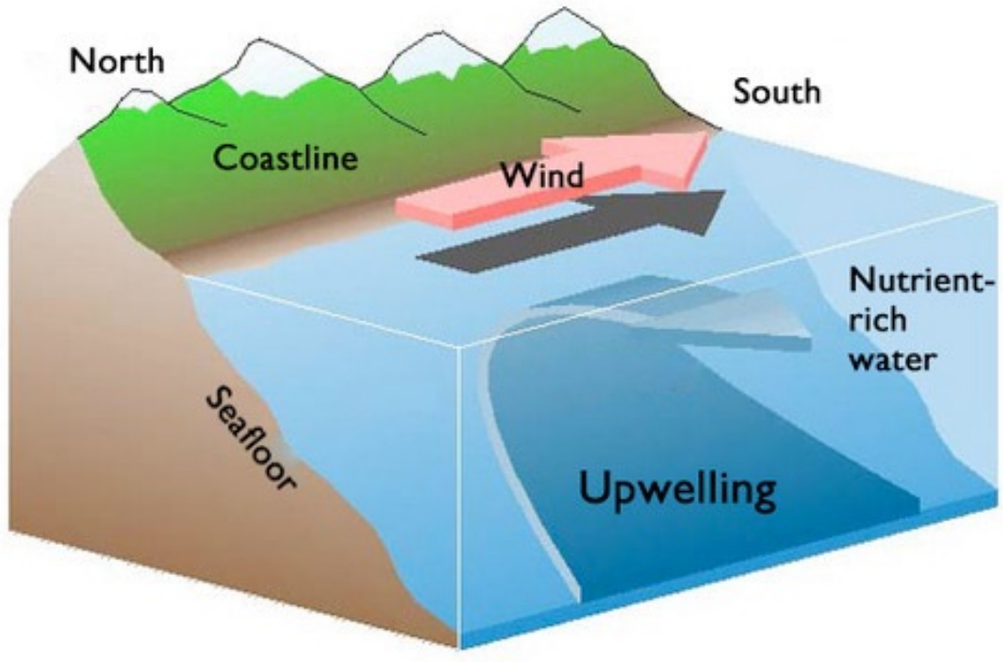


Figure 19.22

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 nutrient 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.

Lesson Summary

•Ocean waves are energy traveling through the water.
•Most ocean waves are generated by wind. Tsunami are exceptionally long wavelength waves usually caused by earthquakes.
•Tides are produced by the gravitational pull of the Moon and Sun.
•Spring tides have large tidal ranges and occur at full and new moons, when Earth, Moon, and Sun are all aligned.
•Neap tides have low tidal ranges and occur at first and last quarter moons, when the Moon is at right angles to the Sun.
•Ocean surface currents are produced by global winds, the Coriolis effect and the shape of each ocean basin.
•The Pacific and Atlantic Oceans have a circular pattern of surface currents called gyres that circle clockwise in the Northern Hemisphere and counterclockwise in the Southern. The Indian Ocean only has a counterclockwise gyre.
•Surface ocean circulation brings warm equatorial waters towards the poles and cooler polar water towards the equator.
•Thermohaline circulation drives deep ocean currents.
•Upwelling of cold, nutrient-rich waters creates biologically rich areas where surface waters are blown away from a shore, or where equatorial waters are blow outward.

Review Questions

1. What factors of wind determine the size of a wave?

2. Tsunami are sometimes incorrectly called “tidal waves.” Explain why this is not correct.

3. Describe what causes the tides.

4. What is a tidal range? In what types of tides is the tidal range greatest? Lowest?

5. Why do some places have a greater tidal range than other places?

6. What causes the patterns of surface currents in the ocean?

7. How do ocean surface currents affect climate?

8. What is the Coriolis effect?

9. What process can make deep, dense water rise to the surface?

10. Why are upwelling areas important to marine life?

Further Reading / Supplemental Links

•Learn About Ocean Currents, 5 min. Life Videopedia http://www.5min.com/Video/Learn-about-Ocean-Currents-117529352
•NOAA’s Ocean Explorer program http://oceanexplorer.noaa.gov/edu/welcome.html

•A tutorial for grades 6 to 12 on currents from NOAA: http://oceanservice.noaa.gov/education/tutorial_currents/welcome.html
•Cool jobs: Oceanographer http://news.discovery.com/videos/cool-jobs-cool-jobs-oceanographer.html

Points to Consider

•Some scientists have hypothesized that if enough ice in Greenland melts, the Gulf Stream might be shut down. Why might this happen?
•If the Gulf Stream shuts down, what would be the result on climate in Europe?
•How do the movements of ocean water contribute to the ocean's life?

Going Further - Applying Math

Tide Generating Force

In this exercise you will use an equation to calculate the tide generating force. Like the force of gravity, the pull of the tide generating force is directly related to the masses of the astronomical objects involved and inversely related to the square of the distance between them. Tides are caused by both the gravitational pull of the Moon and the gravitational pull of the Sun on surface water. Unlike the gravitational force, the tide generating force varies with the distance between the Moon (or the Sun) and the Earth cubed.

The equation for the tide generating force is: T = G (m1 . m2 / d3) where T is the tide generating force, G is the universal gravitational constant, m1 and m2 are the mass of the Earth and the mass of the Moon (or the mass of the Earth and the mass of the Sun), and d is the distance between them.

If we plug in values for the gravitational constant, the mass of the Earth and the mass of the Moon, we can calculate the tide generating force when the Moon is at apogee (farthest from the Earth in its orbit). Use G = 6.673 x 10 -11 m 3 / kg . s 2; m 1 = 7.35 x 10 22 kg for the mass of the Moon, m 2 = 5.974 x 10 24 kg for the mass of the Earth; and d = 405,500 km for the distance from the Earth to the Moon at apogee.

You could use all the same values but substitute in d = 363,300 km for the distance from the Earth to the Moon when the Moon is at perigee (point when the Moon is closest to the Earth) and compare the tide generating force each distance.

Tsunami Tag

Could you outrun a tsunami? How fast would you have to run? You can calculate how fast a tsunami travels in the ocean using the equation for the speed of a shallow water wave, which is: V = the square root of g x d, where V = wave speed (velocity), g = the acceleration of gravity: 9.8 meters / s 2, and d = the depth of the water. If you use d = 3,940m (the average depth of the Pacific Ocean), how fast does a tsunami travel? Do you think you could outrun this wave?

The Seafloor

Lesson Objectives

- Describe the methods scientists have for studying the seafloor.
- Describe the features of the seafloor.
- List the living and non-living resources that people use from the seafloor.

Vocabulary

- bottom trawling
- manganese nodule

Introduction

Oceanographers like to say that we know more about the dark side of the Moon than we do about the oceans. That statement is doubly true of the seafloor. Although modern technology has allowed us to learn more about the seafloor, vast regions remain unexplored.

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.

Mapping

In the Plate Tectonics chapter you learned that echo sounders designed to locate enemy submarines allowed scientists to create bathymetric maps of the seafloor (**Figure** below). Prior to this advance, 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.

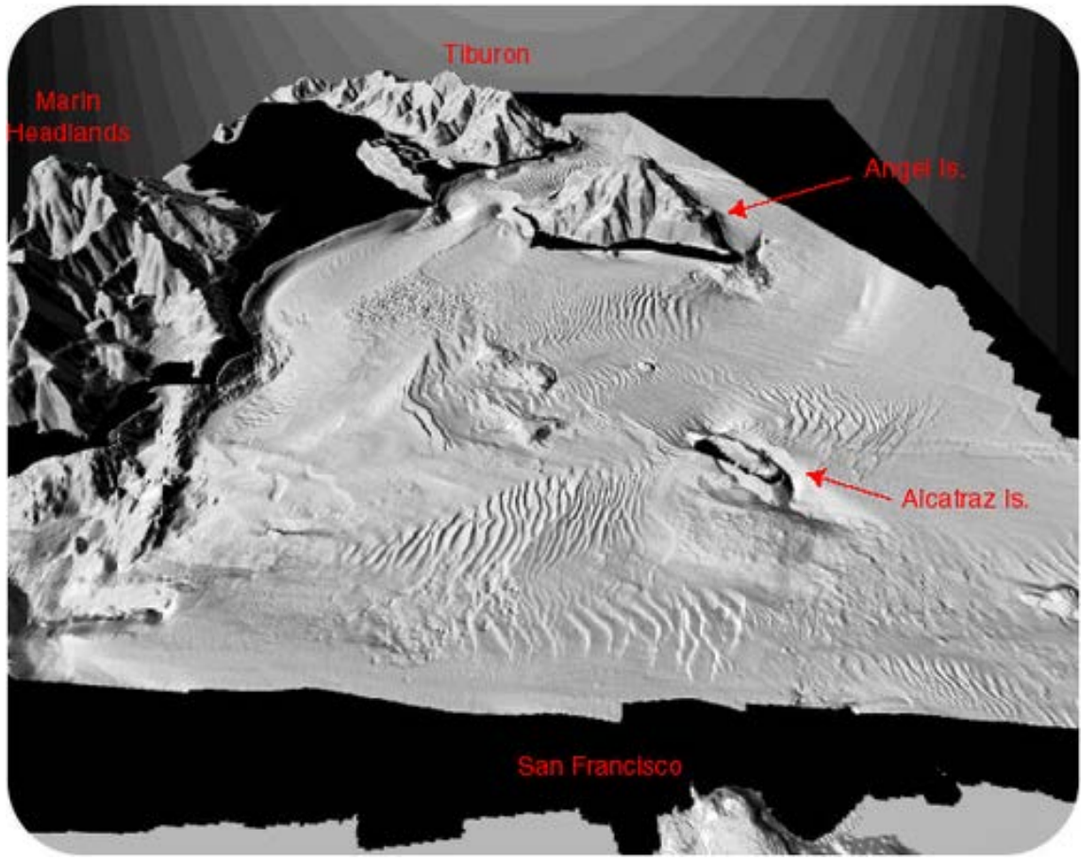


Figure 19.23

Map of San Francisco Bay, oblique view.

KQED: Sea 3-D: Charting the Ocean Floor

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. Learn more at: http://science.kqed.org/quest/video/sea-3-d-charting-the-ocean-floor/ .



Click on the image above for more content

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** below).

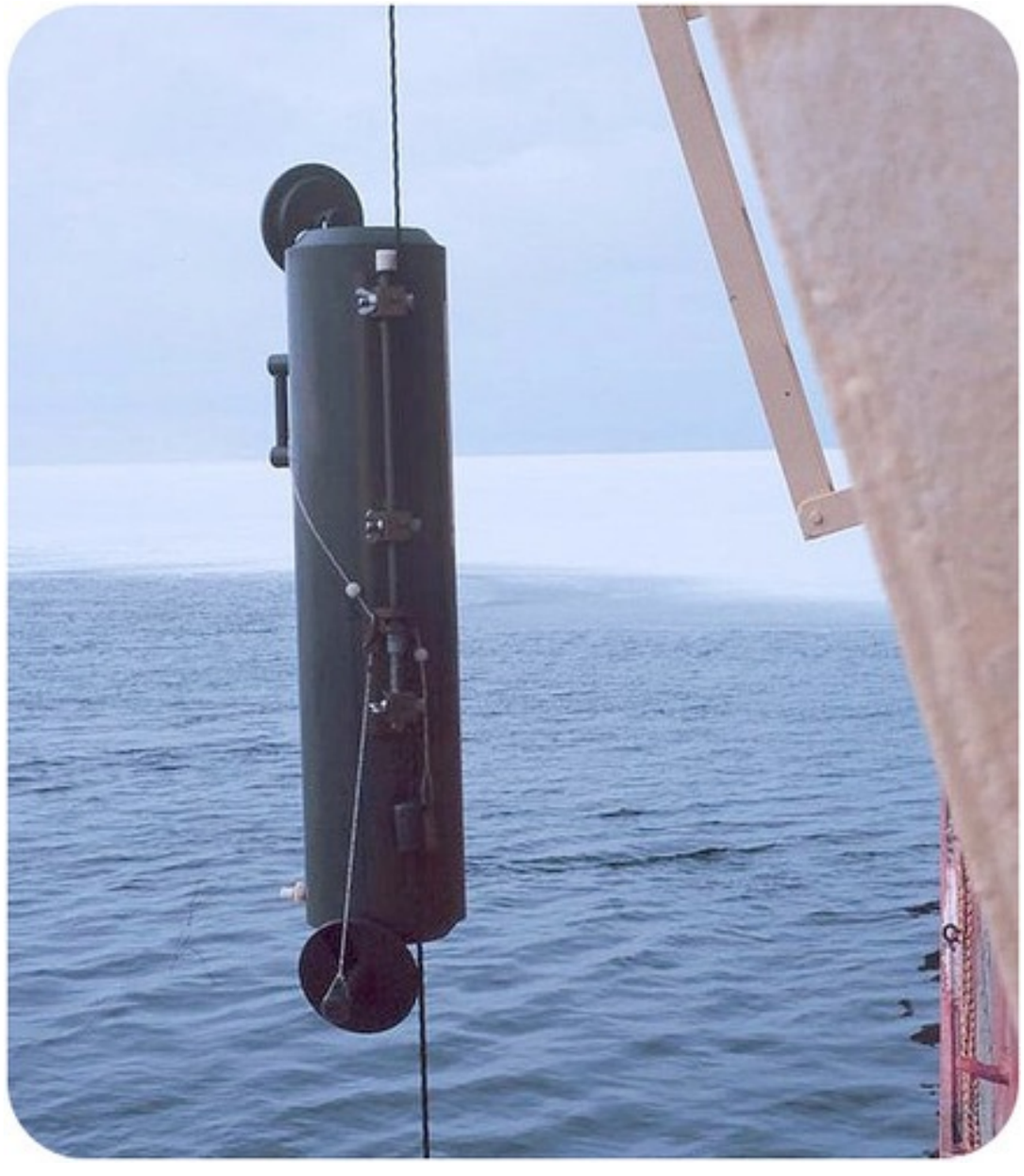


Figure 19.24

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

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.

Videos of the drill bit and core samples taken by the Joides Resolution are seen here: http://www.youtube.com/watch?v=4c9HlHBCSCY ; http://www.youtube.com/watch?v=MXqlRUbqHz0 ; http://www.youtube.com/watch?v=50VeS0TxCvU .

Submersibles

Samples of seawater and rocks can be collected directly by scientists in a submersible. These subs can take scientists down to make observations and the subs have arms for collecting samples. The submersible Alvin is an HOV, a human operated vehicle. Alvin can dive up to 4,500 m beneath the ocean surface and has made more than 4000 dives since 1964 (**Figure** below). Other submersibles can dive deeper.

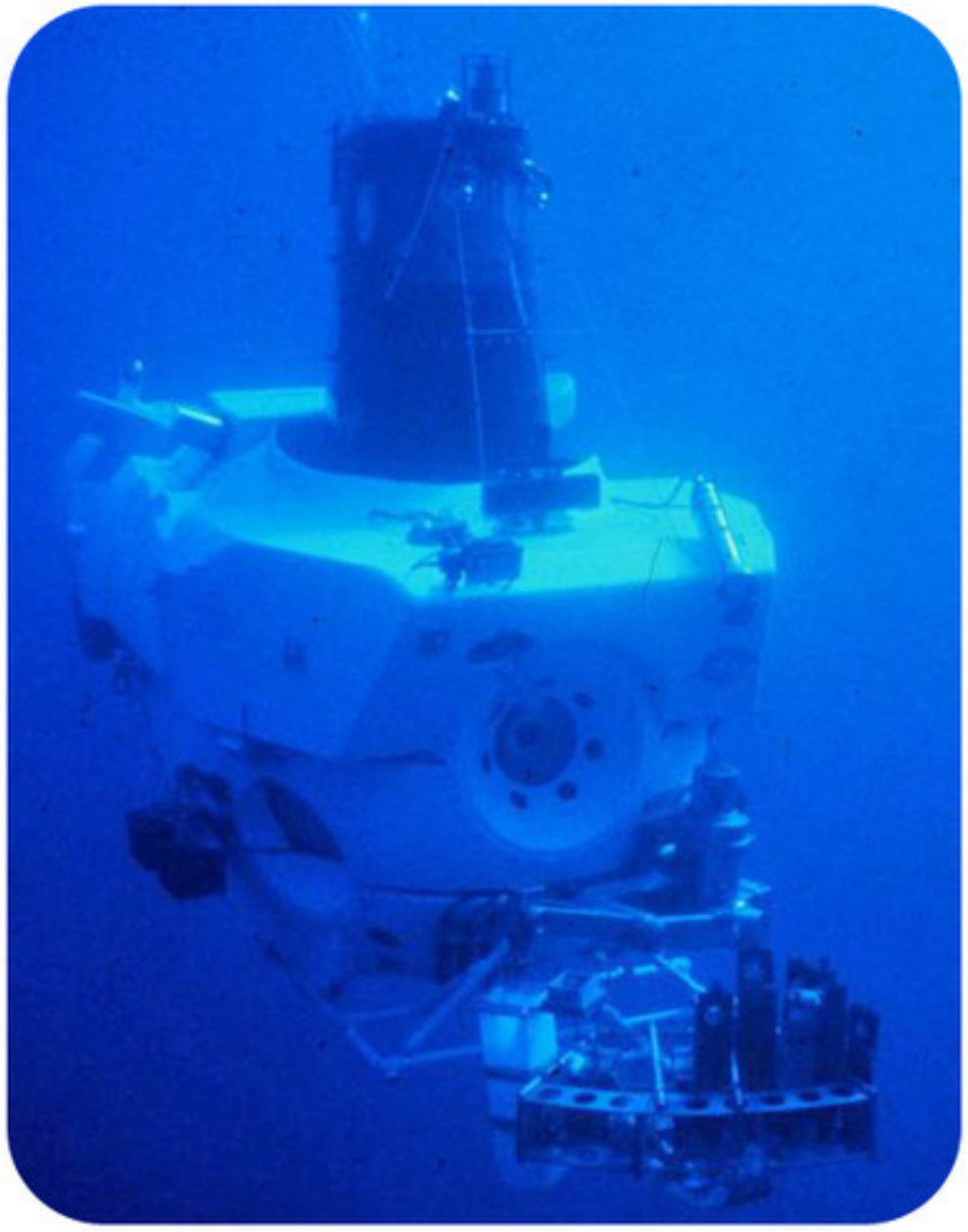


Figure 19.25

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

View a slide show of DSV Alvin and its history from the Woods Hole Oceanographic Institution: http://www.whoi.edu/page.do?pid=8422&tid=201&cid=14616&ct=362# .

Remotely Operated Vehicles

To avoid the expense, dangers, and limitations of human missions under the sea, remotely operated vehicles or ROV's, 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 (**Figure** below).

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

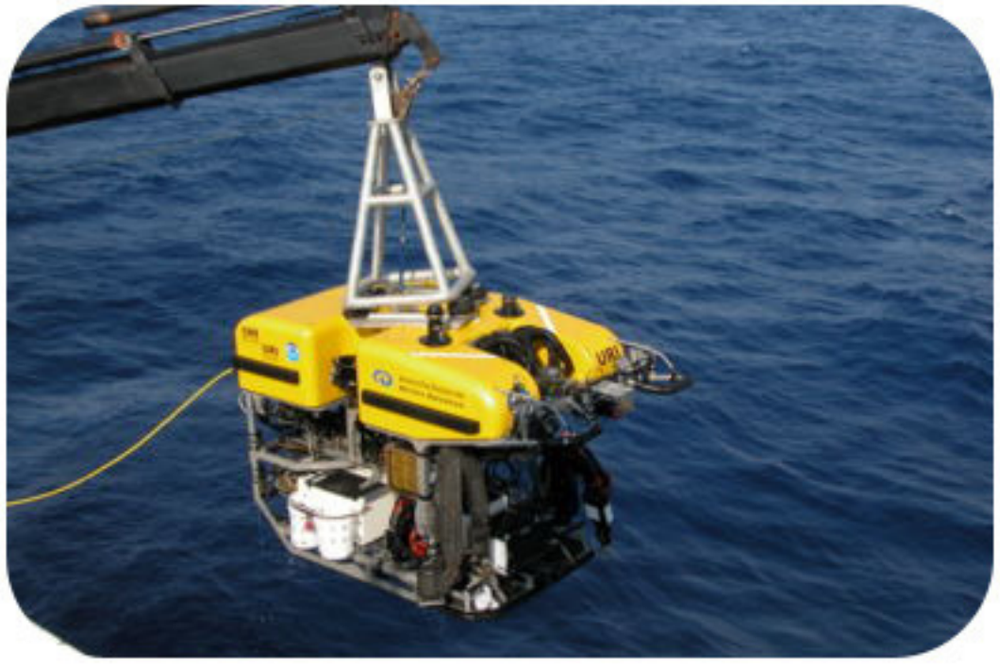


Figure 19.26

Remotely operated vehicles such as this one allow scientists to study the seafloor.

A video of the ROV Nereus from the Woods Hole Oceanographic Institution is shown here: http://www.youtube.com/watch?v=wwdF_2wMRfU .

Ocean Resources

The ocean provides important living and non-living resources. To be maintained for future use, these resources must be managed sustainably.

Living Resources

Most fish are caught by lines or nets as they swim in the open waters of the ocean. Some species of fish are being overharvested, which means their rate of reproduction cannot keep up with the rate at which people consume them.

Bottom trawling is a method of fishing that involves towing a weighted net across the seafloor to harvest fish. In many areas where bottom trawling is done, ecosystems are severely disturbed by the large nets. For this reason, in a few areas in the world, laws limit bottom trawling to waters not more than 1,000 m deep or waters far from protected and sensitive areas. Still these actions protect some of the seafloor. Besides food, ocean organisms have other uses. Some provide us with medications.

Non-living Resources

Oil and natural gas are the most valuable non-living resources taken from the ocean. Extracting these resources requires drilling

into the seafloor. Oil platforms have dozens of oil wells that are drilled in places where the ocean is sometimes 2,000 m deep (**Figure** below). A description of the Deepwater Horizon oil spill affecting the Gulf of Mexico is located in the Human Actions and Earth's Waters chapter.



Figure 19.27

Oil platforms can be fixed or they can float.

The seafloor has some valuable minerals. **Manganese nodules** containing manganese, iron, copper, nickel, phosphate, and cobalt (**Figure** below) may be as small as a pea or as large as a basketball. Estimates are that there may be as much as 500 billion tons of nodules on the seafloor. The minerals in manganese nodules have many uses in the industrial world, but currently they are not being mined. Think back to the discussion of ore deposits in the Earth's Minerals chapter. Why do you think these seafloor resources are not being mined?

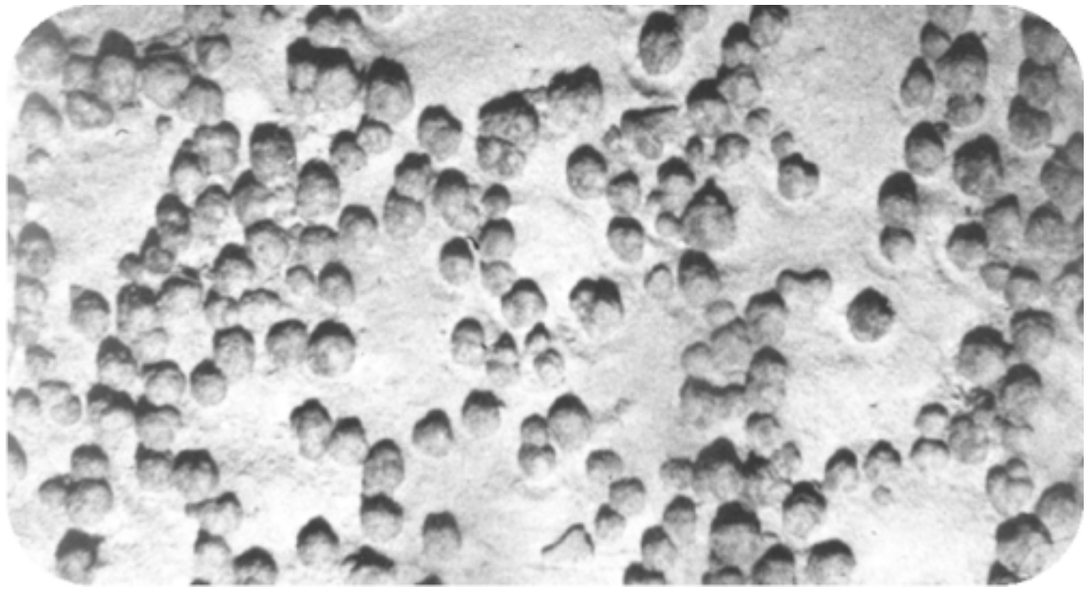


Figure 19.28

Manganese nodules from the seafloor are often rich in metals such as manganese, iron, nickel, copper, and cobalt.

Lesson Summary

•Scuba divers can only explore near the surface so most oceanographic research is done from satellites, ships, and submersibles.
•The oceans are divided into zones by water depth, distance from shore, and the slope of the seafloor.
•The oceans provide us with both living and non-living resources.
•Living oceanic resources include fish and invertebrates used for food.
•The most valuable non-living resources from the oceans are oil and natural gas.

Review Questions

1. Scientists sometimes say that we know less about the oceans than the far side of the Moon. Why is it so difficult to learn about the oceans?

2. The atmospheric pressure is about 1 kilogram per centimeter squared (14.7 pounds per square inch or 1 atmosphere) at sea level. About what is the pressure if you are 100 meters deep in the ocean?

3. Where on the ocean floor will you find the greatest amount of living organisms?

4. Compare and contrast the continental shelf and the abyssal plain.

5. Why do you think mapping the seafloor is important to the Navy? What part of the seafloor is the navy most interested in?

6. Why is bottom trawling damaging to the seafloor?

7. As world population grows and the ocean is called on to provide more and more resources, what can people do to be sure the resources are used sustainably?

8. What is a manganese nodule?

Further Reading / Supplemental Links

News and information about the ROV Alvin: http://www.whoi.edu/page.do?pid=8422

More about the Joides Resolution: http://joidesresolution.org/

Points to Consider

•If the seafloor is not well known, how much do you think is known about marine life?
•What methods are needed to learn about organisms at the ocean surface, the mid-depths, or on the seafloor?
•Are techniques that are used for understanding ocean physics, chemistry, and geology also useful for studying marine life?

Ocean Life

Ocean Life

Lesson Objectives

- Describe the different types of ocean organisms.
- Describe the interactions among different ocean organisms.

Vocabulary

- chemosynthesis
- hydrothermal vent
- invertebrate
- phytoplankton
- plankton
- primary productivity
- reef
- vertebrate
- zooplankton

Introduction

Oceans are a harsh placed to live. In the intertidal zone, conditions change rapidly as water covers and uncovers the region and waves pound on the rocks. Most of the environments at sea are cold and at just about any depth below the surface the pressure is very high. Beyond the photic zone, the ocean is entirely black. Organisms have adapted to these conditions in many interesting and effective ways. The size and variety of different habitats means that 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** below).

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.

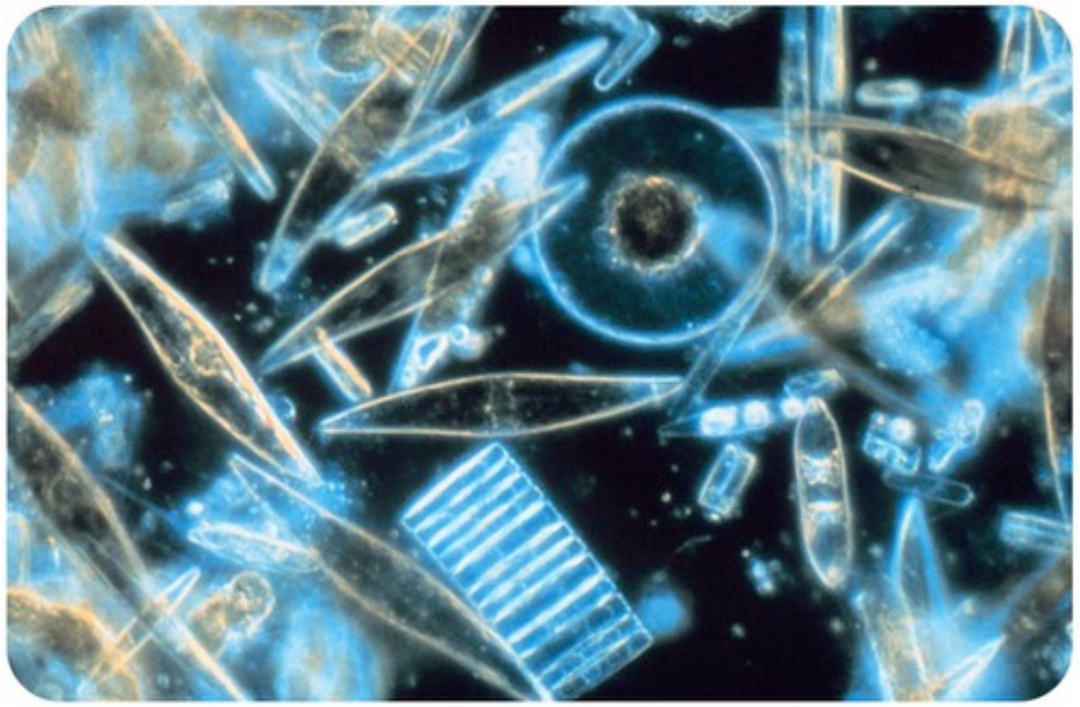


Figure 19.29

Microscopic diatoms are a type of phytoplankton.

A video of a research vessel sampling plankton is seen here: http://www.youtube.com/watch?v=mQG4zAoh6xc .

Zooplankton , or animal plankton, eat phytoplankton as their source of food (**Figure** below). 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 19.30

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** below).



Figure 19.31

Kelp grow 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** below). Marine invertebrates include sea slugs, sea anemones, starfish, octopi, 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.

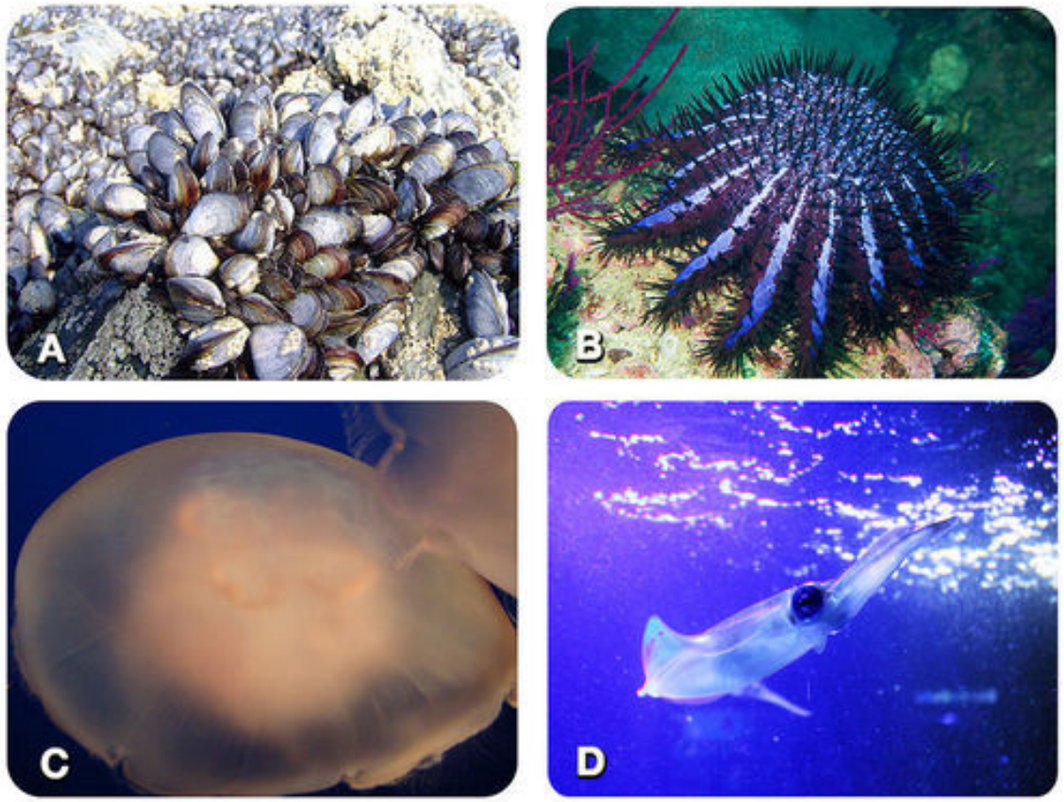
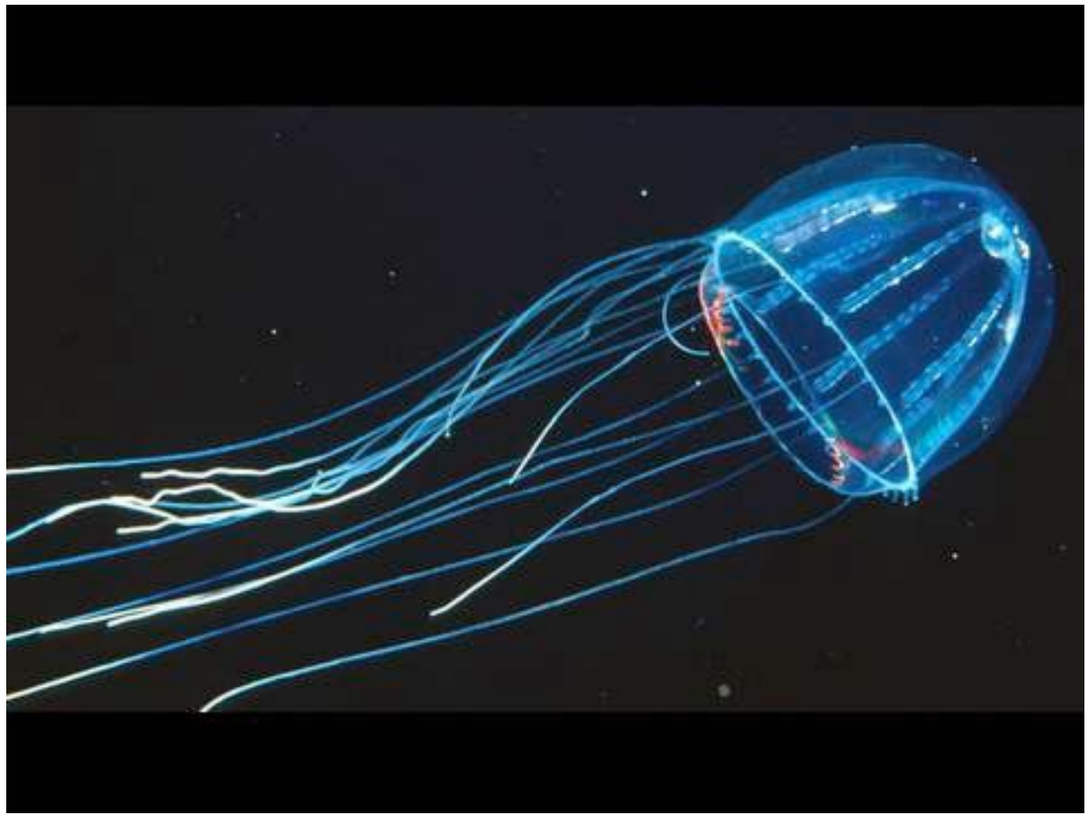


Figure 19.32

(a) Mussels; (b) Crown of thorns sea star; (c) Moon jelly; (d) A squid.

KQED: Amazing Jellies

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 at: http://science.kqed.org/quest/video/amazing-jellies/ .



Click on the image above for more content

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: 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** below).

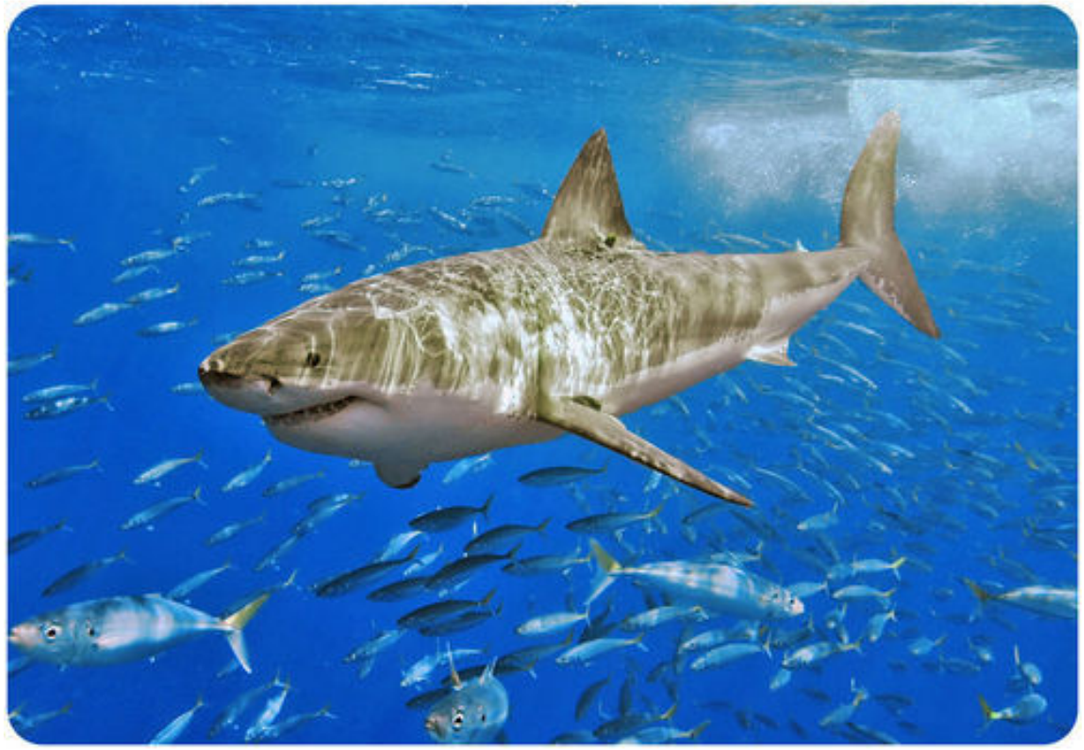


Figure 19.33

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** below). Sea snakes bear live young in the ocean, but turtles, crocodiles, and marine iguanas all lay their eggs on land.



Figure 19.34

Sea turtles are found all over the oceans, but their numbers are diminishing.

Seabirds

Many types of birds are adapted to living in the sea or on the shore. A few are shown: (**Figure** below).



Figure 19.35

(a) With their long legs for wading and long bills for digging in sand for food, shorebirds are well adapted for the intertidal. (b) Many seabirds live on land but go to sea to fish, such as gulls, pelicans, and this frigate bird. (c) Albatross spend months at sea and only come on shore to raise chicks.

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** below).



Figure 19.36

(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.

KQED: Into the Deep with Elephant Seals

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. Learn more at: http://science.kqed.org/quest/video/into-the-deep-with-elephant-seals/ .



Click on the image above for more content

Interactions Among Ocean Organisms

The previous section briefly discussed the adaptations different types of organisms have to live in the ocean. A look at a few of the different habitats organisms live in can focus even more on these important adaptations.

The Intertidal

A great abundance of life is found in the intertidal zone (**Figure** below). High energy waves pound the organisms that live in this zone and so they must be adapted to pounding waves and exposure to air during low tides. Hard shells protect from

pounding waves and also protect against drying out when the animal is above water. Strong attachments keep the animals anchored to the rock.



Figure 19.37

In a tide pool, animals cling to the rock at low tide.

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.

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** below).



Figure 19.38

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** below).



Figure 19.39

In this image of Maupiti Island in the South Pacific, the remnants of the volcano are surrounded by the circular reef.

Eventually, all that is left is a reef island called an atoll. A lagoon is found inside the reef (**Figure** below).

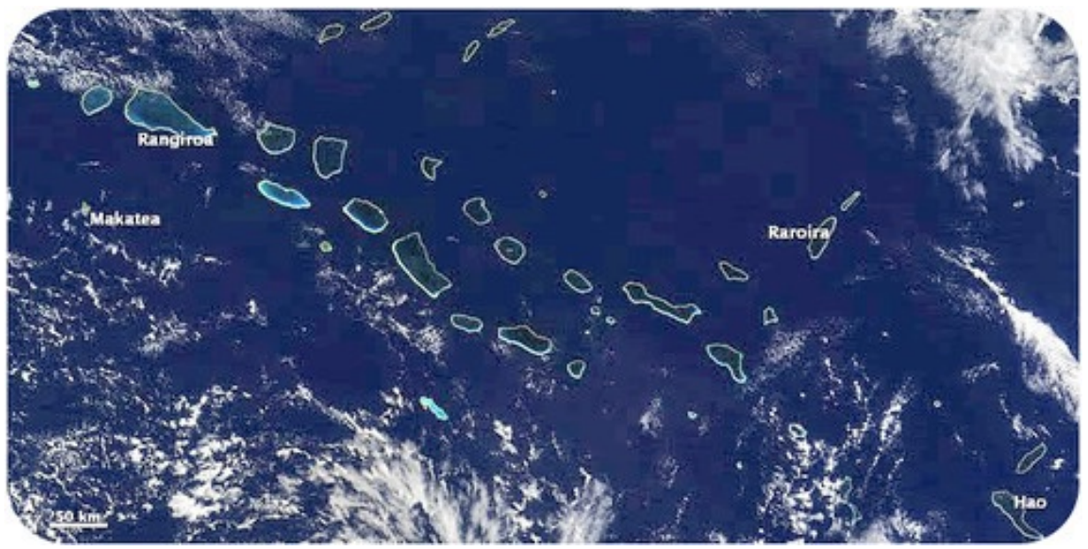


Figure 19.40

The Tuamotos are coral atolls that rest on volcanoes that are not beneath sea level.

Coral reef are near shore and so are subject to pollution from land. The coral animals are very sensitive to temperature and reefs around the world are stressed from rising ocean temperatures.

Some videos about threats to coral reefs are found at: National Geographic Videos, Environment Video, Threats to Animals, http://video.nationalgeographic.com/video/player/environment/ .

- Coral Reefs
- Belize's Coral 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** below). 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.

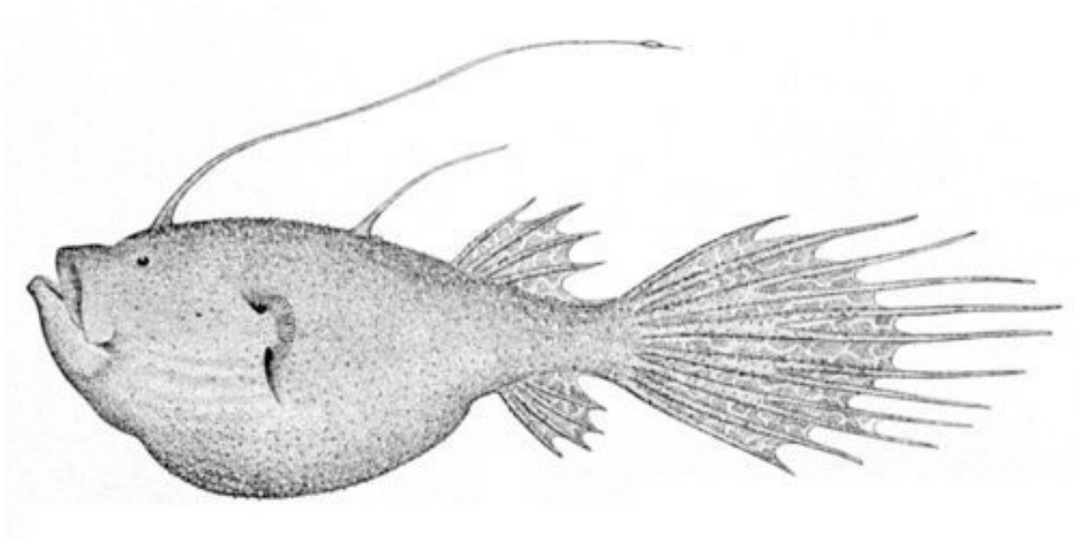


Figure 19.41

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

At mid-ocean ridges at **hydrothermal vents** , bacteria that use **chemosynthesis** for food energy are the base of a unique ecosystem (**Figure** below). 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 19.42

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 .

Lesson Summaries

•The oceans have a tremendous diversity of life: bacteria, plankton, invertebrates, and vertebrates, which include fish, reptiles, seabirds, and mammals.
•Photosynthesis and chemosynthesis create food energy in two very different ways.
•Plankton are tiny freely floating plants (phytoplankton) or animals (zooplankton).
•All marine organisms must be specialized for the harsh conditions of the ocean environment in which they live.

Review Questions

1. What is an invertebrate? Name two types.

2. What is the role of phytoplankton in ocean ecosystems?

3. If fish require oxygen to live, why can't they survive on land?

4. Are polar bears marine mammals or land animals like all other bears. What is your opinion?

5. What are four major habitats of ocean organisms?

6. Describe adaptations that an organism that lives in a reef might have. How might these adaptations be different from an organism that lives in the open ocean?

7. Describe the importance of maintaining the ocean ecosystems.

Points to Consider

•How does the ocean interact with the atmosphere?
•How is energy transferred around the planet and how does this affect life on Earth?
•What would be the effect of pollution on the oceans?

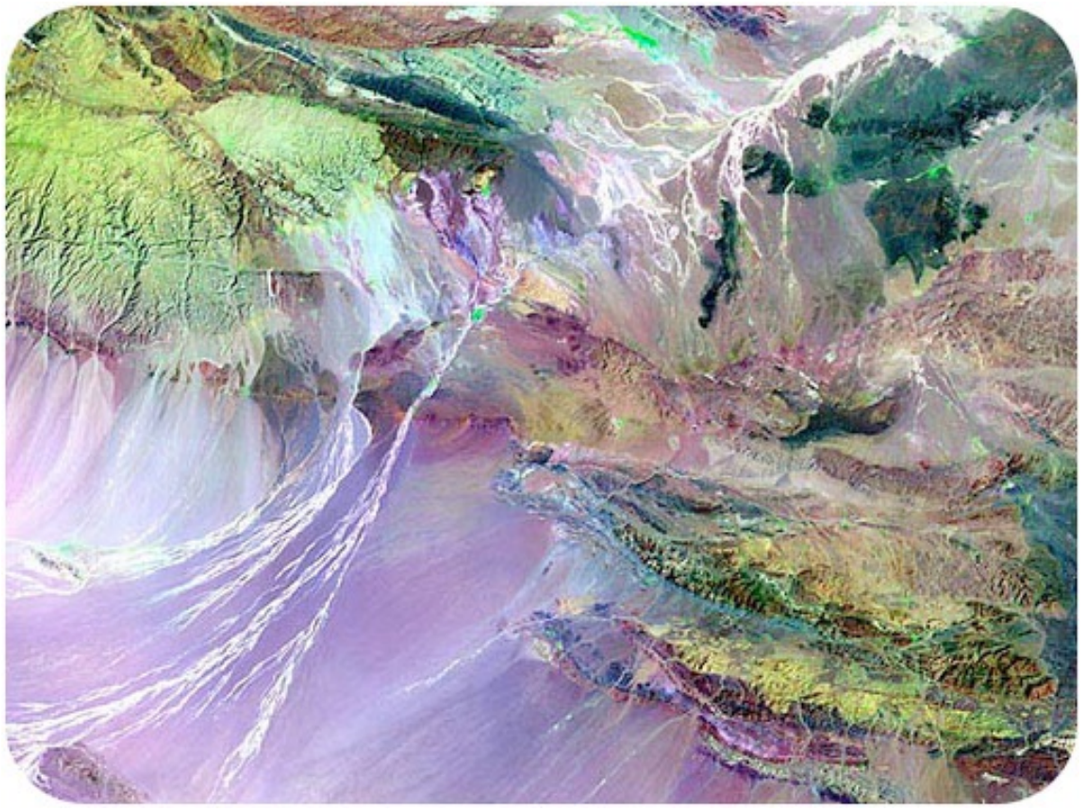
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Ch. 17: Evidence About Earth's Past



Identifying locations where abundant and interesting fossils are found is a paleontologist’s first step in unraveling Earth history. First, rocks of the right age need to be identified. Desert areas are better for fossil hunting because the rocks are better exposed and weathering processes have not degraded the rocks or their fossils. But there are a lot of desert areas in the world and it is not possible to search them all on foot. Paleontologists now use satellites to locate good fossil sites. This Landsat image of Mongolia’s Gobi Desert allowed researchers to locate exposed sedimentary rocks. While the true-color image gave a broad look at the area of interest, the false-color image shown here elucidates so much more. Different colors highlight vegetation and individual rock types. By studying the different colors scientists can single out the area they think is most likely to produce fossils. In this chapter, you will learn about some of the ways that scientists study the history of Earth and how they use clues from rocks and fossils to piece together pictures of how the Earth has changed over billions of years.

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Section 1

Fossils

Fossils

Lesson Objectives

- Explain why it is rare for an organism to be preserved as a fossil.
- Distinguish between body fossils and trace fossils.
- Describe five types of fossilization.
- Explain the importance of index fossils, and give several examples.

Vocabulary

- amber
- body fossil
- cast
- fossilization
- index fossil
- microfossil
- mold
- permineralization
- trace fossil

Introduction

Throughout human history, people have discovered fossils and wondered what they are and what they represent. In ancient times, fossils inspired legends of monsters and other strange creatures. The Chinese writer, Chang Qu, 2,000 years ago reported the discovery of "dragon bones," which were probably dinosaur fossils. Look at the two photos in the **Figure** below and try to trace the origin of the creature on the left.



Figure 20.1

The griffin, a mythical creature with a lion's body and an eagle's head and wings (left), was probably based on skeletons of Protoceratops (right) that were discovered by nomads in Central Asia.



Figure 20.2

Ammonites (left) and elephant skull (right).

Ancient Greeks named ammonites after the ram god Ammon since they look like the coiled horns of a ram. Legends of the Cyclops may be based on fossilized elephant skulls found in Crete and other Mediterranean islands (**Figure** above). Can you see why?

Many of the real creatures whose bones became fossilized were no less marvelous than the mythical creatures they inspired (**Figure** below).

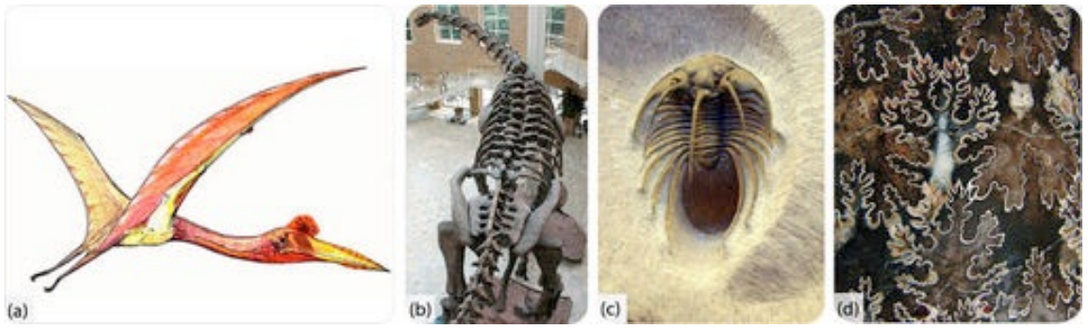


Figure 20.3

(a) The giant pterosaur Quetzalcoatlus had a wingspan of up to 12 meters (39 feet). (b) Argentinosaurus had an estimated weight of 80,000 kg, equal to the weight of seven elephants! Other fossils, such as the trilobite Kolihapeltis ch (c) impress us with their bizarre forms. These suture marks on an ammonite fossil (d) display a delicate beauty.

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) (**Figure** below). Collections of fossils that are found together are known as **fossil assemblages** .

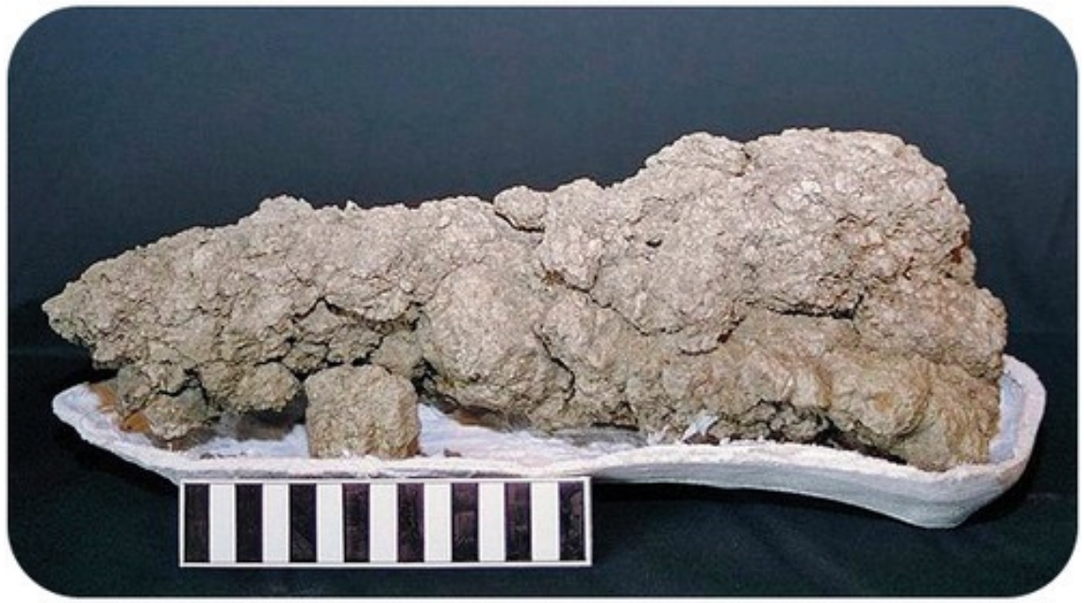


Figure 20.4

Coprolite from a meat-eating dinosaur.

The process of a once-living organism becoming a fossil is called **fossilization** . Fossilization is very rare: 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** below).



Figure 20.5

Hyenas eating an antelope. Will the antelope in this photo become a fossil?

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** below).



Figure 20.6

Shell that has been attacked by a boring sponge.

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** below).

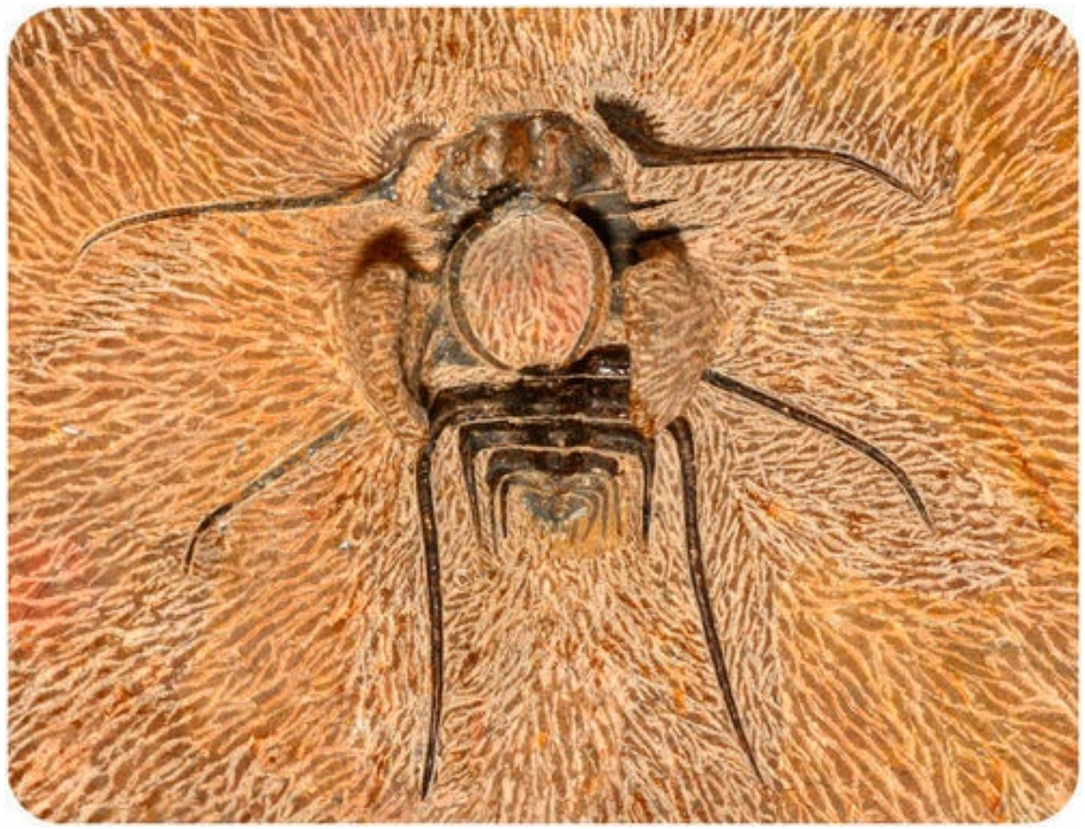


Figure 20.7

A rare insect fossil.

Despite these problems, there is a rich fossil record. How does an organism become fossilized?

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.

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** below).



Figure 20.8

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** below). Skeletons can be covered by mud in lakes, swamps, or bogs.

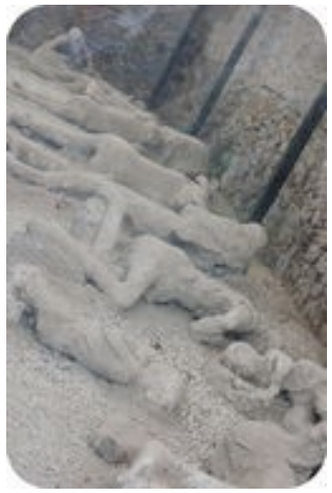


Figure 20.9

People buried by the extremely hot eruption of ash and gases at Mt. Vesuvius in 79 AD.

Unusual circumstances may lead to the preservation of a variety of fossils, as at the La Brea Tar Pits in Los Angeles, California (**Figure** below).



Figure 20.10

Although the animals trapped in the Ta Brea Tar Pits probably suffered a slow, miserable death, their bones were preserved perfectly by the sticky tar.



Figure 20.11

A mammoth stuck in a tar pit looks like an easy feast until the predator realizes this will be its final meal. This sequence shows how rapid burial can create a perfect fossil assemblage.

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** below). The 145 million-year-old Solnhofen Limestone in Germany has fossils of soft body parts that are not normally preserved (**Figure** below).

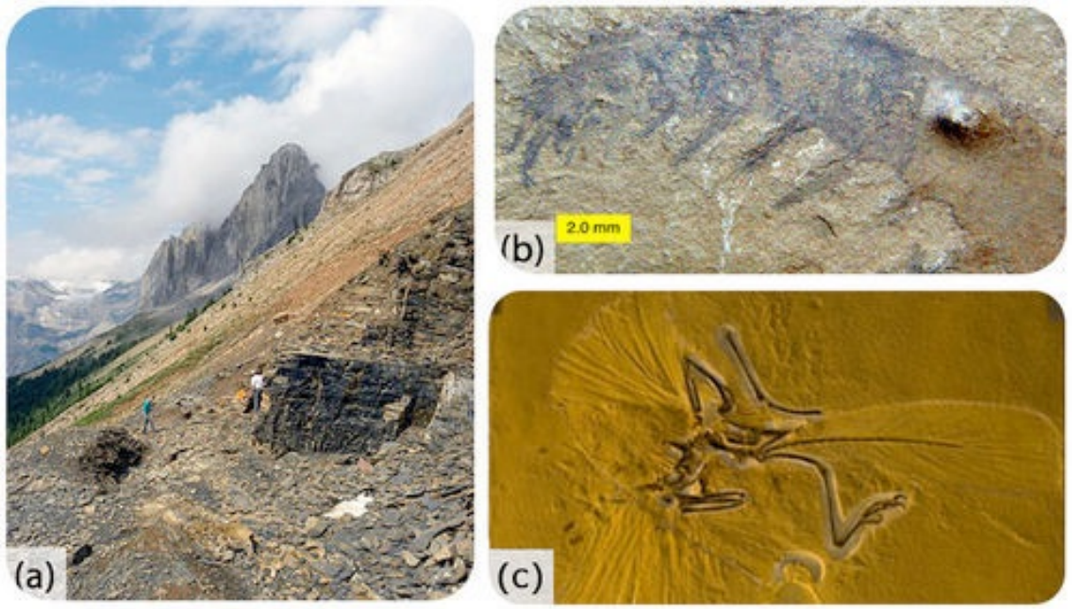


Figure 20.12

(a) The Burgess shale contains soft-bodied fossils. (b) Anomalocaris, meaning “abnormal shrimp” is now extinct. The image is of a fossil. (c) The famous Archeopteryx fossil from the Solnhofen Limestone has distinct feathers and was one of the earliest birds.

Bill Nye on Fossils

Types of Fossilization

Most fossils are preserved by one of five processes outlined in the **Figure** below .

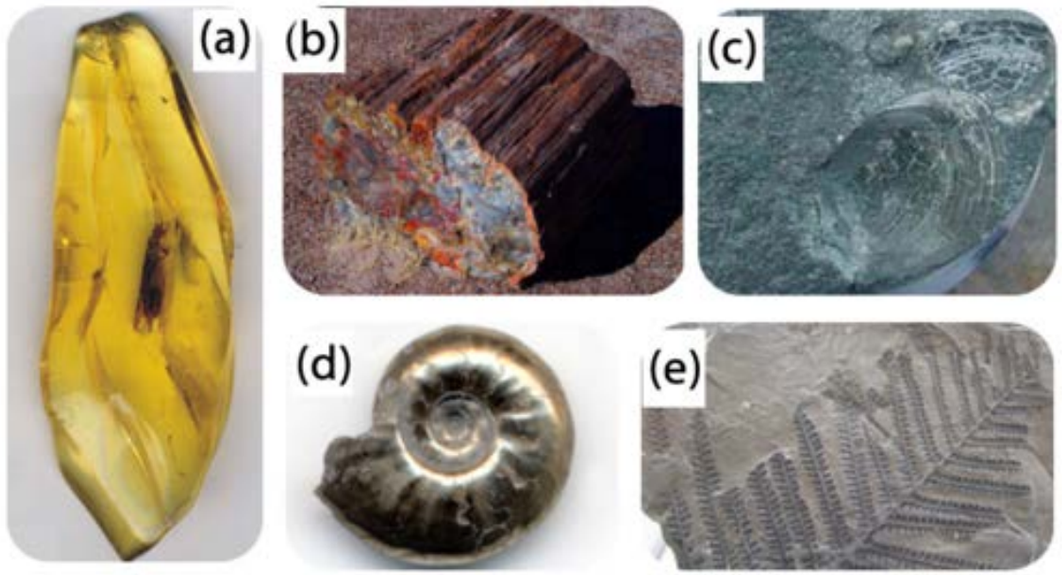


Figure 20.13

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.

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 produces a fossil. Fossil dinosaur bones, petrified wood, and many marine fossils were formed by permineralization.

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.

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.

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. The history of life will be discussed in the "Earth's History" chapter.

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 (**Figure** below).



Figure 20.14

The summit of Mt. Everest, the world's tallest mountain, is limestone that formed in an ancient sea.

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 the chapter about 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 that period of time over a large area. Index fossils play an important role in sequence stratigraphy, helping scientists place rock layers in order.

Lesson Summary

•Fossils are the remains of ancient life. Body fossils are the remains of the organism itself; trace fossils are burrows, tracks, feces, or other evidence of activity.
•Fossilization is a very rare process. The chances of becoming a fossil are enhanced by quick burial and the presence of hard parts, such as bones or shells.
•Fossils form in five ways: by preservation of the remains, permineralization, molds and casts, replacement, and compression.
•Types of organisms that make good index fossils are widespread but only existed for a short period of time. Index fossils help scientists to determine the approximate age of a rock layer and to match that layer up with other rock layers.
•Fossils give clues about the history of life on Earth, environments, climate, geologic history, and other events of geological importance.

Review Questions

1. What factors make it more likely that an animal will be preserved as a fossil?

2. What are the five main processes of fossilization?

3. A scientist wants to determine the age of a rock. The rock contains an index fossil and an ancient relative of a living organism. Which is more useful for dating the rock, and why?

4. The island of Spitzbergen is in the Arctic Ocean, near the North Pole. Fossils of tropical fruits have been found in coal deposits in Spitzbergen. What does this indicate?

Further Reading / Supplemental Links

This site is all about fossils: http://www.fossils-facts-and-finds.com/index.html

Fossil myths and legends: http://www.tonmo.com/science/fossils/mythdoc/mythdoc.php

More about the Burgess Shale: http://www.sciencechannel.com/tv-shows/greatest-discoveries/videos/100-greatest-discoveries-burgess-shale-creation.htm

More about the Solenhofen Limestone: http://www.ucmp.berkeley.edu/mesozoic/jurassic/solnhofen.html

The story of Otzi the Iceman: http://en.wikipedia.org/wiki/%C3%96tzi_the_Iceman

Points to Consider

- What are some other examples of mythical creatures that may be based on fossils?
- Why is it so rare for an animal to be preserved as a fossil?
- Some organisms are more easily preserved than others. Why is this a problem for scientists who are studying ancient ecosystems?
- Why are examples of amazing fossil preservation so valuable for scientists?
- Many fossils of marine organisms have been found in the middle of continents, far from any ocean. What conclusion can you draw from this?

Section 2

Relative Ages of Rocks

Relative Ages of Rocks

Lesson Objectives

- Explain Steno's laws of superposition and original horizontality.
- Based on a geological cross-section, identify the oldest and youngest formations.
- Explain what an unconformity represents.
- Know how to use fossils to correlate rock layers.

Vocabulary

- biozone
- cross-cutting relationships
- geologic time scale
- key bed
- lateral continuity
- mass extinction
- microfossil
- original horizontality
- relative age
- superposition
- unconformity
- uniformitarianism

Introduction

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° 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.

Fossils were 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** below).



Figure 20.15

Fossil Shark Tooth (left) and Modern Shark Tooth (right).

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. He then sought to explain how fossil seashells could be found in rocks and mountains far from any ocean. This led him to the ideas that are discussed below.

Superposition of Rock Layers

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. Based on these assumptions, Steno made a remarkable series of conjectures that are now known as Steno's Laws. These laws are illustrated in **Figure** below .

Original Horizontality - all sedimentary rocks are originally deposited horizontally.

Law of Lateral Continuity – Horizontal strata extend laterally until they thin to zero thickness (pinch out) at the edge of their basin of deposition.

Law of Superposition – In undisturbed strata, the oldest layer lies at the bottom and the youngest layer lies at the top.

Law of Cross-Cutting Relationships – An event that cuts across existing rock is younger than that disturbed rock.

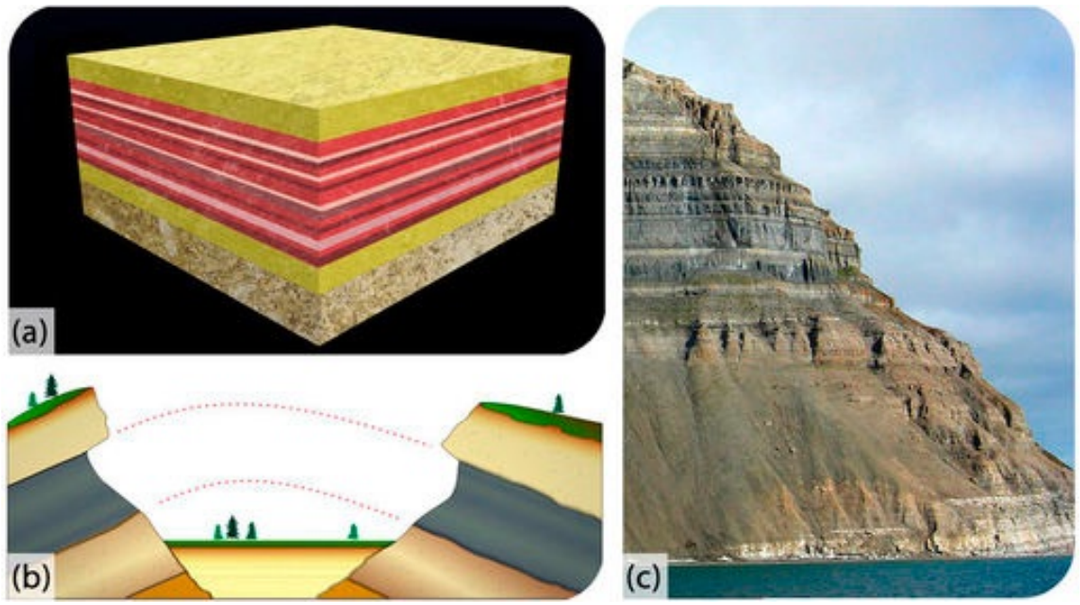


Figure 20.16

(a) 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. (b) 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. (c) 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.

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** below).

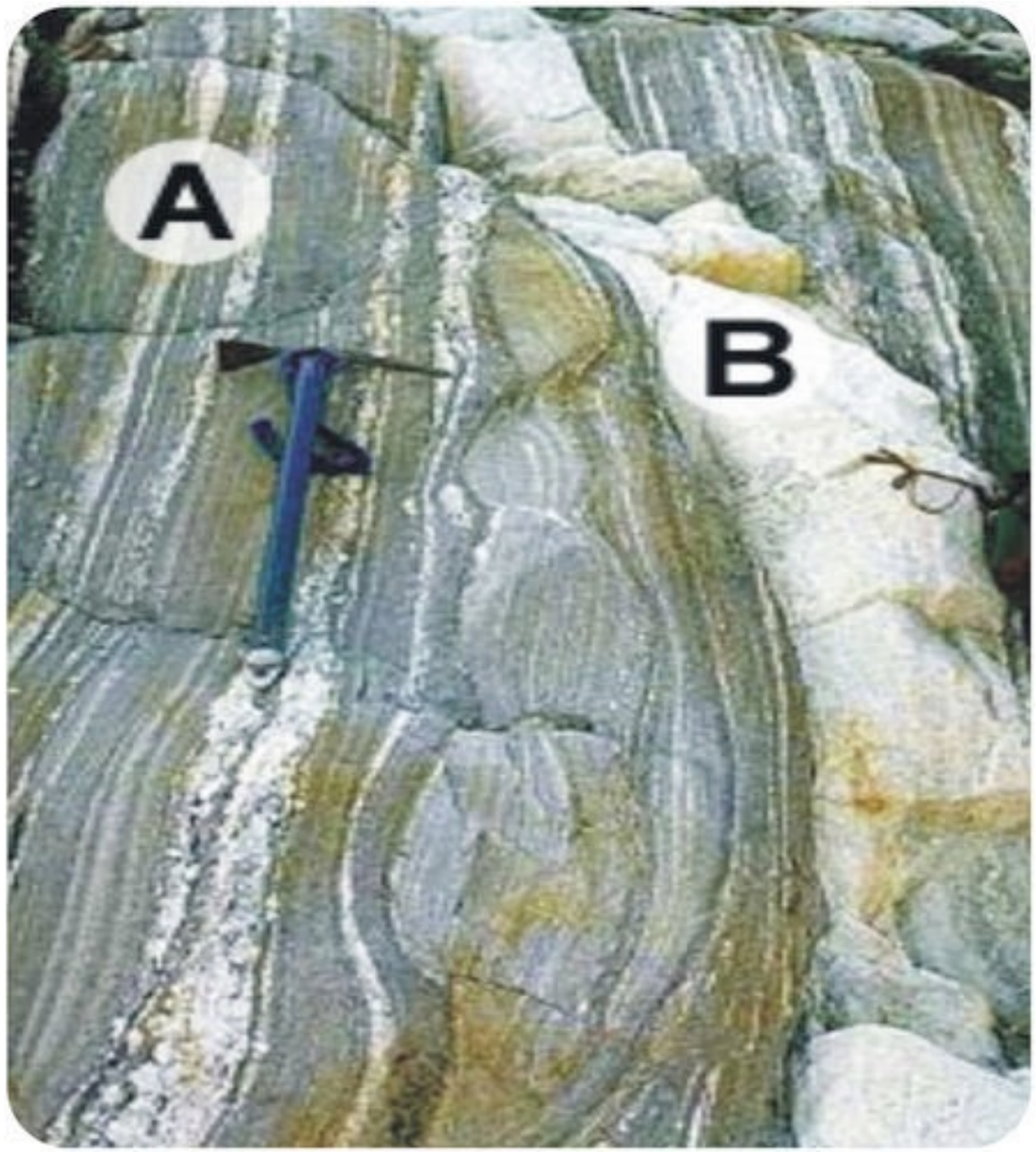


Figure 20.17

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.

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** below).

- 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 Coconino Sandstone, 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 20.18

At the Grand Canyon, the Coconino Sandstone appears across canyons. The Coconino is the distinctive white layer; it is a vast expanse of ancient sand dunes.

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** below)? Write it down and then check the following paragraphs.

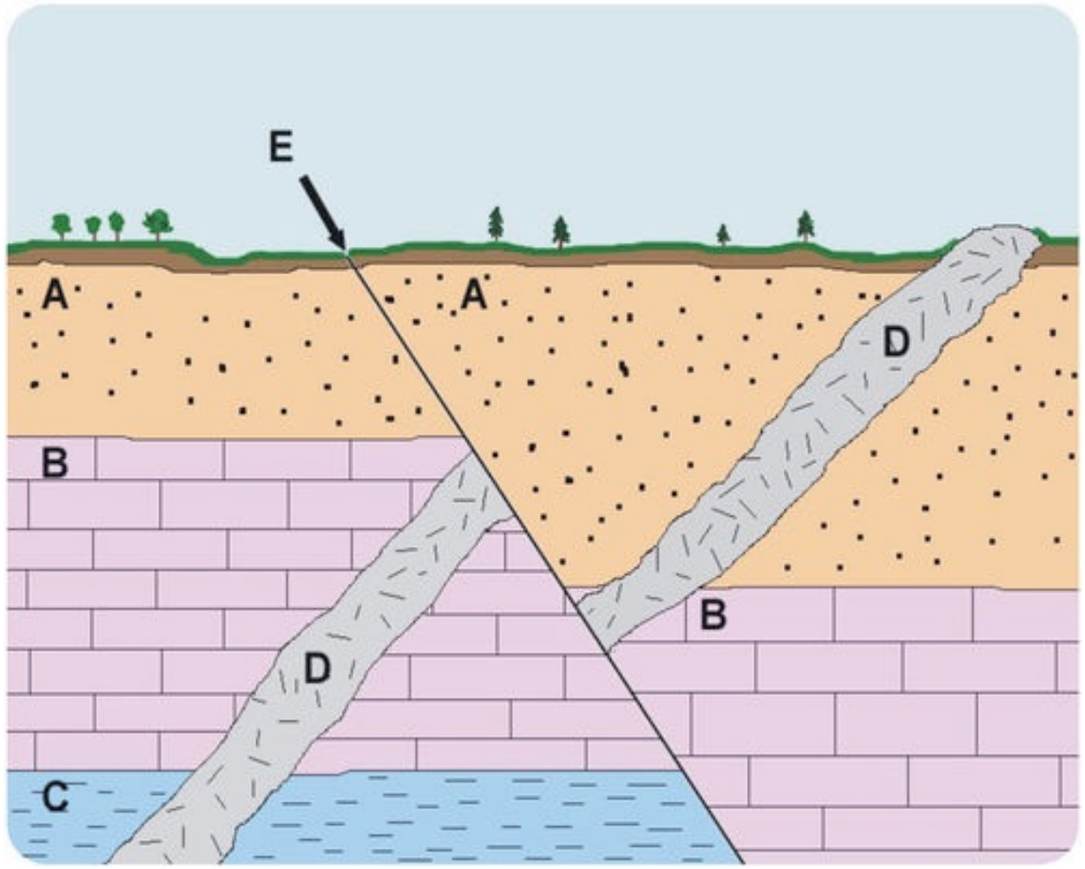


Figure 20.19

A geologic cross section: Sedimentary rocks (A-C), igneous intrusion (D), fault (E).

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:

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.

Earth's Age

During Steno's time, most Europeans believed that the Earth was around 6,000 years old, a figure that was based on the amount of time estimated for the events described in the Bible. One of the first scientists to question this assumption and to understand geologic time was James Hutton. Hutton traveled around Great Britain in the late 1700s, studying sedimentary rocks and their fossils (**Figure** below).

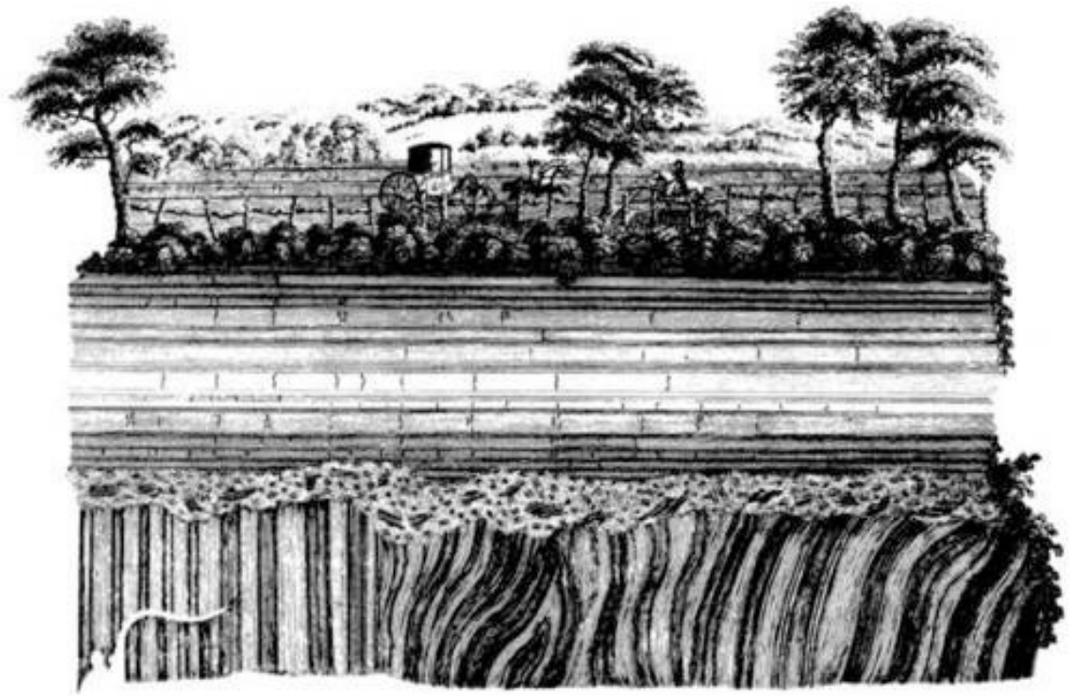


Figure 20.20

A drawing by James Hutton. "Theory of the Earth," 1795.

Often described as the founder of modern geology, Hutton formulated **uniformitarianism** : The present is the key to the past. According to uniformitarianism, the same processes that operate on Earth today operated in the past as well. Why is an acceptance of this principle absolutely essential for us to be able to decipher Earth history?

Hutton questioned the age of the Earth when he looked at rock sequences like the one below. On his travels, he discovered places where sedimentary rock beds lie on an eroded surface. At this gap in rock layers, or **unconformity** , some rocks were eroded away. For example, consider the famous unconformity at Siccar Point, on the coast of Scotland (**Figure** below).



Figure 20.21

Hutton's Unconformity on the Coast of Scotland. Can you find the unconformity? What are the geological events that you can find in this image? (Hint: There are nine.)

1. A series of sedimentary beds was deposited on an ocean floor.

2. The sediments hardened into sedimentary rock.

3. The sedimentary rocks are uplifted and tilted, exposing them above sea level.

4. The tilted beds were eroded to form an irregular surface.

5. A sea covered the eroded sedimentary rock layers.

6. New sedimentary layers were deposited.

7. The new layers hardened into sedimentary rock.

8. The whole rock sequence was tilted.

9. Uplift occurred, exposing the new sedimentary rocks above the ocean surface.

Since he thought that the same processes at work on Earth today worked at the same rate in the past, he had to account for all of these events and the unknown amount of missing time represented by the unconformity, Hutton realized that this rock sequence alone represented a great deal of time. He concluded that Earth's age should not be measured in thousands of years, but in millions of years.

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, but how do geologists correlate rock layers that are separated by greater distances? There are three kinds of clues:

1. Distinctive rock formations may be recognizable across large regions (**Figure** below).



Figure 20.22

The famous White Cliffs of Dover in southwest England can be matched to similar white cliffs in Denmark and Germany.

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** below). Ammonites, trilobites, and graptolites are often used as index fossils.

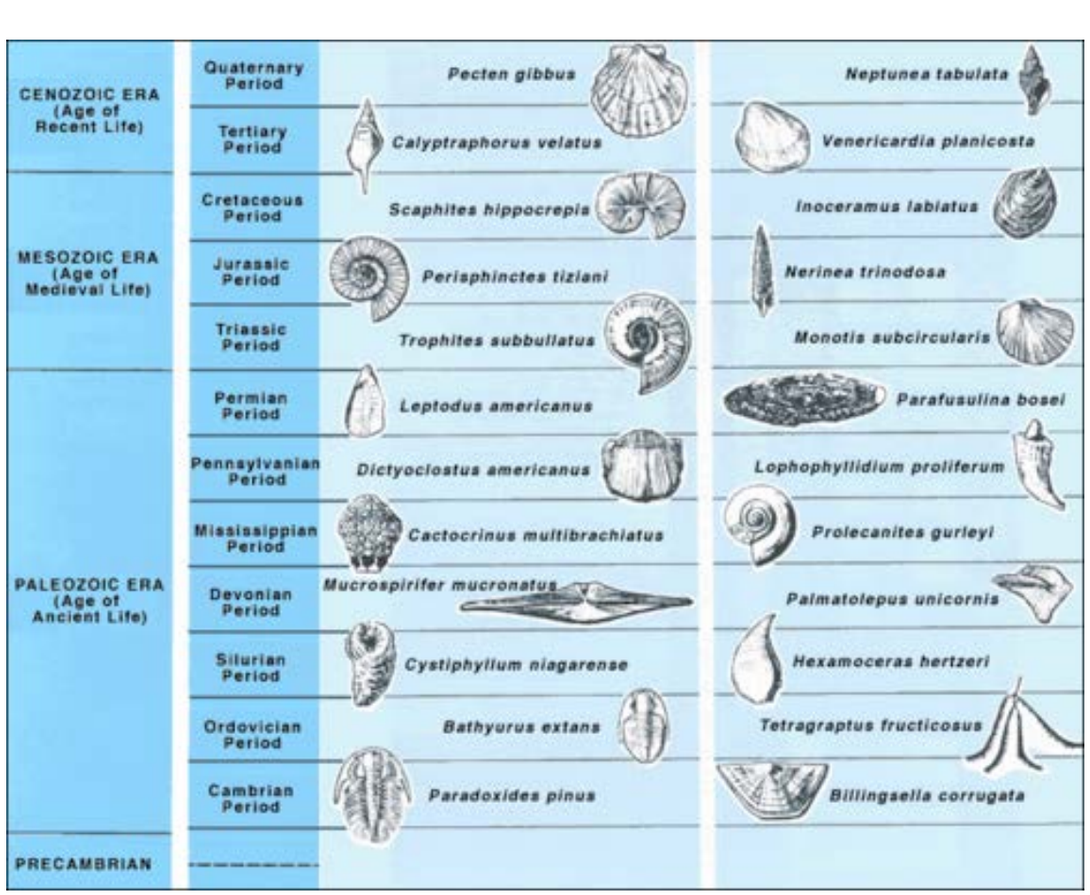


Figure 20.23

Several examples of index fossils are shown here. Mucrospirifer mucronatus is an index fossil that indicates that a rock was laid down from 416 to 359 million years ago.

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.

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** below). This 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 20.24

The white clay is a key bed that marks the Cretaceous-Tertiary Boundary.

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** below). 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 **Figure** below are proportional to the amount of time each time period represented in Earth history?



Figure 20.25

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.

Mass Extinctions

More than 90 percent of all organisms that have ever lived on Earth are extinct. As new species evolve to fit ever changing

ecological niches, older species fade away. But the rate of extinction is far from constant. At least a handful of times in the last 500 million years, 50 to more than 90 percent of all species on Earth have disappeared in a geological blink of the eye.

Though these mass extinctions are deadly events, they open up the planet for new life-forms to emerge. Dinosaurs appeared after one of the biggest mass extinction events on Earth, the Permian-Triassic extinction about 250 million years ago. The most studied mass extinction, between the Cretaceous and Paleogene periods about 65 million years ago, killed off the dinosaurs and made room for mammals to rapidly diversify and evolve.

The causes of these mass extinction events are **unsolved mysteries** , though volcanic eruptions and the impacts of large asteroids or comets are prime suspects in many of the cases. Both would eject tons of debris into the atmosphere, darkening the skies for at least months on end. Starved of sunlight, plants and plant-eating creatures would quickly die. Space rocks and volcanoes could also unleash toxic and heat-trapping gases that—once the dust settled—enable runaway global warming.

An extraterrestrial impact is most closely linked to the **Cretaceous extinction event** . A huge crater off Mexico's Yucatán Peninsula is dated to about 65 million years ago, coinciding with the extinction. Global warming fueled by volcanic eruptions at the Deccan Flats in India may also have aggravated the event. Whatever the cause, dinosaurs, as well as about half of all species on the planet, went extinct.

Massive floods of lava erupting from the central Atlantic magmatic province about 200 million years ago may explain the **Triassic-Jurassic extinction** . About 20 percent of all marine families went extinct, as well as most mammal-like creatures, many large amphibians, and all non-dinosaur archosaurs. An asteroid impact is another possible cause of the extinction, though a telltale crater has yet to be found.

Largest Ever Die-Off

The **Permian-Triassic extinction event** about 250 million years ago was the deadliest: More than 90 percent of all species perished. Many scientists believe an asteroid or comet triggered the massive die-off, but, again, no crater has been found. Another strong contender is flood volcanism from the Siberian Traps, a large igneous province in Russia. Impact-triggered volcanism is yet another possibility.

Starting about 360 million years ago, a drawn-out event eliminated about 70 percent of all marine species from Earth over a span of perhaps 20 million years. Pulses, each lasting 100,000 to 300,000 years, are noted within the larger late **Devonian extinction** . Insects, plants, and the first proto-amphibians were on land by then, though the extinctions dealt landlubbers a severe setback.

The **Ordovician-Silurian extinction** , about 440 million years ago, involved massive glaciations that locked up much of the world's water as ice and caused sea levels to drop precipitously. The event took its hardest toll on marine organisms such as shelled brachiopods, eel-like conodonts, and the trilobites.

Happening Now?

Today, many scientists think the evidence indicates a **sixth mass extinction** is under way. The blame for this one, perhaps the fastest in Earth's history, falls firmly on the shoulders of humans. By the year 2100, human activities such as pollution, land

clearing, and overfishing may have driven more than half of the world's marine and land species to extinction.

Lesson Summary

•Nicholas Steno formulated the principles in the 17th century that allow scientists to determine the relative ages of rocks. Steno stated that sedimentary rocks are formed in continuous, horizontal layers, with younger layers on top of older layers.
•William Smith and James Hutton later discovered the principles of cross-cutting relationships and faunal succession.
•Hutton also realized the vast amounts of time that would be needed to create an unconformity and concluded that Earth was much older than people at the time thought.
•The guiding philosophy of Hutton and geologists who came after him is: The present is the key to the past.
•To correlate rock layers that are separated by a large distance look for sedimentary rock formations that are extensive and recognizable, index fossils, and key beds.
•Changes of fossils over time led to the development of the geologic time scale, which illustrates the relative order in which events on Earth have happened.

Review Questions

1. A 15th century farmer finds a rock that looks exactly like a clamshell. What did he likely conclude about how the fossil got there?

2. Which of Steno's Laws is illustrated by each of the images in **Figure** below ?

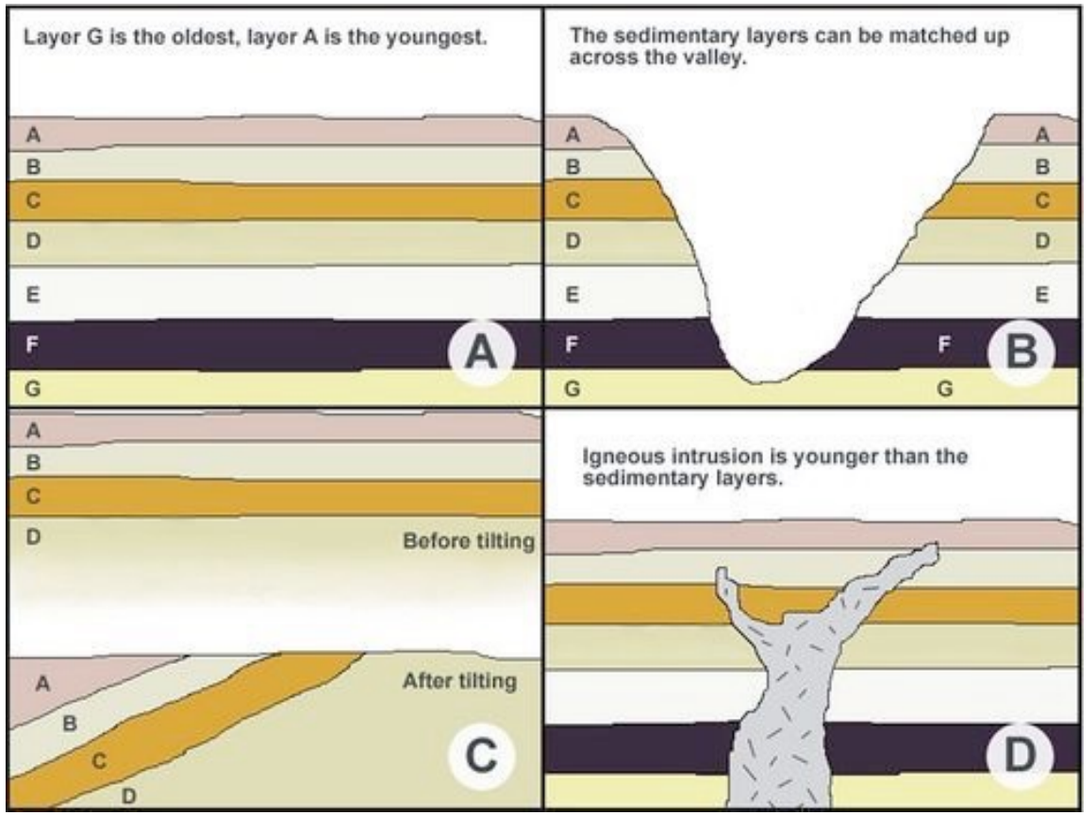


Figure 20.26

3. What is the sequence of rock units in **Figure** below , from oldest to youngest?

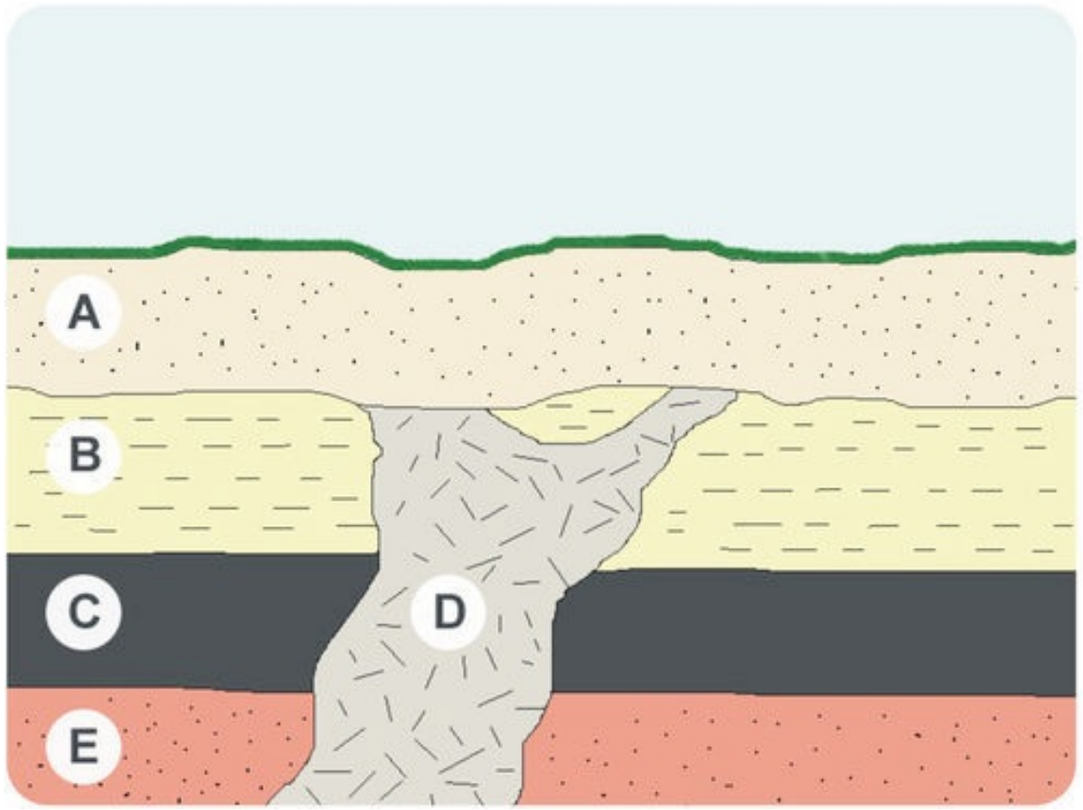


Figure 20.27

Sequence of Rock Units

4. What kind of geological formation is shown in the outcrop in **Figure** below , and what sequence of events does it represent?



Figure 20.28

Outcrop

5. The three outcrops in **Figure** below are very far apart. Based on what you see, which fossil is an index fossil, and why?

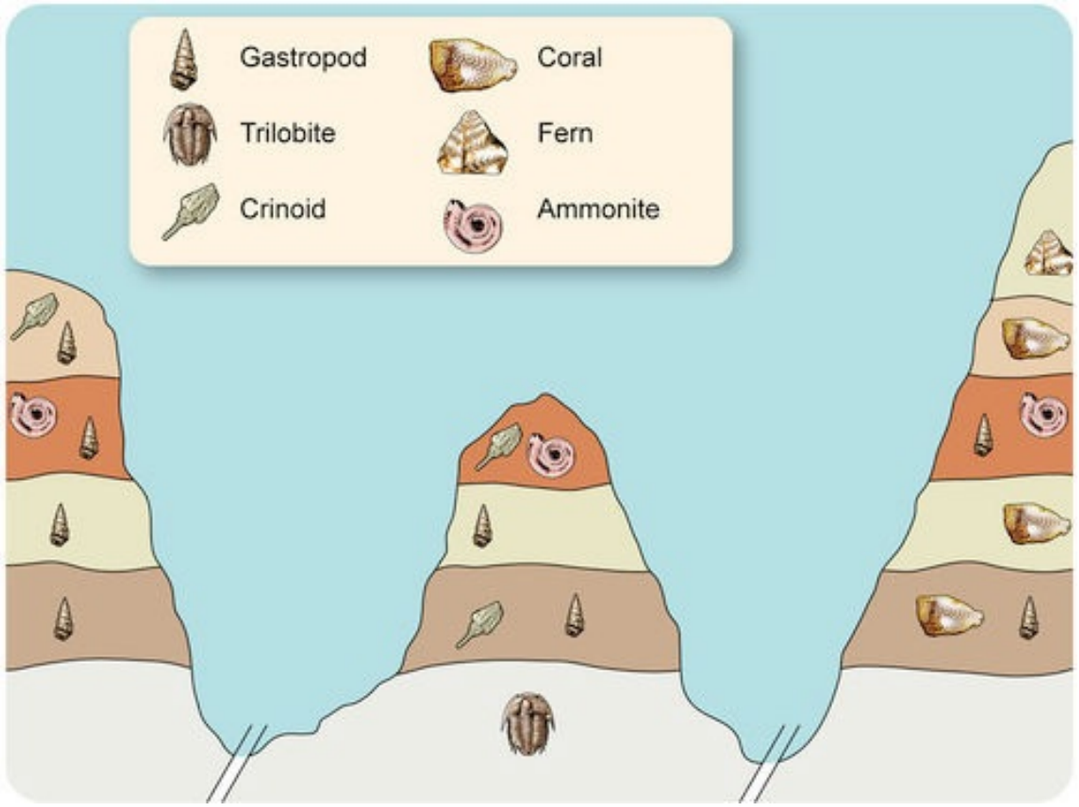


Figure 20.29

Three outcrops

6. Why didn't the early geologic time scale include the number of years ago that events happened?

7. Dinosaurs went extinct about 66 million years ago. Which period of geologic time was the last in which dinosaurs lived?

8. Suppose that while you're hiking in the mountains of Utah, you find a fossil of an animal that lived on the ocean floor. You learn that the fossil is from the Mississippian period. What was the environment like during the Mississippian in Utah?

9. Why are sedimentary rocks more useful than metamorphic or igneous rocks in establishing the relative ages of rock?

10. Which is likely to be more frequently found in rocks: fossils of very old sea creatures or very old land creatures?

11. Name and describe four mass extinctions.

Further Reading / Supplemental Links

A US Geological Survey paper on Rocks, Fossils and Time: http://pubs.usgs.gov/gip/fossils/contents.html

Try to guess the mystery fossils in these pictures and see if you're right. There are more in the archives: http://www.ucmp.berkeley.edu/exhibits/mysteryfossil/mysteryfossil.php

An interactive "Virtual Museum of Fossils" http://fossils.valdosta.edu/.

The fossil record in North America http://www.paleoportal.org/.

An excerpt of the book "The Seashell on the Mountaintop" is found here http://alan-cutler.com/excerpt.html

Determining the ages of rocks and fossils: http://www.ucmp.berkeley.edu/fosrec/McKinney.html

Points to Consider

- How did preconceived ideas in Steno's time make people blind to the reality of what fossils represent?
- How did Steno explain the presence of marine fossils in high mountains?

•Why was Hutton's recognition of unconformities so significant?
•Can the relative ages of two rock layers that are very far apart be determined?
•Can the same principles used to study Earth's history also be used to study the history of other planets?

Absolute Ages of Rocks

Absolute Ages of Rocks

Lesson Objectives

- Define the differences between absolute age and relative age.
- Describe four methods of absolute dating.
- Explain what radioactivity is and give examples of radioactive decay.
- Explain how the decay of radioactive materials helps to establish the age of an object.
- Estimate the age of an object, given the half-life and the amounts of radioactive and daughter materials.
- Give four examples of radioactive materials that are used to date objects, and explain how each is used.
- Describe how scientists know earth is billions of years old.

Vocabulary

- absolute age
- daughter product
- half-life
- ice core
- parent isotope
- radioactive isotope
- radioactivity
- radiometric dating
- tree ring

Introduction

What was missing from the early geologic time scale? While the order of events was given, the dates at which the events happened were not. With the discovery of radioactivity in the late 1800s, scientists were able to measure the **absolute age** , or the exact age of some rocks in years. Absolute dating allows scientists to assign numbers to the breaks in the geologic time scale. Radiometric dating and other forms of absolute age dating allowed scientists to get an absolute age from a rock or fossil.

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. The study of tree rings is dendrochronology and by counting **tree rings** it is possible to find the number of years the tree lived (**Figure** below).



Figure 20.30

Cross-section showing growth rings.

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.

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 and Varves

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** below). 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 20.31

Ice core section showing annual layers.

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** below). A warm summer might result in a very thick sediment layer while a cooler summer might yield a thinner layer.



Figure 20.32

Ancient varve sediments in a rock outcrop.

Age of Earth

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 (**Figure** below). 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.



Figure 20.33

Lord Kelvin.

Thomson's calculations were soon shown to be flawed when **radioactivity** was discovered in 1896. Radioactivity is the tendency of certain atoms to decay into lighter atoms, a process that emits energy. Radioactive decay of elements inside Earth's interior provides a steady source of heat, which meant that Thomson had grossly underestimated Earth's age.

Radioactive Decay

Radioactivity also provides a way to find the absolute age of a rock. To begin, go back to the Earth's Minerals chapter and review the material about atoms.

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** below):

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** below).

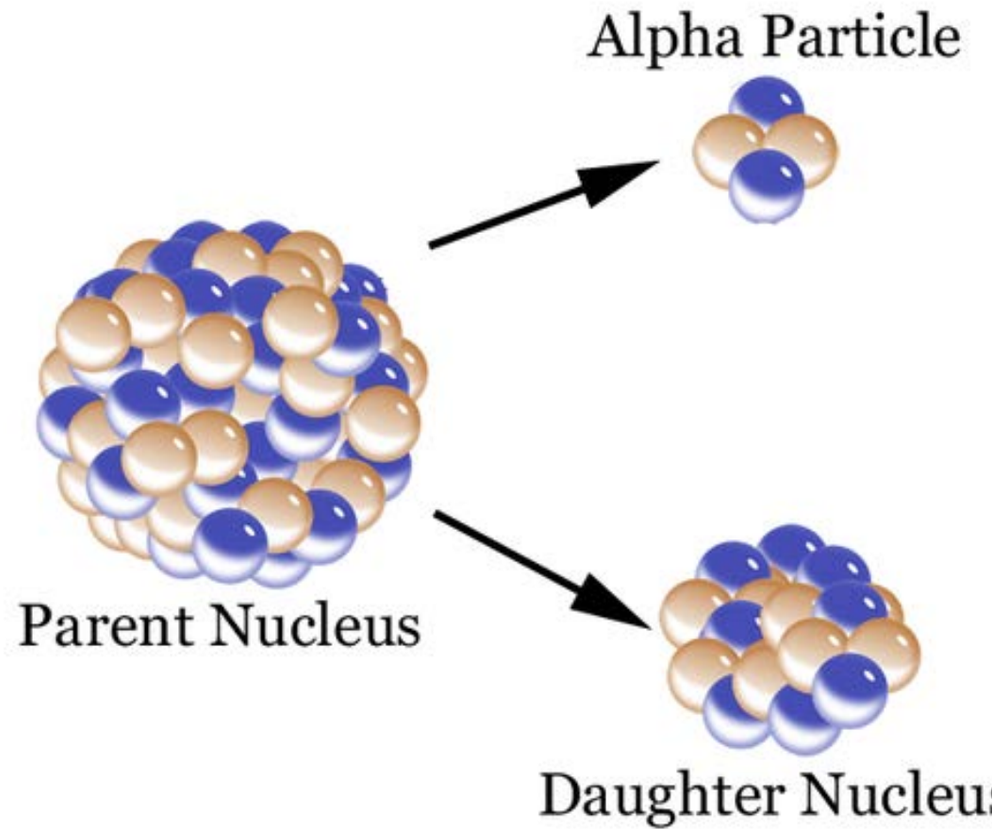


Figure 20.34

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 .

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** below).

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** below).

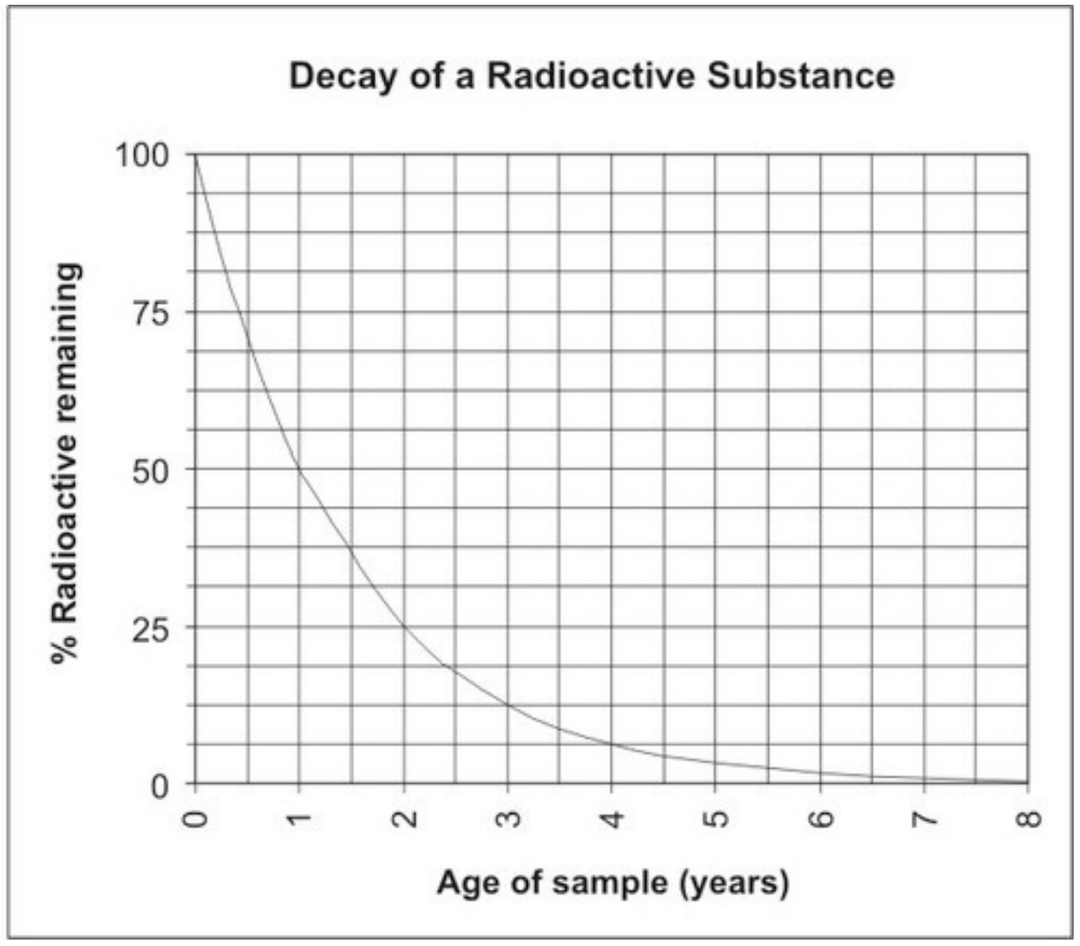


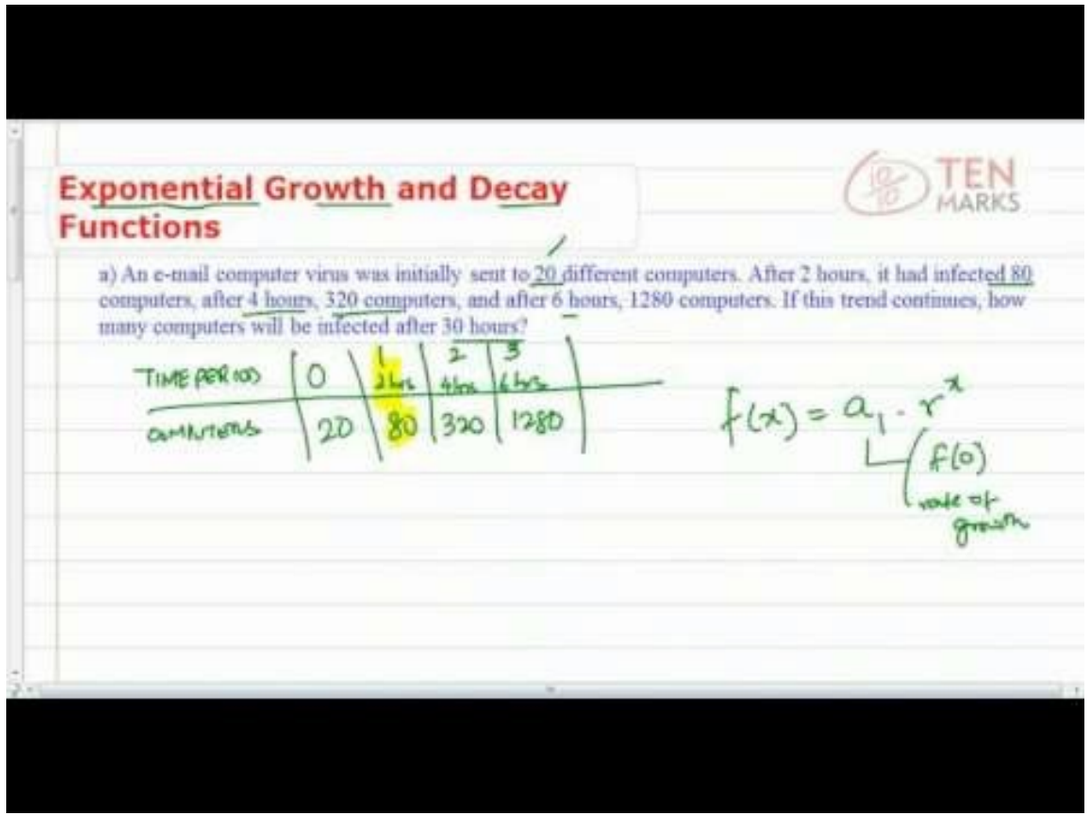
Figure 20.35

Decay of an imaginary radioactive substance with a half-life of one year.

An animation of half-life: http://einstein.byu.edu/~masong/htmstuff/Radioactive2.html .

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).



Click on the image above for more content

Radiometric Dating of Rocks

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** below).



Figure 20.36

Carbon isotopes from the black material in these cave paintings places their creating at about 26,000 to 27,000 years BP (before present).

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.

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 .

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** below). 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.



Figure 20.37

Zircon crystal.

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.

Limitations of Radiometric Dating

Radiometric dating , or the process of using the concentrations of radioactive substances and daughter products to estimate the age of a material, 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 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.

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 .

Lesson Summary

- Earth is very old, and the study of Earth's past requires us to think about times that were millions or even billions of years ago.
- Techniques such as superposition and index fossils can tell you the relative age of objects, which objects are older and which are younger.
- Geologists use a variety of techniques to establish absolute age, including radiometric dating, tree rings, ice cores, and annual sedimentary deposits called varves.
- The concentrations of several radioactive isotopes (e.g. carbon-14, potassium-40, uranium-235 and -238) and their daughter products are used to accurately determine the age of rocks and organic remains.

Review Questions

1. Name four techniques that are used to determine the absolute age of an object or event.

2. A radioactive substance has a half-life of 5 million years. What is the age of a rock in which 25% of the original radioactive atoms remain?

3. A scientist is studying a piece of cloth from an ancient burial site. She determines that 40% of the original carbon-14 atoms remain in the cloth. Based on the carbon-decay graph (**Figure** below), what is the approximate age of the cloth?

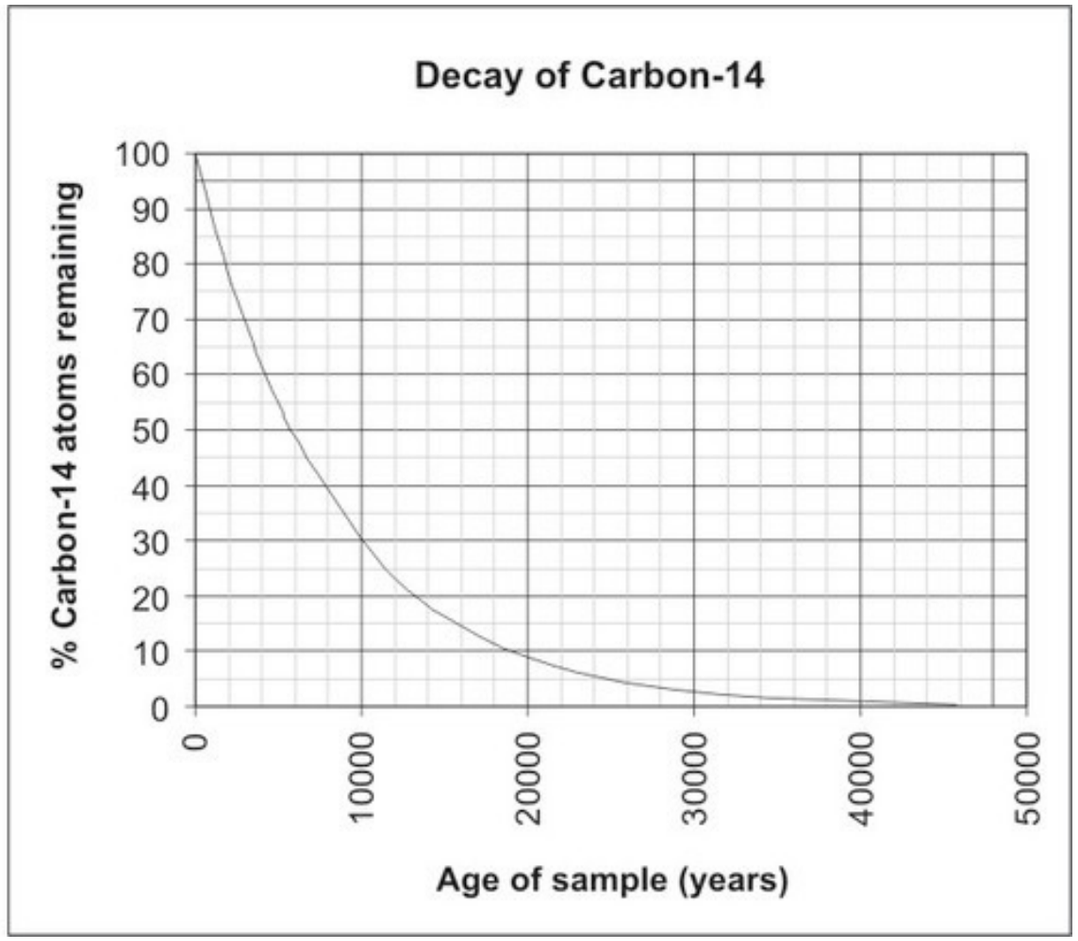


Figure 20.38

Carbon-decay graph.

4. Which radioactive isotope or isotopes would you use to date each of the following objects? Explain each of your choices.

1.) A 4-billion-year-old piece of granite.
2.) A 1-million-year-old bed of volcanic ash that contains the footprints of human ancestors.
3.) The fur of a woolly mammoth that was recently recovered, frozen in a glacier.
4.) A fossilized trilobite from a bed of sandstone that is about 500 million years old.

5. Why is it important to assume that the rate of radioactive decay has remained constant over time?

Further Reading / Supplemental Links

Using tree rings and ice cores to track El Nino events: http://www.pbs.org/wgbh/nova/elnino/reach/living.html .

Points to Consider

•Why are techniques for dating, such as using tree rings, ice cores, and varves only useful for events that occurred in the last few thousand years?
•Why is it important for geological and biological processes that the earth is very old?
•Why is it important to use more than one method to find the age of a rock or other object?

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Ch. 18: Earth's History



Earth looks very different today than it did when it first formed more than 4.5 billion years ago. Rare parts of the planet may retain a bit of the feel of the ancient environment, such as the Grand Prismatic Spring in Yellowstone National Park. Earth’s internal heat creates hot springs that are home to extremophiles, organisms that thrive in extreme environments. The orange, spongy materials in this photo are mats of thermophilic bacteria, organisms that thrive in extremely hot environments. Since the Earth’s environment was undoubtedly more extreme in the early days, it seems likely that the most ancient life forms were forms of extremophiles.

Life on Earth has changed tremendously since those early days. Creatures have become multicellular; they have gained the ability to make their own food energy by photosynthesis; they have adapted to living in water, on land and in the air; and they've even evolved intelligence. The geology of the planet has also changed. The Earth's crust has hardened, mountains have risen, oceans have grown, and erosion has reduced features to flat plains. All of this has happened over an extremely long period of time, and humans have been around for only a tiny part.

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

Section 1

Early Earth

Early Earth

Lesson Objectives

- Describe how the Earth formed with other parts of the solar system about 4.6 billion years ago.
- Recount the Moon's birth story.
- Explain how Earth's atmosphere has changed over time.
- Explain the conditions that allowed the first forms of life to develop on Earth.

Vocabulary

- differentiation
- outgassing
- paleontologist

Introduction

Historical geologists study Earth's past to understand what happened and when it happened. **Paleontologists** do the same thing, but with an emphasis on the history of life, especially as it is understood from fossils. Despite having very little material from those days, scientists have many ways of learning about the early Earth.

Formation of Earth

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. More information about planet formation is in the chapter about the solar system.

There is little hard evidence for scientists to study from Earth's earliest days. Much of what scientists know about the early Earth come 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** below); and (3) lunar rocks, which represent the early days of the Earth-Moon system as far back as 4.5 billion years ago.



Figure 21.1

The Allende Meteorite is a carbonaceous chondrite that struck Earth in 1969. The calcium-aluminum-rich inclusions are fragments of the earliest solar system.

Molten Earth

When Earth first came together it was really hot, hot enough to melt the metal elements that it contained. Why was the early Earth so hot?

•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** below).

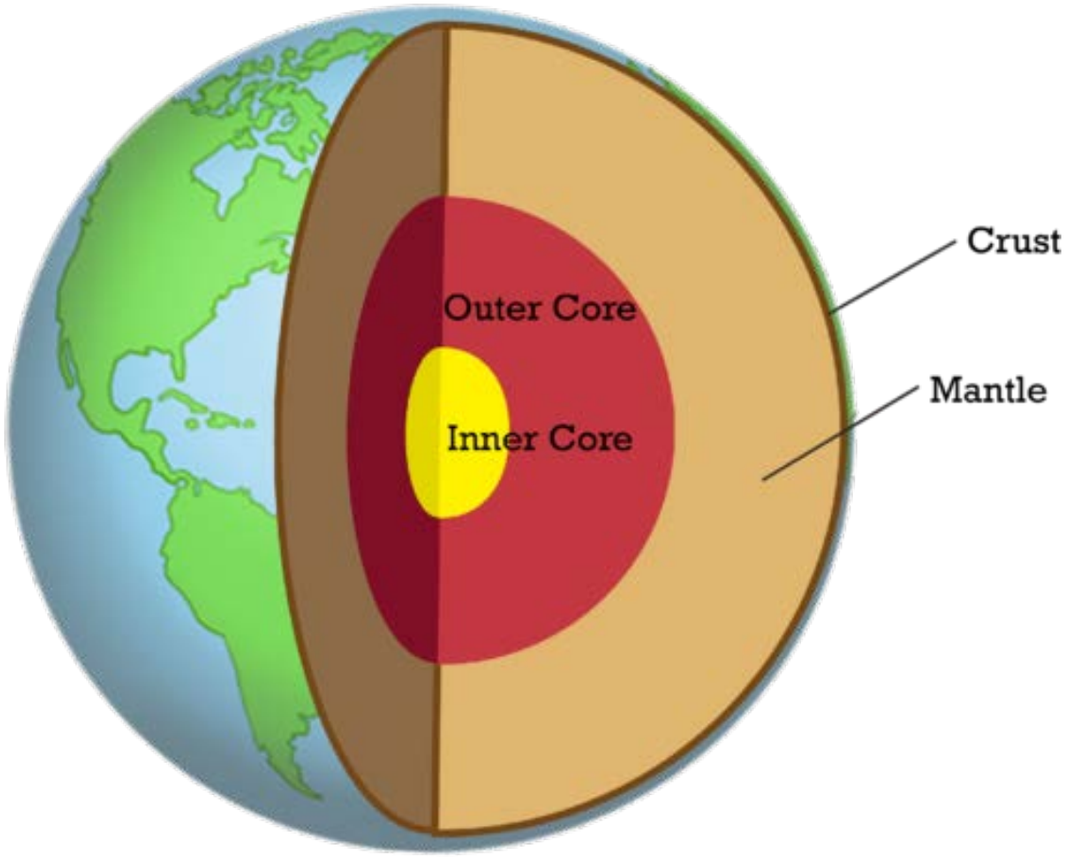


Figure 21.2

Earth's interior: Inner core, outer core, mantle, and 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.

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.

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?

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** below).



Figure 21.3

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.



Figure 21.4

The Genesis Rock was brought back to Earth by the Apollo 15 astronauts.

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 (**Figure** above). 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?

Earth's Early Atmosphere and Oceans

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.

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 (**Figure** below). Just as today, volcanic **outgassing** was a source of water vapor, carbon dioxide, small amounts of nitrogen, and other gases.



Figure 21.5

Nearly constant volcanic eruptions supplied gases for Earth's early atmosphere.

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** below).

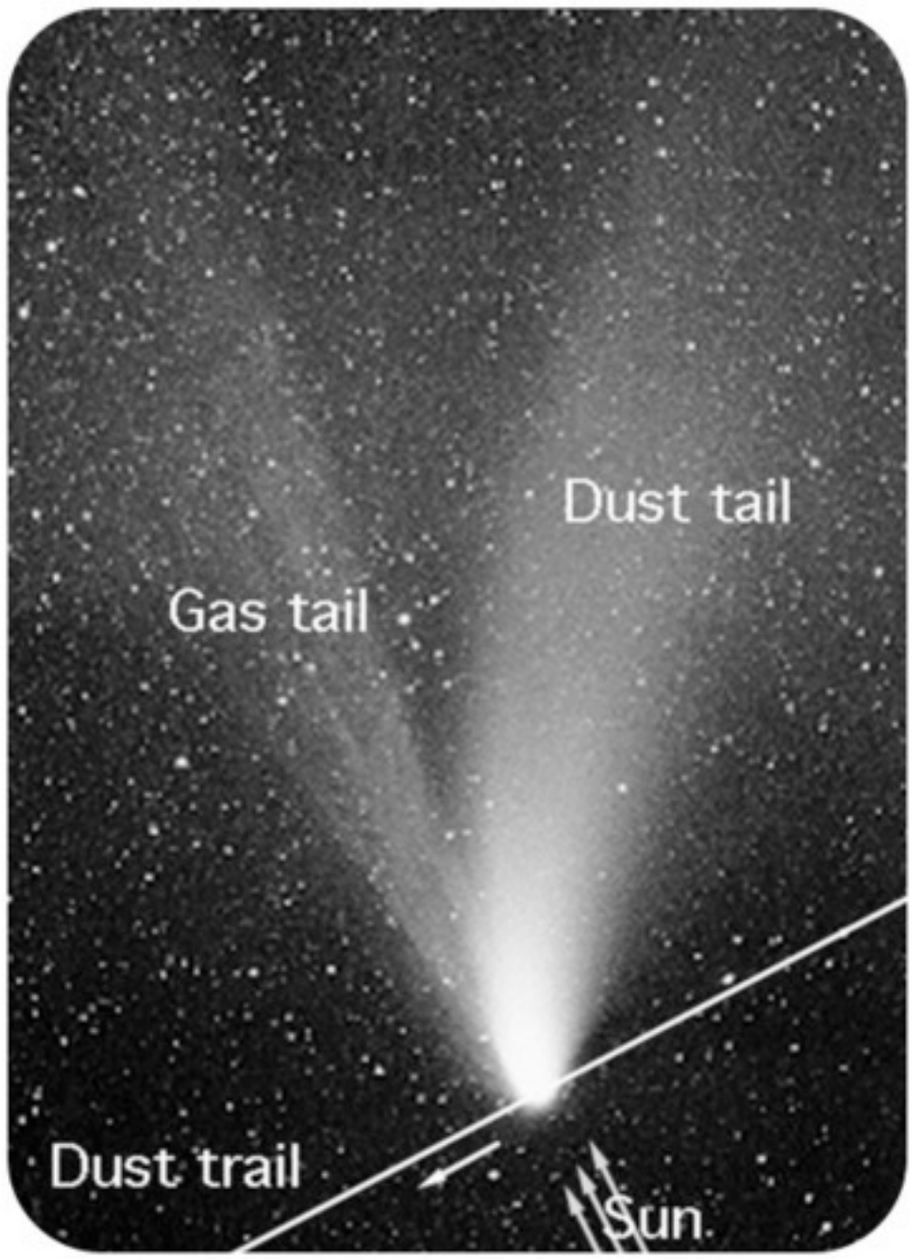


Figure 21.6

The gases that create a comet's tail can become part of the atmosphere of a planet.

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.

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.

Lesson Summary

- Earth and the other planets in the solar system formed about 4.6 billion years ago.
- The early Earth was frequently hit with asteroids and comets. There were also frequent volcanic eruptions. Both were sources of water and gases for the atmosphere
- The early Earth had no ozone layer, no free oxygen, and was very hot.
- The oceans originally formed as water vapor released by volcanic outgassing and comet impacts cooled and condensed.
- Earth was struck by a giant impactor, which flung material out into orbit around the planet. This material accreted into Earth's only natural satellite, the Moon.

Review Questions

1. From what sources did water arrive in Earth's atmosphere?

2. Describe how the Earth's different layers vary by density. When did the layers undergo differentiation?

3. What are the two main reasons that an oxygen-rich atmosphere is important for life on Earth?

4. List three ways Earth is different today from when it was first formed.

5. If Earth had been much cooler when it first formed, how would the planet be different now from the way it is today?

Further Reading / Supplemental Links

Read about the oldest material yet found in the Solar System: http://news.nationalgeographic.com/news/2010/08/100823-oldest-solar-system-two-million-years-older-science/ .

Watch the history of Earth:

http://www.youtube.com/watch?v=RQm6N60bneo

Points to Consider

- What would you recognize from modern times if you traveled back to the early days of Earth?
- How do scientists know what happened in the early Earth?
- When was the planet ready for life to begin?

The Precambrian

The Precambrian

Lesson Objectives

- Describe how the early continents came together.
- Understand what was needed for the first life and the various ways it may have come about.
- Discuss the early atmosphere and how and why free oxygen finally increased.
- Know the features and advantages of multicellular organisms.

Vocabulary

- amino acid
- banded iron formation
- craton
- cyanobacteria
- eukaryote
- extinct
- greenstone
- LUCA (last universal common ancestor)
- metabolism
- microbe
- microcontinent
- nucleic acid
- paleogeography
- photosynthesis
- platform
- prokaryote
- RNA world hypothesis
- shield
- stromatolites
- supercontinent
- symbiotic

Introduction

The longest span of time is the Precambrian Era, which includes the Proterozoic, Archean, and Pre-Archean (also called the Hadean). The Precambrian began when the Earth formed 4.6 billion years ago and ended at the beginning of the Cambrian period, 570 million years ago. The events recounted in the previous section were all part of the earliest Earth history, the Hadean. But there was still much more to come in the Precambrian Era. The geological principles explained in the earlier chapters of this book apply to understanding the geological history of these old times (**Figure** below).

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic		2500
Archean	Late Archean Middle Archean Early Archean		3800?
Pre-Archean			

Figure 21.7

The Geologic Time Scale.

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. The felsic crust was less dense then the basaltic crust and as tectonic forces began the felsic crust would survive and over ride the basaltic crust.

Cratons and Shields

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.

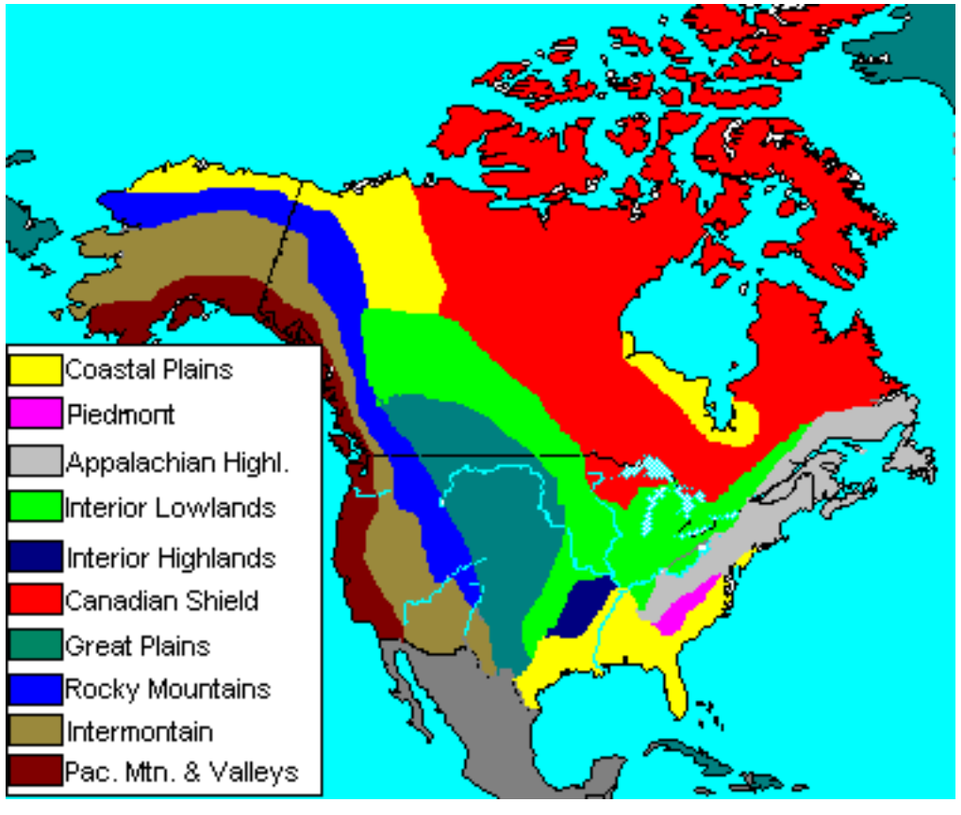


Figure 21.8

Places the craton crops out at the surface is known as a **shield** . The closest shield to the US is the Canadian shield(**Figure**

above). It is the oldest part of the North American crustal plate and contains fossils of bacteria and algae over 2 billion years old. The shield is composed of granite and the earth's greatest area of exposed Precambrian rock (igneous and metamorphic rock formed in the Precambrian geological era 500 million years ago). Cratons date from the Precambrian and are called Precambrian shields. Many Precambrian shields are about 570 million years old (**Figure** below).



Figure 21.9

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.

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.

- Banded Iron formations occur in Proterozoic rocks, ranging in age from 1.8 to 2.4 billion years old. They are composed of alternating layers of iron-rich material (commonly magnetite) and silica (chert). They mark the introduction of O_2 into Earths oceans and atmosphere. We will discuss this further at the end of this section.

- One common rock type in the cratons is **greenstone** , a metamorphosed volcanic rock (**Figure** below). 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 21.10

Ice age glaciers scraped the Canadian Shield down to the 4.28 billion year old greenstone in Northwestern Quebec.

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.

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** below).



Figure 21.11

The Precambrian craton is exposed in the Grand Canyon where the Colorado River has cut through the younger sedimentary rocks.

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.

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** below). Rodinia probably contained all of the landmass at the time, which was about 75% of the continental landmass present today.



Figure 21.12

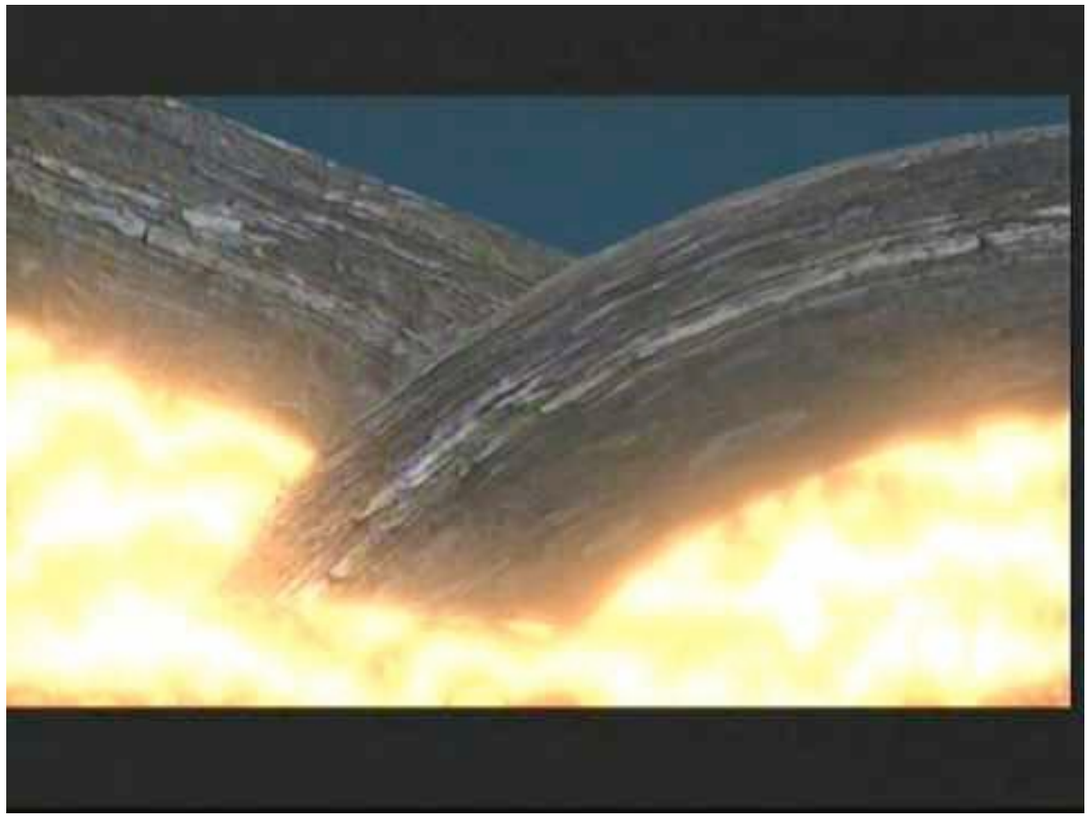
Rodinia as it came together about 1.1 billion years ago.

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.

The breakup of Rodinia may have triggered Snowball Earth around 700 million years ago. Snowball Earth is the hypothesis

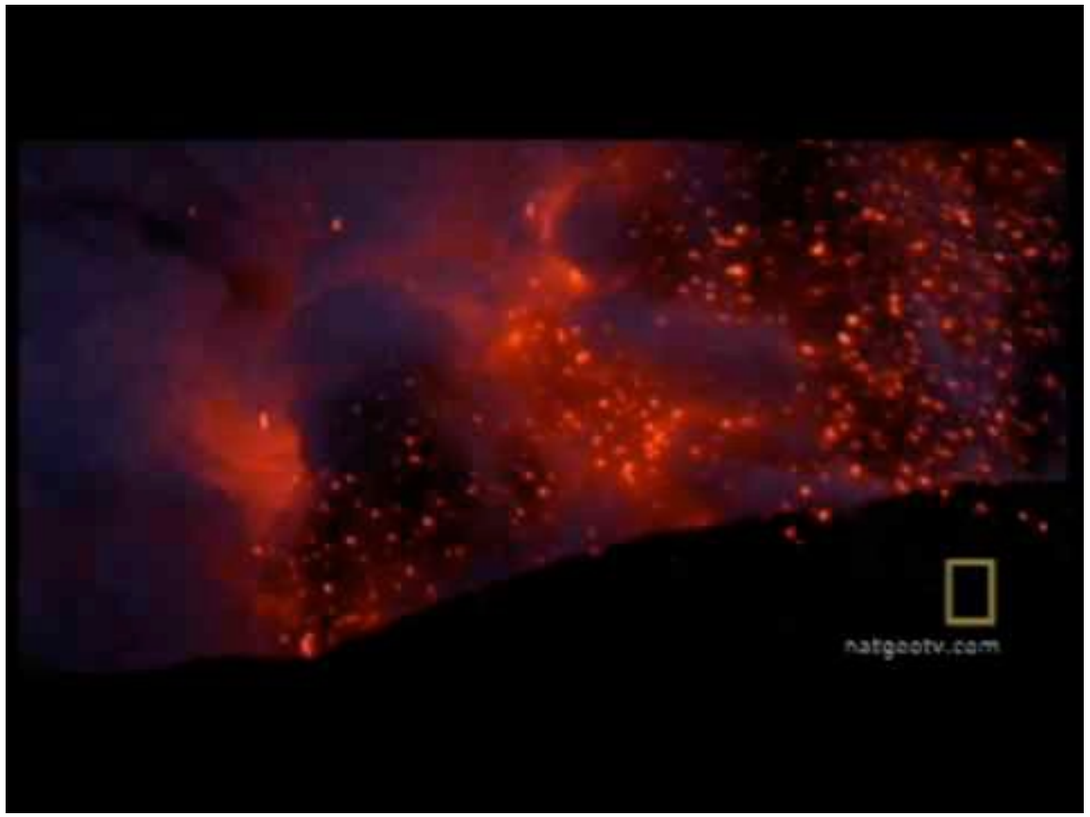
that much of the planet was covered by ice at the end of the Precambrian. When the ice melted and the planet became habitable, life evolved rapidly. This explains the rapid evolution of life in the Ediacaran and Cambrian periods.

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).



Click on the image above for more content

The presence of water on ancient Earth is revealed in a zircon crystal **(1c)** : http://www.youtube.com/watch?v=V21hFmZP5zM (3:13).



Click on the image above for more content

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.

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.

What does a molecule need to be and do to be considered alive? The 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).

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** below).

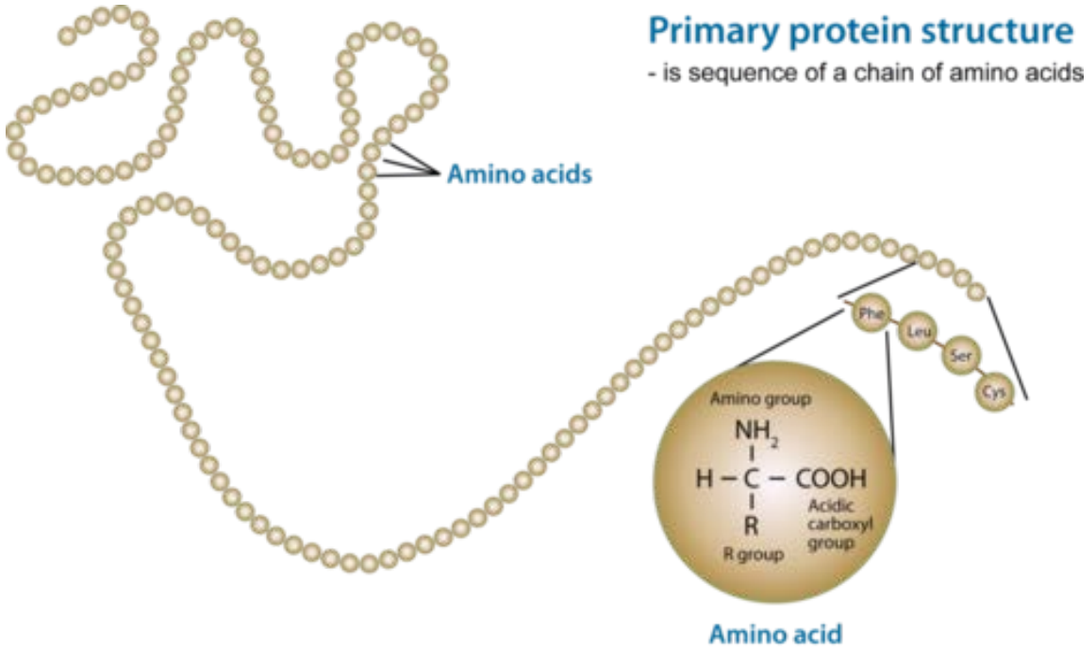


Figure 21.13

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.

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 (**Figure** below). 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.

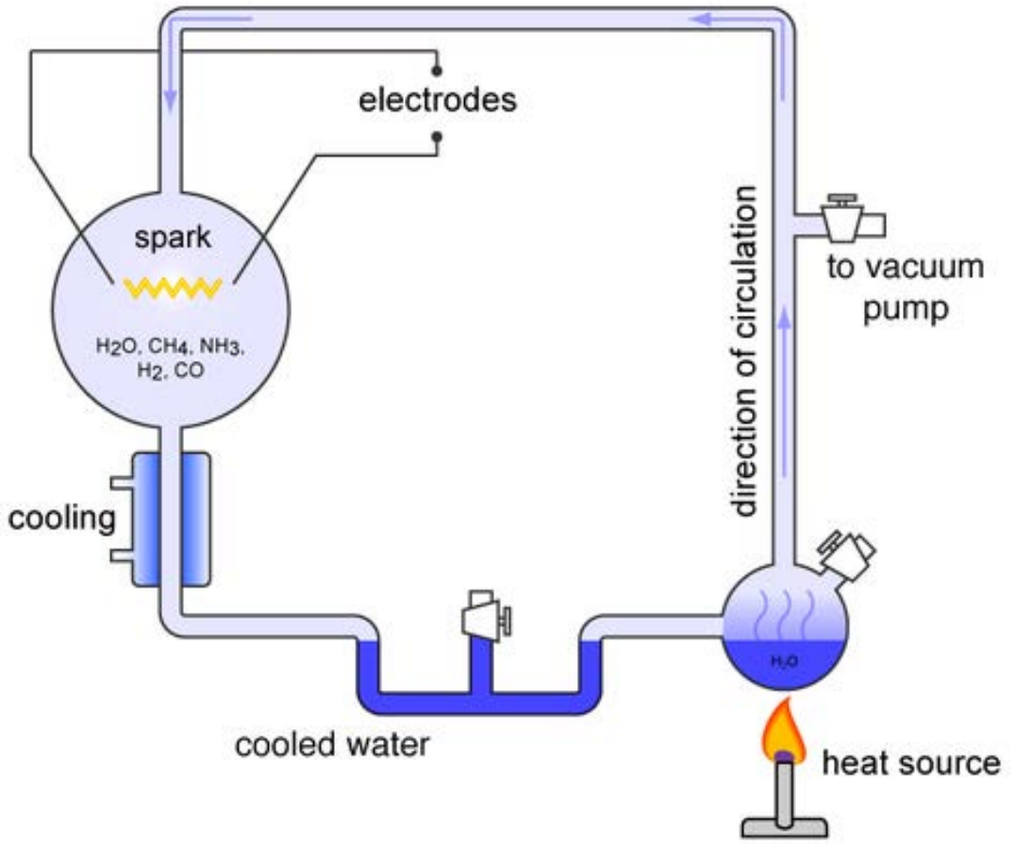


Figure 21.14

The Miller-Urey experiment was simple and elegant.

Click for Muller-Urey experiment animation.

Additional interactive site about Miller-Urey experiment.

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).

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 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 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 .

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.

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.

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.

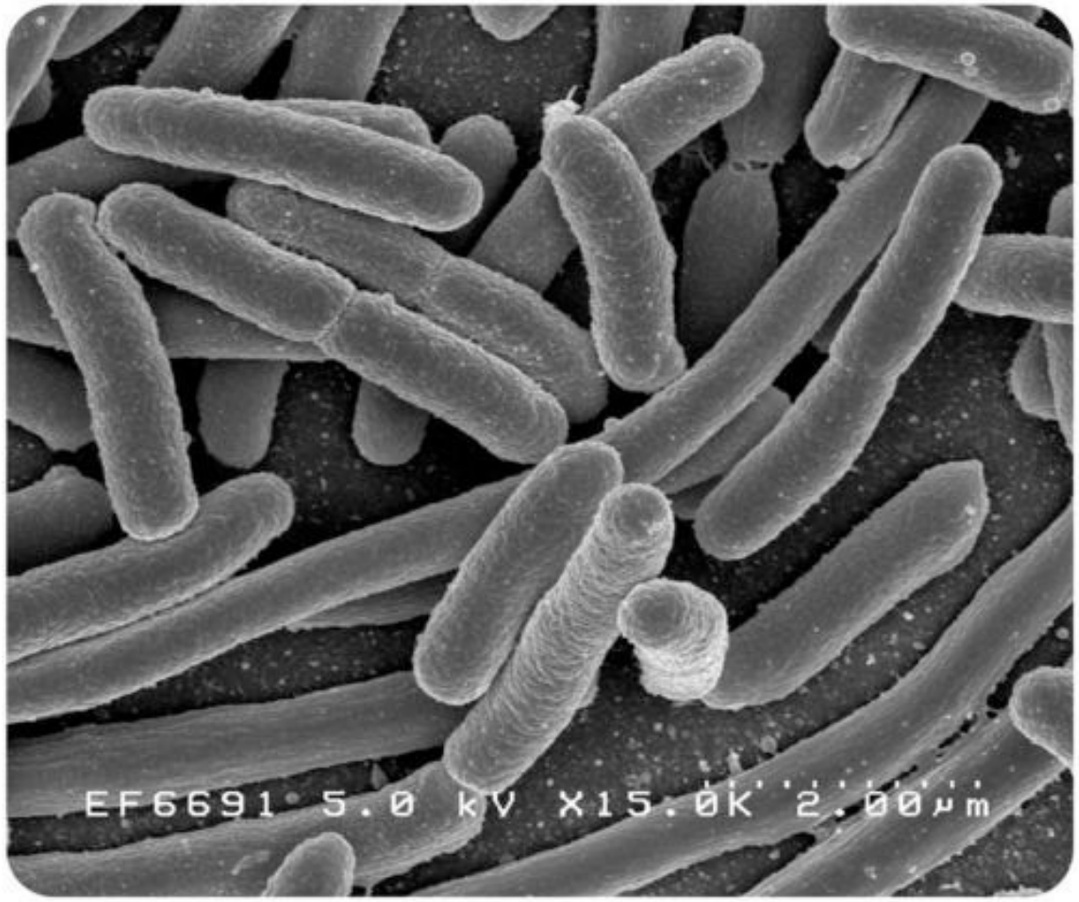


Figure 21.15

E. coli (*Escherichia coli*) is a primitive prokaryote that may resemble the earliest cells.

The earliest cells were **prokaryotes** (**Figure** above). 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.

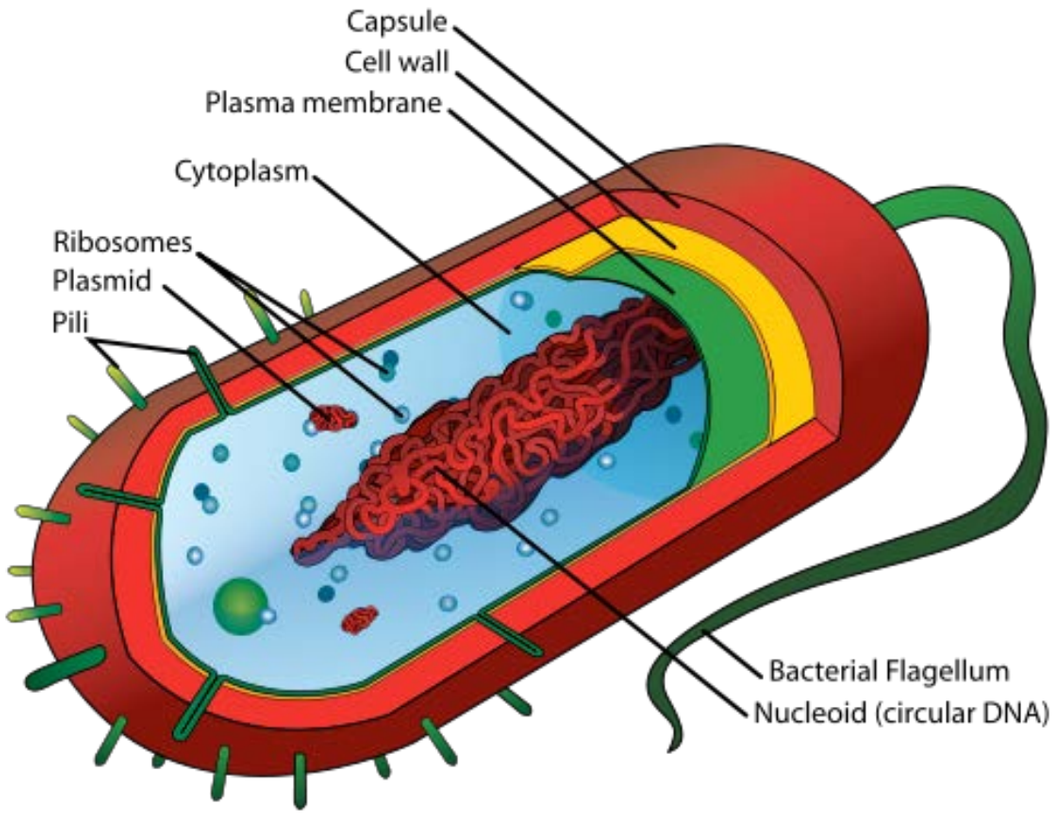


Figure 21.16

A diagram of a bacterium.

Evidence for bacteria, the first single-celled life forms, goes back 3.5 billion years (**Figure** above).

Eventually life began to diversify from these extremely simple cells. The last life form that was the ancestor to all life that came afterward is called **LUCA** , which stands for the **Last Universal Common Ancestor** . LUCA was a prokaryote but differed from the first living cells because its genetic code was based on DNA. LUCA lived 3.5 to 3.8 billion years ago. The oldest fossils are tiny microbe-like objects that are 3.5 billion years old.

Photosynthesis and the Changing Atmosphere

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.

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** below).

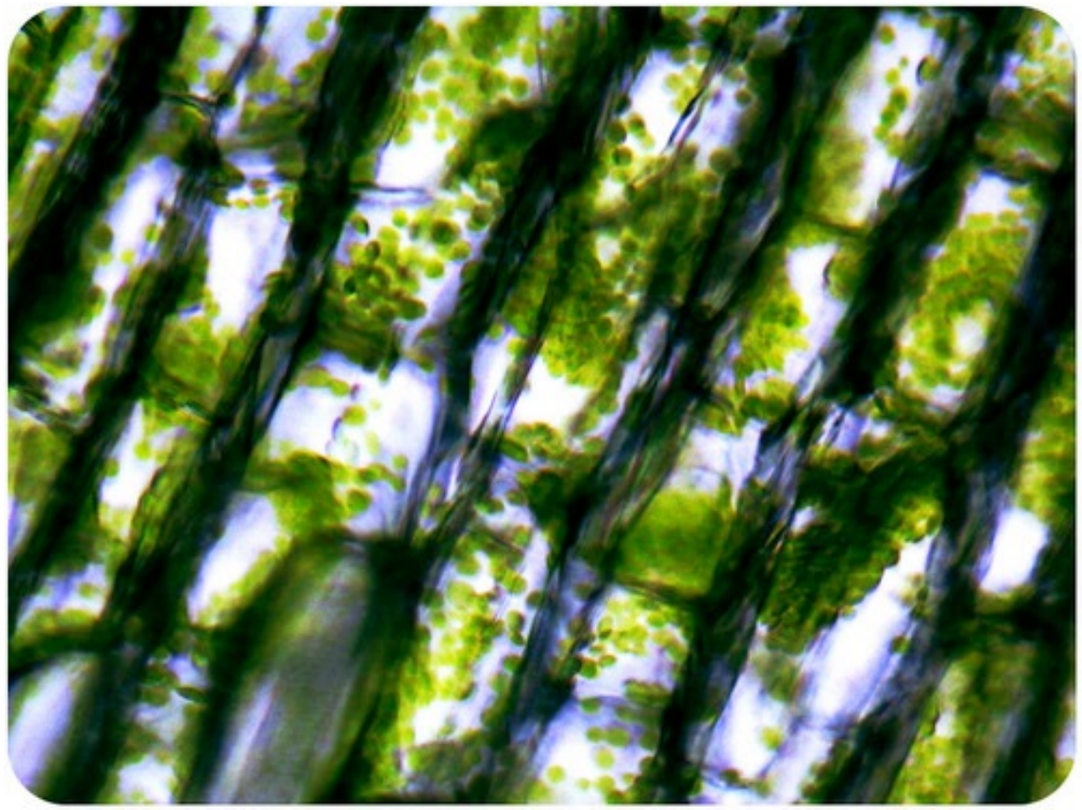


Figure 21.17

Chloroplasts are visible in these cells found within the leaf of a water plant.

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.

Earth's Third Atmosphere

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 many 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.

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. 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** below). 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 21.18

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.

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. Click for more information.

Early Organisms

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** (**Figure** below). Cyanobacteria were present by 2.8 billion years ago, and some may have been around as far back as 3.5 billion years.



Figure 21.19

Thermophilic (heat-loving) bacteria in Yellowstone National park.

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** below). Even now cyanobacteria account for 20% to 30% of photosynthesis on Earth.



Figure 21.20

A large bloom of cyanobacteria is harmful to this lake.

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** below). Stromatolites continued on into the Cambrian but their numbers declined.



Figure 21.21

These rocks in Glacier National Park, Montana may contain some of the oldest fossil microbes on Earth.

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 multi-celled 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 other. 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 multi-celled organisms were probably prokaryotic cyanobacteria. Multicellularity may have evolved more than once in life 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. Multicellular organism will be discussed in the lesson, History of Earth's Complex Life Forms.

Lesson Summary

•After partial melting of the original basaltic crust began, silca-rich rock formed the early continental crust.
•The oldest felsic continental crust is found in cratons. A craton found at the surface is a shield; a sediment covered craton is a platform.
•Precambrian rocks help scientists piece together the geology of that time.
•The continents formed as cratons collided with microcontinents and island arcs to form large continents.
•Rodinia was a supercontinent composed of Laurentia and other continents.

•Snowball Earth may have occurred during the late Precambrian and its end may have led to the explosion of life forms that developed during the Ediacaran and Cambrian.
•Amino acids were essential for the origin of life. They link together to form proteins.
•RNA may have been the first and only nucleic acid at the beginning of life.
•A cell needs a way to replicate itself, a metabolism, and a way to separate itself from its environment.
•An atmosphere that contains oxygen is important because of the ozone layer and cellular respiration.
•Multicellular organisms evolved long after prokaryotes evolved and they may have evolved more than once.

Review Questions

1. What is the difference between a craton, shield, and platform?

2. If a rock contains rounded grains of sediments, what can you tell about that rock?

3. What does a greenstone indicate about the plate tectonic environment in which it formed?

4. What happened to all of the heat Earth had when it formed?

5. What was Laurentia and what lands was it composed of? What happened to it?

6. How was Rodinia like Pangaea?

7. What were the possible sources of amino acids on the ancient Earth?

8. What was the significance of the Miller-Urey experiment?

9. What is the RNA world hypothesis and why is it called that?

10. What is the difference between prokaryotes and eukaryotes?

11. What was LUCA? Is LUCA still alive?

12. Why are banded-iron formations important?

13. Why were cyanobacteria important in the early Earth?

14. How are eukaryotes thought to have originated?

Further Reading / Supplemental Links

Read about the oldest material yet found in the Solar System: http://news.nationalgeographic.com/news/2010/08/100823-oldest-solar-system-two-million-years-older-science/ .

Points to Consider

•What would life be like on Earth if there were no free oxygen?
•Why did it take so long for eukaryotes or multicellular organisms to evolve?
•How did the evolution of life affect the non-biological parts of the planet?

Phanerozoic Earth History

Lesson Objectives

- The Phanerozoic is divided into the Paleozoic, Mesozoic, and Cenozoic.
- Marine transgressions and regressions were common during the Paleozoic and Mesozoic.

Vocabulary

- facies
- marine regression
- marine transgression
- orogeny

Introduction

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.

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. The paleogeography of the Paleozoic begins and ends with a supercontinent.

Marine Transgressions and Regressions

Some of the most important events of the Paleozoic 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 (**Figure** below).

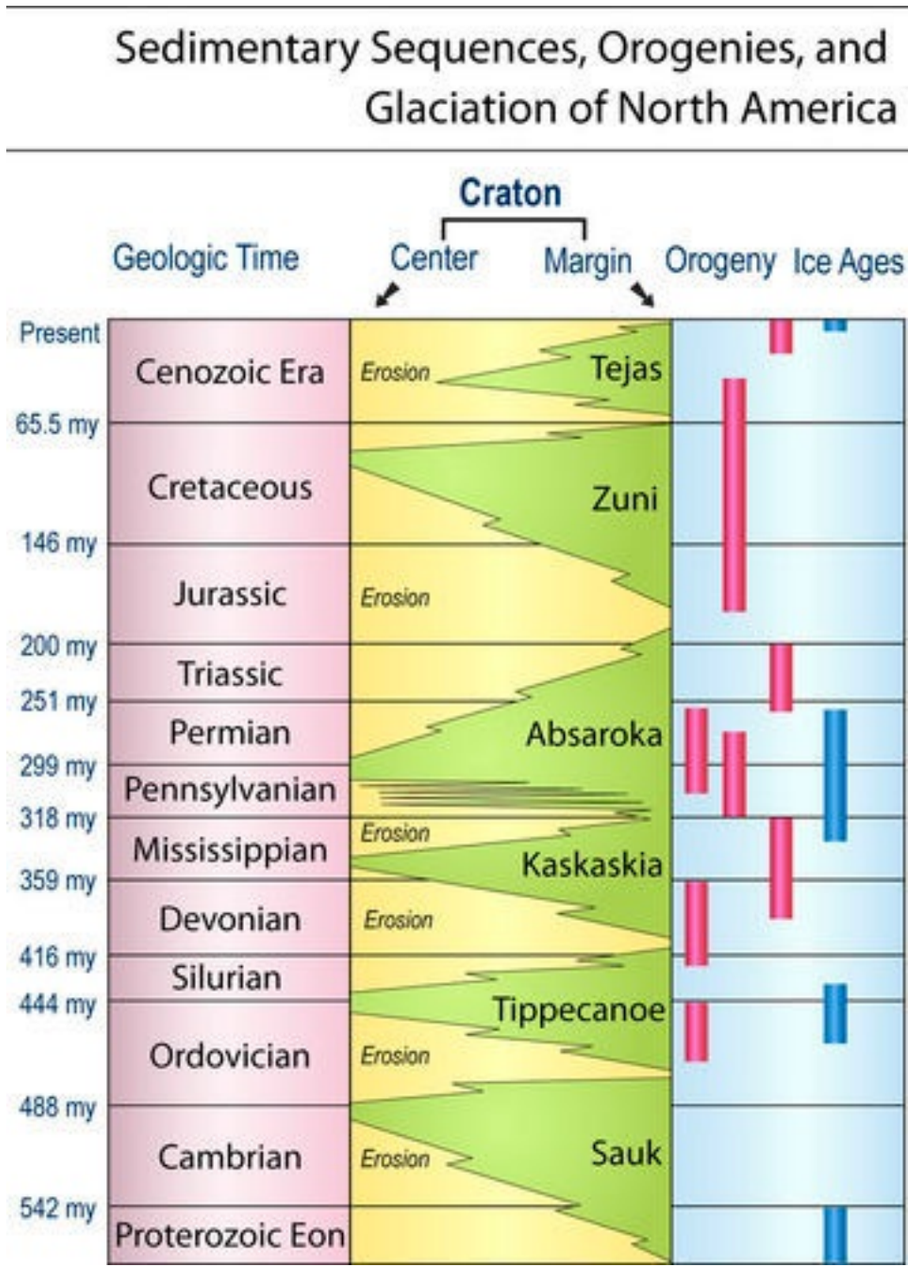


Figure 21.22

Six marine transgressions and regressions have occurred during the Phanerozoic.

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.

The Paleozoic sedimentary rocks of the Grand Canyon 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.

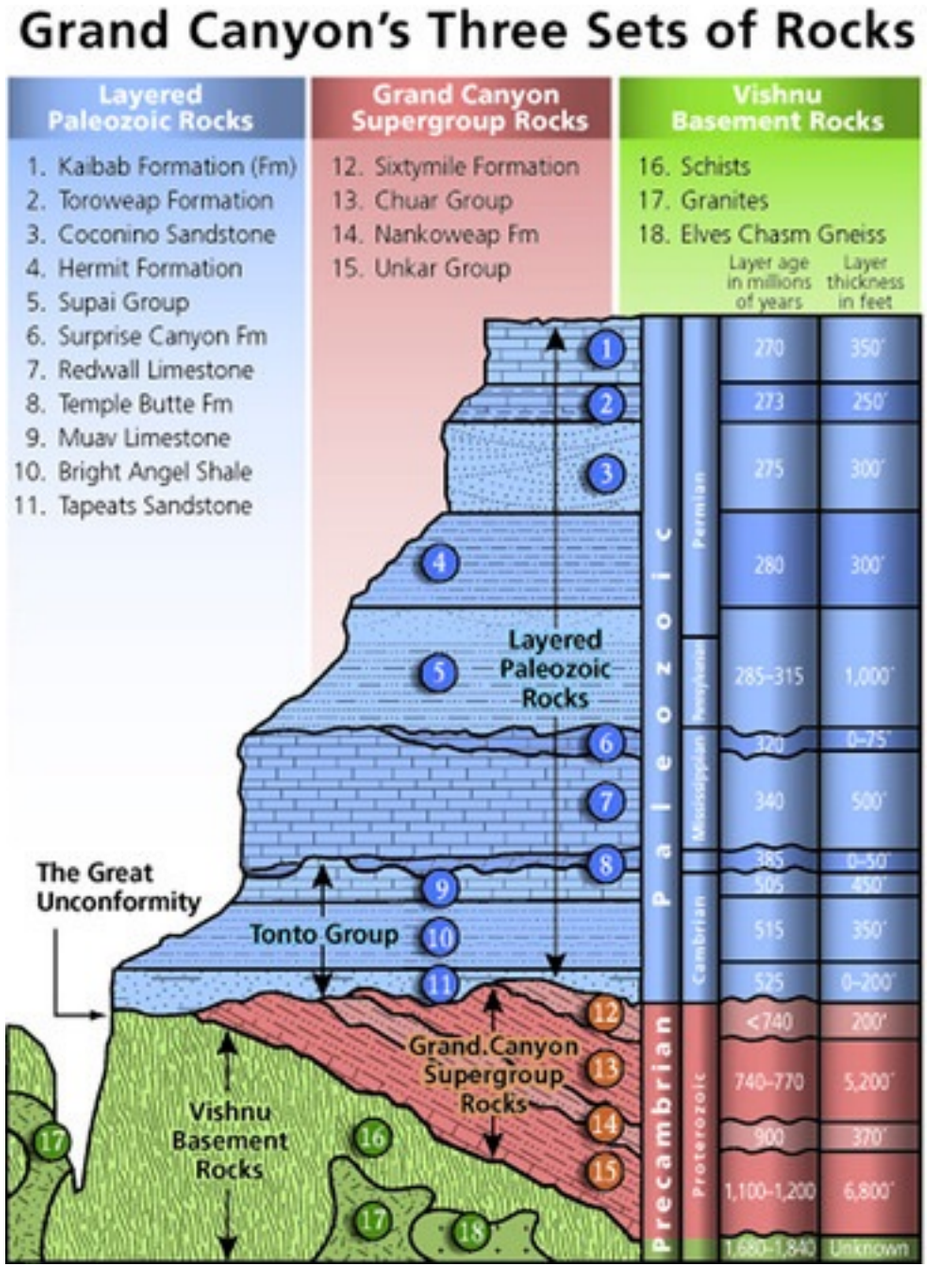


Figure 21.23

The Paleozoic sedimentary rocks of the Grand Canyon were deposited during marine transgressions and regressions.

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.

Plate Tectonics

A mountain-building event is called an **orogeny** . Orogenies take place over tens or hundreds of millions of years. At the beginning of the Paleozoic, the supercontinent Rodinia began to split up. At the end, Pangaea came together. As continents smash into microcontinents and island arcs collided, mountains rise.

Geologists find evidence for these collisions in many locations. For example, Laurentia collided with the Taconic Island Arc during the Taconic Orogeny (**Figure** below). The remnants of this mountain range make up the Taconic Mountains in New York.

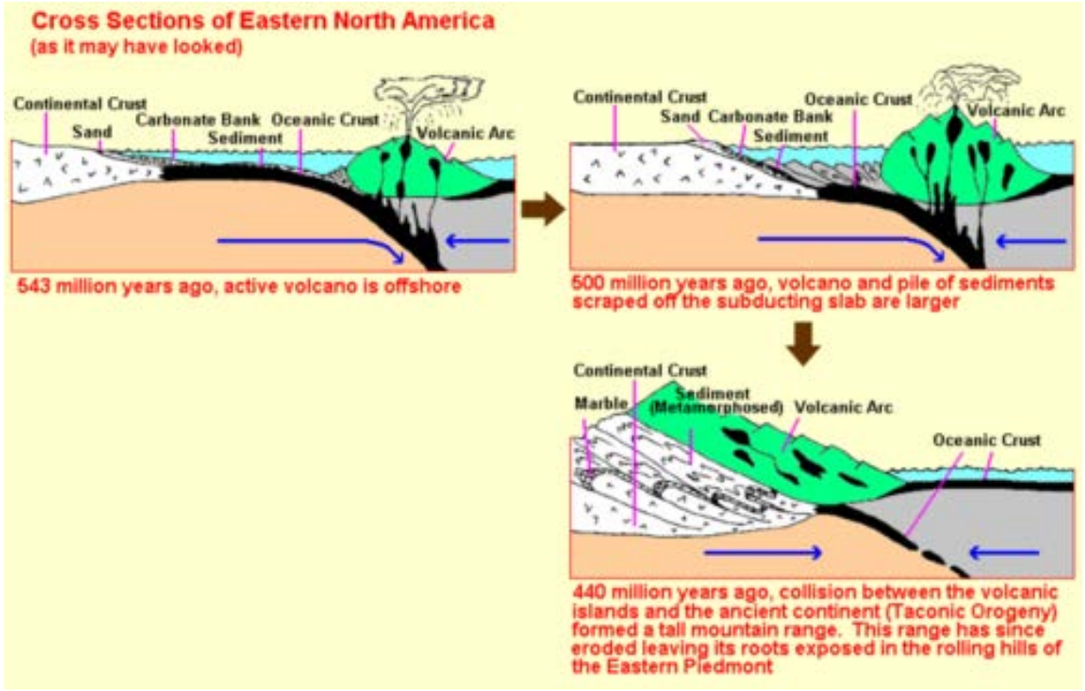


Figure 21.24

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 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 the Plate Tectonics chapter.

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** below).



Figure 21.25

Pangea was the sole landform 250 million years ago, leaving a huge ocean called Panthalassa, along with a few smaller seas.

Mesozoic

The Mesozoic is known as the age of the dinosaurs, but things were happening geologically as well. The Mesozoic was dominantly warm and tropical.

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.

Why would a supercontinent break up after being together for tens of millions of years? A continent is a giant insulating blanket that does not allow mantle heat to escape very effectively. 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.



Figure 21.26

In the Afar Region of Ethiopia, Africa is splitting apart. Three plates are pulling away from a central point.

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** above).

Plate Tectonics

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.

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** below).

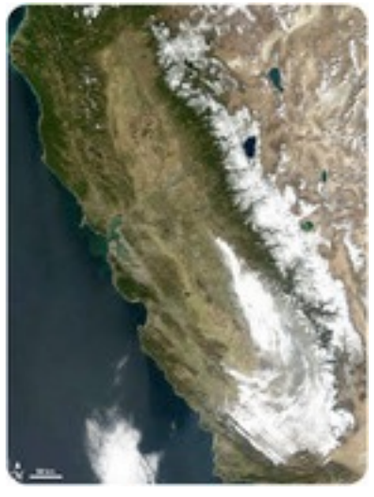


Figure 21.27

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.

A marine transgression during the Cretaceous covered much of the North American continent with water (**Figure** below).



Figure 21.28

Lands that had been uplifted during tectonic activity remained above water during this marine transgression that took place during the Cretaceous.

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 in the first chapters of this book describes the geological situation of the Cenozoic.

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.

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** below).

Figure 21.29

This figure shows the evolution of the San Andreas Fault zone from 30 million years ago (bottom) to present (top). 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.

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** below). During the retreats, the climate was often warmer than it is today.



Figure 21.30

Glacial ice at its maximum during the Pleistocene.

These continental ice sheets were extremely thick, like the Antarctic ice cap is today.

Lesson Summary

- The Phanerozoic began 570 million years ago and continues today.

•The Paleozoic was a time of four marine transgressions and regressions, which left characteristic sedimentary facies.
•An orogeny is a mountain building event that takes place when a continent runs into another continent, a microcontinent, or a volcanic island arc.
•The general climate trend in the Cenozoic was cooling, leading to the Pleistocene ice ages from 2.6 million to about 10,000 years ago.

Review Questions

1. What are the possible causes of a marine transgression? Of a marine regression?

2. What rock sequence indicates a marine transgression? What rock sequence indicates a marine regression?

3. How do the rocks of the Grand Canyon indicate marine transgressions or regressions?

4. What was the configuration of oceans during the time of the supercontinent Pangaea?

5. What geologic evidence is left after a continent breaks apart?

6. What was the Pleistocene climate like?

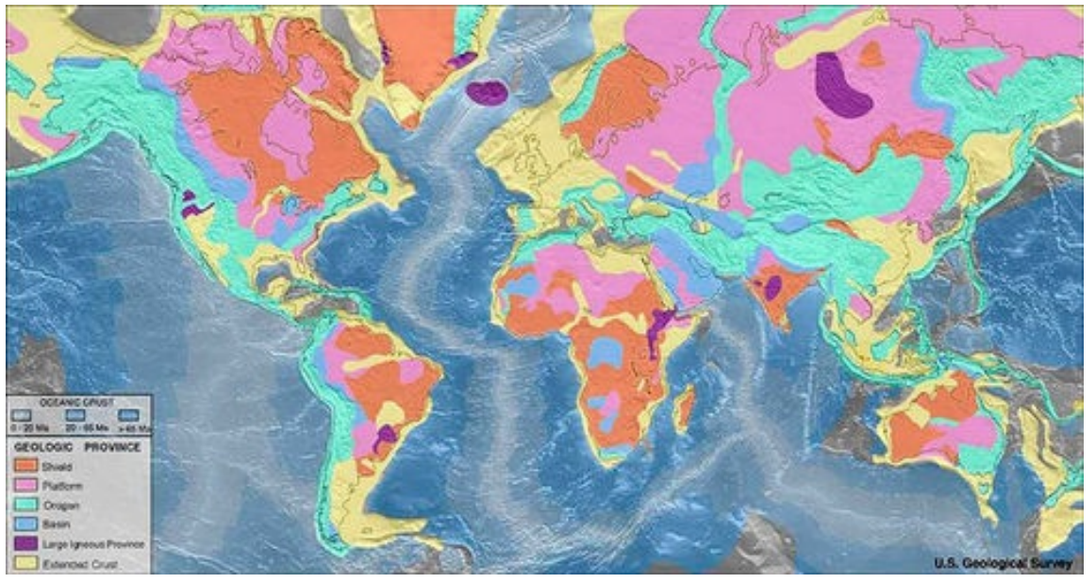


Figure 21.31

Describe the geologic history of North America.

7. Using the map (**Figure** above), describe the geologic history of North America. In what order did events occur? What is the cause of the orogenies lining the western and eastern continental margins?

8. Look at Africa. Why is there no orogenic province on the western or eastern margins of the continent? What is the cause of the purple province in the northeast?

9. Where are the mountains of South America located? What is the reason for those mountains?

Points to Consider

•How did the paleogeography of the planet affect the evolution of life?
•How did climate affect the evolution of life?

•How was human evolution related to major climatic events?

History of Earth's Complex Life Forms

Lesson Objectives

- Describe how adaptations develop.
- Explain how the fossil record shows us that species evolve over time.
- Describe the general development of Earth's life forms over the last 540 million years.

Vocabulary

- adaptation
- adaptive radiation
- amniote egg
- evolution
- mutation
- natural selection
- paleontologist
- tropical
- variation

Introduction

Organisms must adapt to their environment or they will die out. Most of the fossils are the remains of animals that are now extinct. The mechanism for change in a population of organisms is natural selection.

Adaptation and Evolution

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** below). 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.

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** .

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.

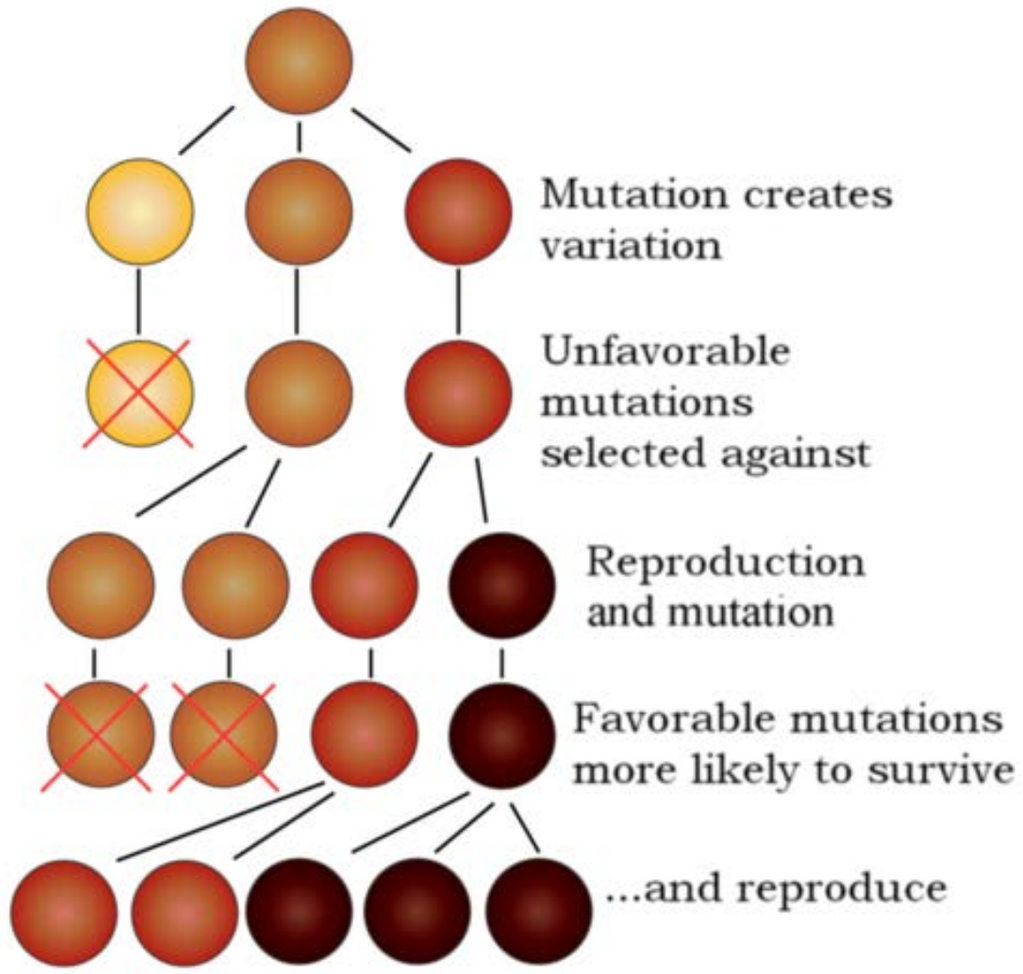


Figure 21.32

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/ .

This animation begins with the Big Bang, which will be discussed in the chapter about the solar system, and goes through the history of life on Earth: http://www.johnkyrk.com/evolution.html .

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 Ma). The Ediacara Fauna 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** below). The organisms seem to have appeared as Earth defrosted from its worldwide glaciation.



Figure 21.33

An example of an Ediacara organism.

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.

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.

Scientists also do not know why the Ediacaran biota died out. 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 such as rising sea level, limited nutrients, or changing atmospheric and oceanic chemistry.

The existence of the Ediacaran biota does show that a diversity of life forms existed before the Cambrian.

Phanerozoic Eon

The **Phanerozoic Eon** is divided into three eras—the Paleozoic, the Mesozoic, and the Cenozoic--spanning from about 540 million years ago to the present (**Table** below). Life has undergone fantastic changes during the long span of the Phanerozoic Eon.

Notice that different types of organisms developed at different times.

Table

Click on the image above to view the table

Extinction and Radiation

The eras of the Phanerozoic Eon are separated by mass extinctions. A mass extinction occurs when large numbers of species become extinct in a short amount of time. 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** below).



Figure 21.34

An extinct Tyrannosaurus rex. This fossil resembling a living organism.

After a mass extinction, many habitats are no longer inhabited by organisms because they have gone extinct. A change in the environment from one in which organisms live in all the available habitats to one in which many habitats are available gives an advantage to organisms that can adapt to new environments. Evolutionary processes act rapidly during 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** .

Paleozoic Life

The Cambrian began with a tremendous diversification of life forms. Shallow seas covered the lands so every major marine organism group 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. One organism had a soft body like a worm, five eyes, and a long nose like a vacuum cleaner hose (**Figure** below). 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.



Figure 21.35

This bizarre animal with five eyes lived during the Cambrian, which began about 540 million years ago.

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. Large extinction events separate the periods of the Paleozoic. After extinctions, new life forms evolved (**Figure** below). 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.



Figure 21.36

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** below). 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 21.37

A modern rainforest has many seed-bearing plants that are similar to those that were common during the Carboniferous.

The largest mass extinction in Earth 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 vertebrates (land organisms) also went extinct. This was also 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.

Mesozoic Life

At the beginning of the Mesozoic, Pangaea began to break apart so more beaches and continental shelf areas were available for colonization. Climate during the entire era was warm and **tropical** . With many niches available after the mass extinction, a great diversity of organisms evolved.

Tiny marine plants called phytoplankton arose to become the base of the marine food web. On land, seed plants and trees diversified. Ferns were common at the time of the dinosaurs (**Figure** below). The earliest known fossil of a flowering plant is from the Cretaceous, 125 million years old.



Figure 21.38

Fern fossil.

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 amniotic 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.

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. Although nearly all species of dinosaurs went extinct, modern birds evolved from theropod dinosaurs (**Figure** below).



Figure 21.39

Archeopteryx, the earliest known bird, lived during the late Jurassic.

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** below).



Figure 21.40

An artist's painting of the impact that caused the Cretaceous extinctions.

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.

Asteroid impacts have profoundly affected earth history from the very beginning, by bringing in water and amino acids for the oceans, atmosphere, and life, and by forming the Moon. Mass extinctions that have occurred throughout Earth history may also have been caused by asteroid impacts. The best known is the impact that brought about the extinction of the dinosaurs **(1f)** :

http://www.youtube.com/watch?v=z2CnH_0V5_I (2:01), http://www.youtube.com/watch?v=uEFYkOh3YYA (1:23).



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Cenozoic Life

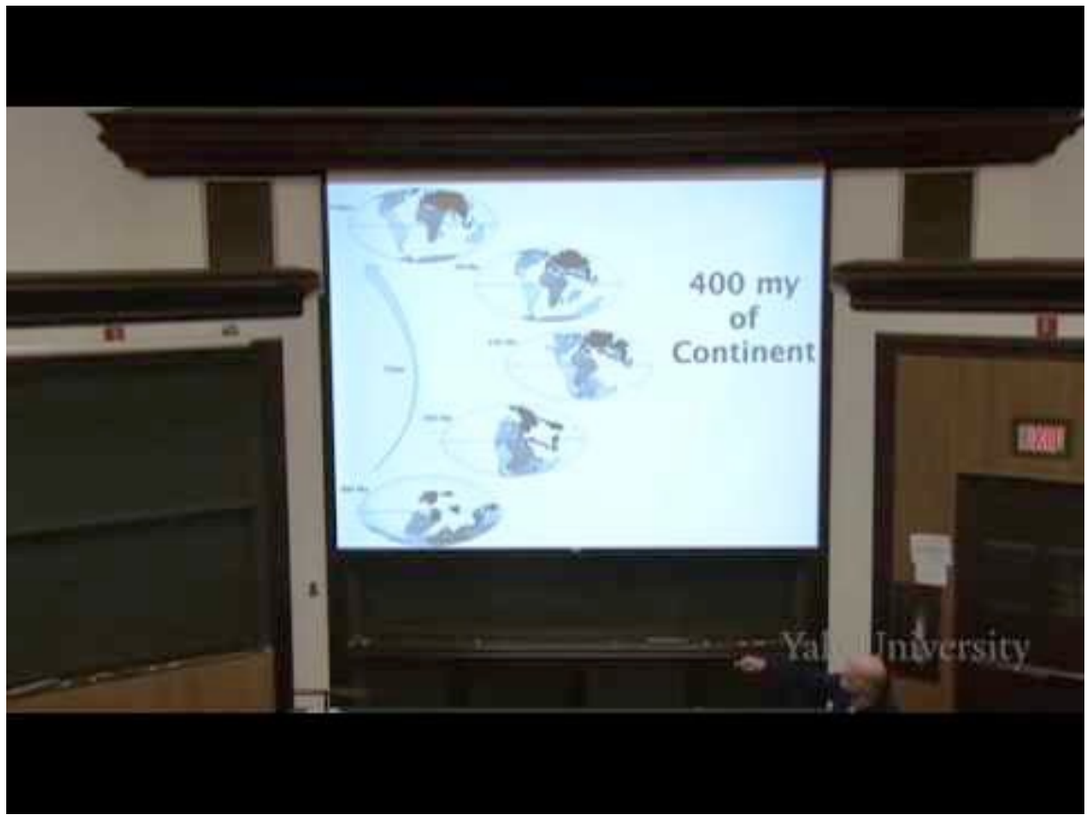
The extinction of so many species again left many niches available to be filled. Although we call the Cenozoic the age of mammals, birds are more common and more diverse.

The adaptations allow mammals to spread to even more environments than reptiles because 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.

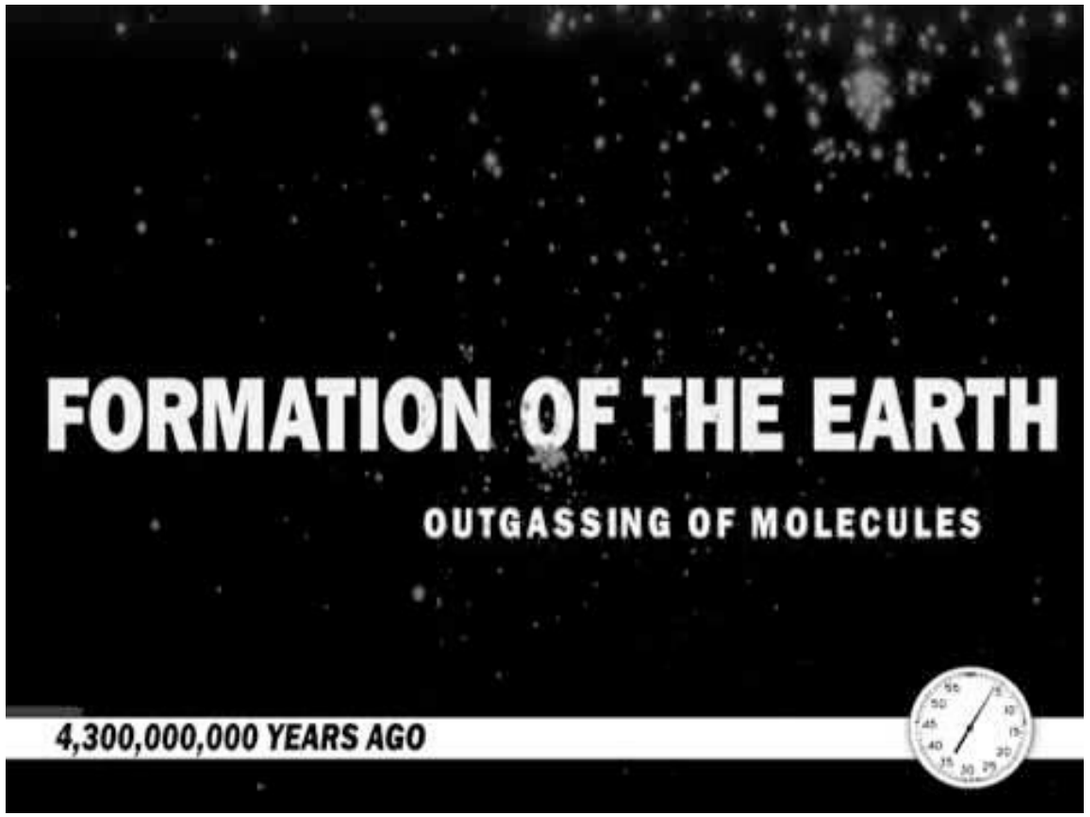
As climate cooled during the ice ages, large mammals were able to stand the cold weather and so many interesting megafauna developed (**Figure** below).

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 (47:10).



Click on the image above 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 (1:03).



Click on the image above for more content



Figure 21.41

The saber-tooth cat lived during the Pleistocene.

Humans also evolved during the later Cenozoic. Bipedal primates first appeared about 6 million years ago when grasslands were common. Standing on two feet allows an organism to see and also to use its hands and arms for hunting (**Figure** below). The brain size of this bipedal primate grew rapidly.



Figure 21.42

Australopithecus afarensis is a human ancestor that lived about 3 million years ago.

The genus Homo appeared about 2 million years ago. Humans developed tools and cultures (**Figure** below). Homo sapiens, our species, originated about 200,000 years ago in Africa.



Figure 21.43

Evidence of a spiritual life appears about 32,000 years ago with stone figurines that probably have religious significance.

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.

Modern Biodiversity

There are more than 1 million species of plants and animals known to be currently alive on Earth (**Figure** below) and many millions more that have not been discovered yet. The tremendous variety of creatures is due to the tremendous numbers of environments (**Figure** below).



Figure 21.44

There is an amazing diversity of organisms on Earth. How do the organisms in this picture each make their living?



Figure 21.45

Polar bears have thick fur coats to stay warm as they hunt in icy waters.

Many adaptations protect organisms from the external environment (**Figure** below).



Figure 21.46

Cacti have thick, water- retaining bodies that help them conserve water.

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.

Lesson Summary

•Adaptations are favorable traits that organisms inherit. Adaptations develop from variations within a population and help organisms to survive in their given environment.
•Changes in populations accumulate over time; this is called evolution.
•The fossil record shows us that present day life forms evolved from earlier life forms.
•Beginning about 540 million years ago more complex organisms developed on Earth. During the Phanerozoic Eon all of the plant and animal types we know today evolved.
•Many types of organisms that once lived are now extinct. Earth's overall environment, especially the climate, has changed many times, and organisms change over time, too.

Review Questions

1. Describe how an adaptation comes about.

2. What is evolution? How is natural selection the mechanism for evolution?

3. How might a hard external skeleton, called an exoskeleton, be a favorable adaptation for the soft bodied organisms that had lived before?

4. Explain why unfavorable traits usually do not get passed to offspring.

5. Why did it take 4 billion years of Earth history for multicellular organisms to evolve and diversify to the point of the Ediacara biota?

6. List the order in which the major types of animals appeared on Earth.

7. How might climate have affected the ability of plants to grow over large areas during a given time?

8. One cause of mass extinctions is a meteorite or comet impact. What might be some additional causes of mass extinctions?

9. What happens immediately after a mass extinction to the diversity of organisms? What happens thousands or millions of years later?

10. Describe the big advance reptiles had over amphibians.

11. Why are there so many different species on Earth today?

Points to Consider

- How did life on Earth change from one period of geologic time to the next?
- How did climate affect the evolution of life?
- Evolution is well documented in the fossil record. Why is it so controversial?

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Ch. 19: Earth's Atmosphere



Courtesy of NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=7373. Public Domain.

Astronauts took this photo of the Moon barely visible above Earth’s atmosphere. Earth’s blue halo appears because the atmosphere scatters blue light more than other wavelengths. At the top of the atmosphere, gases become so thin that they just cease to exist and then there is nothing but empty space. Since there is no easy way to define the top of the atmosphere, scientists say that it is 100 km above Earth’s surface. At that location, solar energy enters the Earth system mostly as visible light. Energy as reflected light and heat leave the Earth system there. If average global temperature remains the same, the incoming and outgoing energy are equal. If more energy is coming in than going out, global temperatures increase. If more energy is going out than coming in, global temperatures decrease. Increases or decreases in greenhouse gases can change this energy balance. Clouds appear in Earth’s atmosphere where there is water vapor. Clouds, along with snow and ice, reflect sunlight and play an important role in global climate. Where clouds reflect light back into space, they reduce the energy in the atmosphere. But water vapor is a greenhouse gas, so clouds can also trap heat. Scientists are interested in the effects of clouds on Earth’s heat balance.

Section 1

The Atmosphere

The Atmosphere

Lesson Objectives

- Describe the importance of the atmosphere to our planet and its life.
- Outline the role of the atmosphere in the water cycle.
- List the major components of the atmosphere and know their functions.
- Describe how atmospheric pressure changes with altitude.

Vocabulary

- air pressure
- altitude
- atmosphere
- greenhouse gas
- humidity
- ozone
- respiration
- ultraviolet (UV) radiation
- water vapor
- weather

Introduction

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. All living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock.

Significance of the Atmosphere

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. Let's consider some of the reasons we are lucky to have an atmosphere.

Atmospheric Gases Are 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?

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:

$$6CO_2 + 6H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6\,(\text{sugar}) + 6O_2$$

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:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + 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** below).

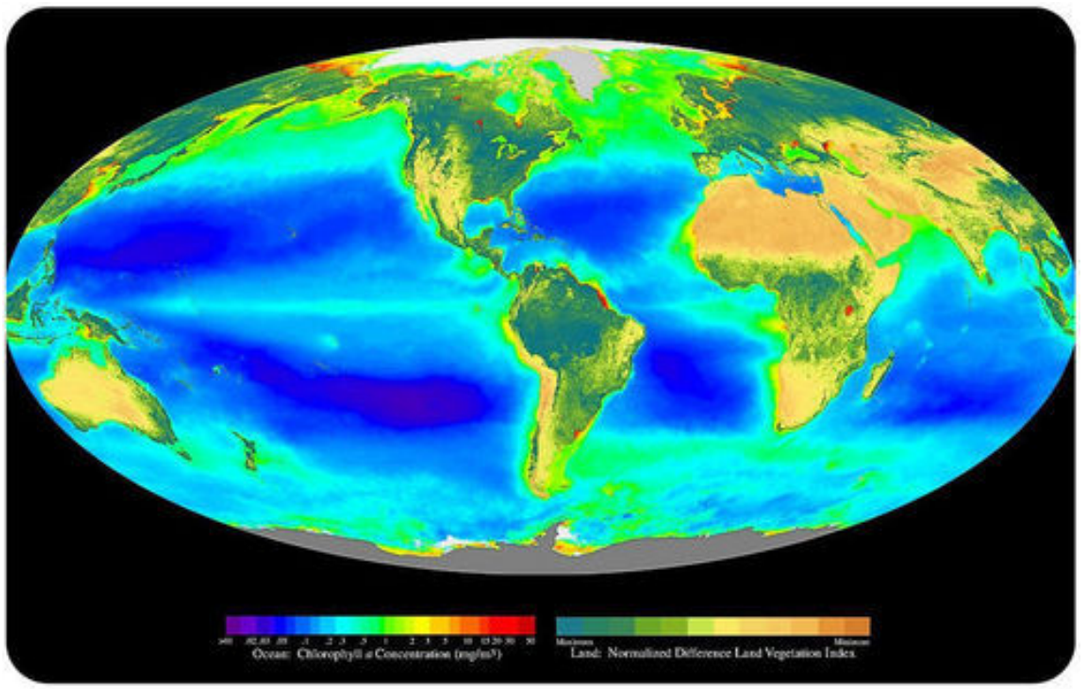


Figure 22.1

Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

The Atmosphere is a Crucial Part of the Water Cycle

As part of the hydrologic cycle, which was detailed in the Earth's Fresh Water chapter, water spends a lot of time in the atmosphere, mostly as water vapor.

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, and may include temperature, wind, and precipitation. Weather is the change we experience from day to day. Climate is the long-term average of weather in a particular spot. Although the weather for a particular winter day in Tucson, Arizona, may include snow, the climate of Tucson is generally warm and dry.

Ozone in the Upper Atmosphere 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 Atmosphere Keeps Earth's Temperature Moderate

Along with the oceans, the **atmosphere** keeps Earth's temperatures within an acceptable range. **Greenhouse gases** trap heat in the atmosphere so they help to moderate global temperatures (**Figure** below). Without an atmosphere with greenhouse gases, Earth's temperatures would be frigid at night and scorching during the day. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

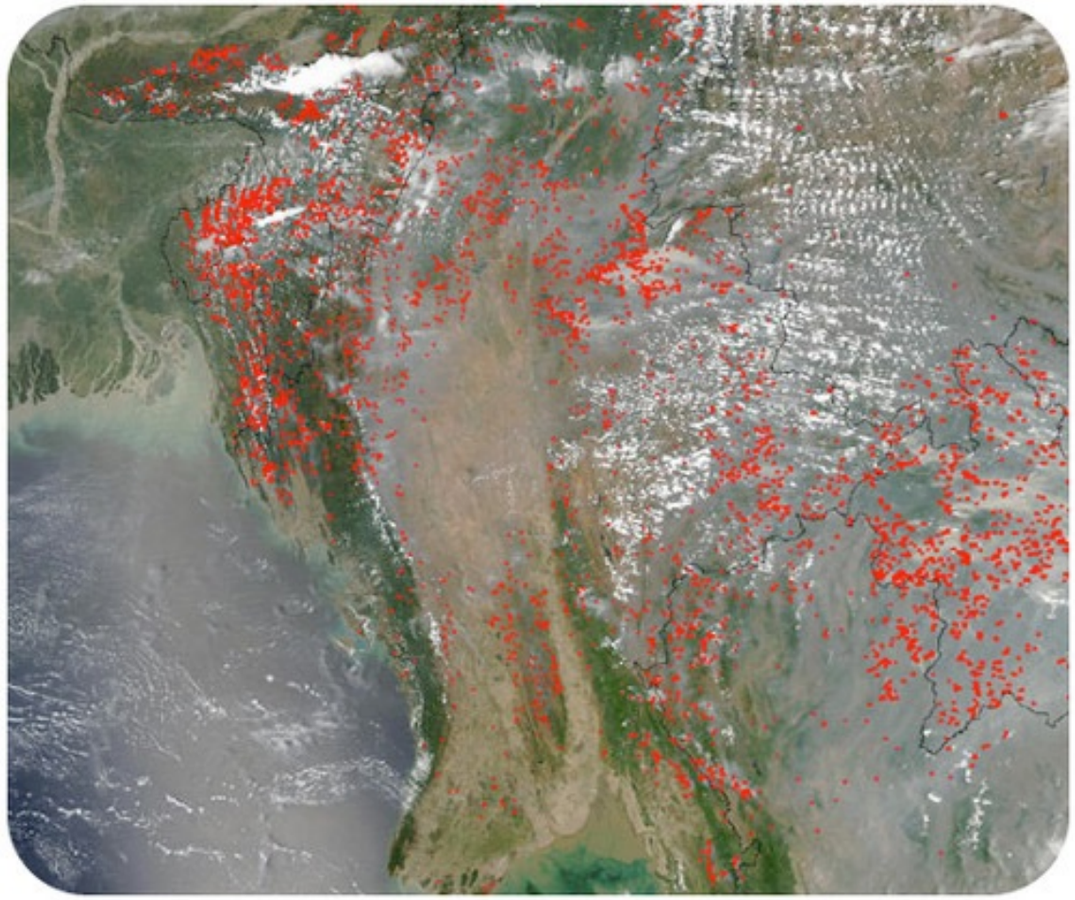


Figure 22.2

Fires, such as these set to burn forests across southeast Asia, contribute greenhouse gases to the atmosphere.

Atmospheric Gases Provide 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. Of course, no insect, bird, or airplane would be able to fly because there would be no atmosphere to hold it up. Explosions in movies about space should be silent.

Composition of Air

Nitrogen and oxygen together make up 99% of the planet's atmosphere. The rest of the gases are minor components but sometimes are very important (**Figure** below).

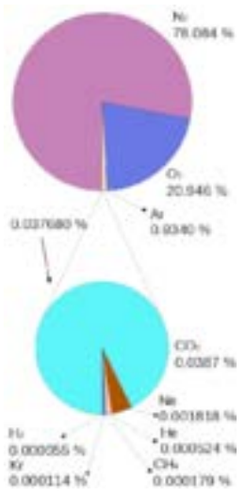


Figure 22.3

Nitrogen and oxygen make up 99% of the atmosphere; carbon dioxide is a very important minor component.

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.

Where around the globe is mean atmospheric water vapor higher and where is it lower and why (**Figure** below)? 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.

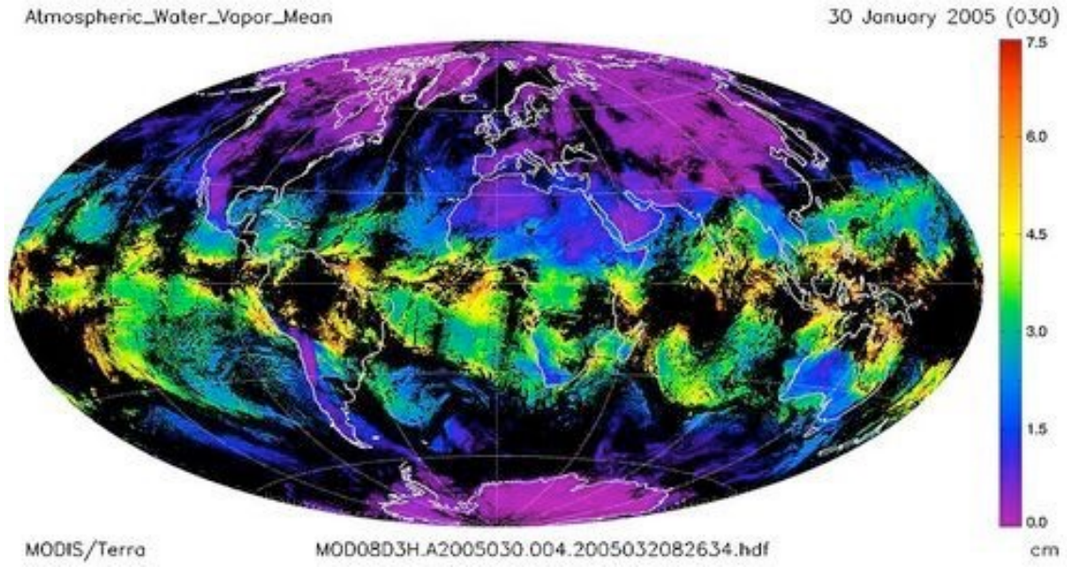


Figure 22.4

Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

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. Particles provide starting points (or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants, which are discussed in the Human Actions and the Atmosphere chapter.

Pressure and Density

The atmosphere has different properties at different elevations above sea level, or **altitudes** . 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 (**Figure** below).

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.

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 22.5

This bottle was closed at an altitude of 3,000 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 higher altitudes. If your ears have ever "popped", you have experienced a change in air pressure. 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.

Although the density of the atmosphere changes with altitude, the composition stays the same with altitude, with one exception. In the ozone layer, 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

Lesson Summary

•Without its atmosphere, Earth would be a very different planet. Gases in the atmosphere allow plants to photosynthesize and animals and plants to engage in respiration.
•Water vapor, which is an atmospheric gas, is an essential part of the water cycle.
•Although the amount of gases do not vary relative to each other in the atmosphere, there is one exception: the ozone layer. Ozone in the upper atmosphere protects life from the Sun's high energy ultraviolet radiation.
•Air pressure varies with altitude and temperature.

Review Questions

1. What gas is used and what gas is created during photosynthesis? What gas is used and what gas is created during respiration?

2. Describe two reasons why photosynthesis is important.

3. On an unusual February day in Portland, Oregon, the temperature is 18°C (65°F) and it is dry and sunny. The winter climate in Portland is usually chilly and rainy. How could you explain a warm, dry day in Portland in winter?

4. What important role do greenhouse gases play in the atmosphere?

5. Why do your ears pop when you are in an airplane and the plane descends for a landing?

Points to Consider

•How would Earth be different if it did not have an atmosphere?
•What are the most important components of the atmosphere?
•How does the atmosphere vary with altitude?

Section 2

Atmospheric Layers

Atmospheric Layers

Lesson Objectives

•List the major layers of the atmosphere and their temperatures.
•Discuss why all weather takes place in the troposphere.
•Discuss how the ozone layer protects the surface from harmful radiation.

Vocabulary

•aurora
•exosphere
•inversion
•ionosphere
•magnetosphere
•mesosphere
•ozone layer
•solar wind
•stratosphere
•temperature gradient
•thermosphere
•troposphere

Introduction

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. While weather takes place in the lower atmosphere, interesting things, such as the beautiful aurora, happen higher in the atmosphere.

Air Temperature



Figure 22.6

Papers held up by rising air currents above a radiator demonstrate the important principle that warm air rises.

Why does warm air rise (**Figure** above)? 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 the Plate Tectonics chapter.

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** .

The atmosphere is divided into layers based on how the temperature in that layer changes with altitude, the layer's temperature gradient (**Figure** below). 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 (**Figure** below).

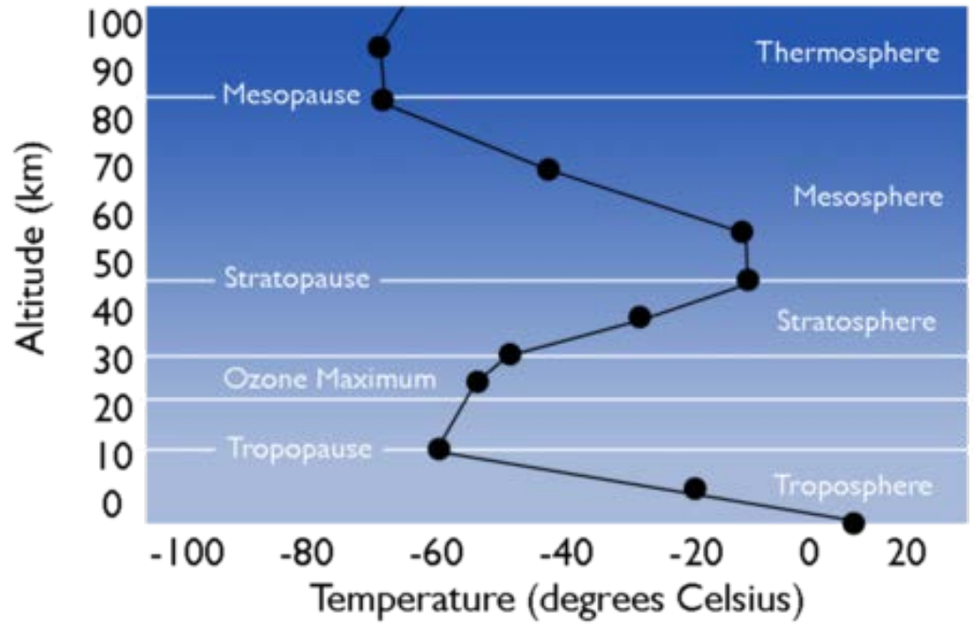


Figure 22.7

The four main layers of the atmosphere have different temperature gradients, creating the thermal structure of the atmosphere.



Figure 22.8

The layers of the atmosphere appear as different colors in this image from the International Space Station.

Most of the important processes of the atmosphere take place in the lowest two layers: the troposphere and the stratosphere.

Troposphere

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°C per 1,000 m (3.6°F per 1,000 ft.) of altitude. What is the source of heat for the troposphere?

Earth's surface is a major source of heat for the troposphere, although nearly all of that heat comes from the Sun. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat. The temperature is also higher near the surface because of the greater density of gases. The higher gravity causes the temperature to rise.

Notice that in the troposphere warmer air is beneath cooler air. What do you think the consequence of this is? This condition is unstable. 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.

Sometimes there is a temperature **inversion** , 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** below).



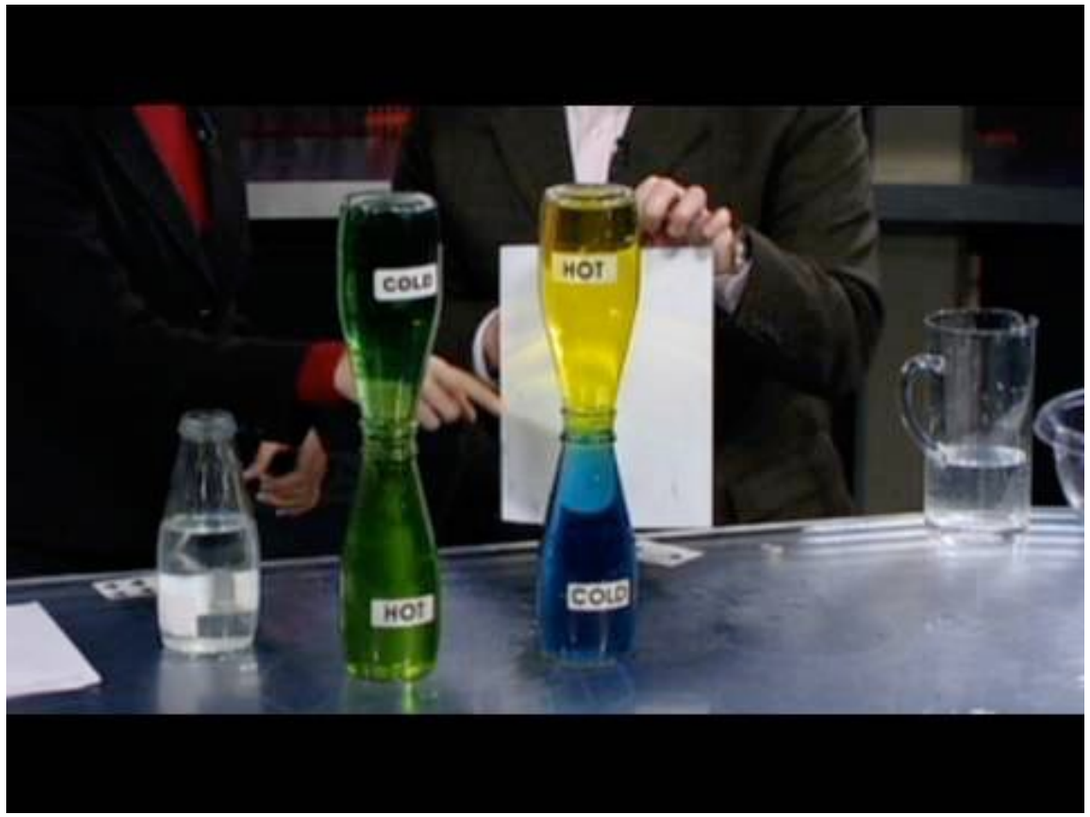
Figure 22.9

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.

A science experiment that clearly shows how a temperature inversion traps air, along with whatever pollutants are in it, near the ground is seen in this video **(5c)** : http://www.youtube.com/watch?v=LPvn9qhVFbM (2:50).



Click on the image above for more content

Stratosphere

Ash and gas from a large volcanic eruption may burst into the **stratosphere** , the layer above the troposphere. Once in the stratosphere, it remains suspended there for many years because there is so little mixing between the two layers. Pilots like to fly in the lower portions of the stratosphere because there is little air turbulence.

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** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The thickness of the ozone layer varies by the season and also by latitude.

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 (**Figure** below).

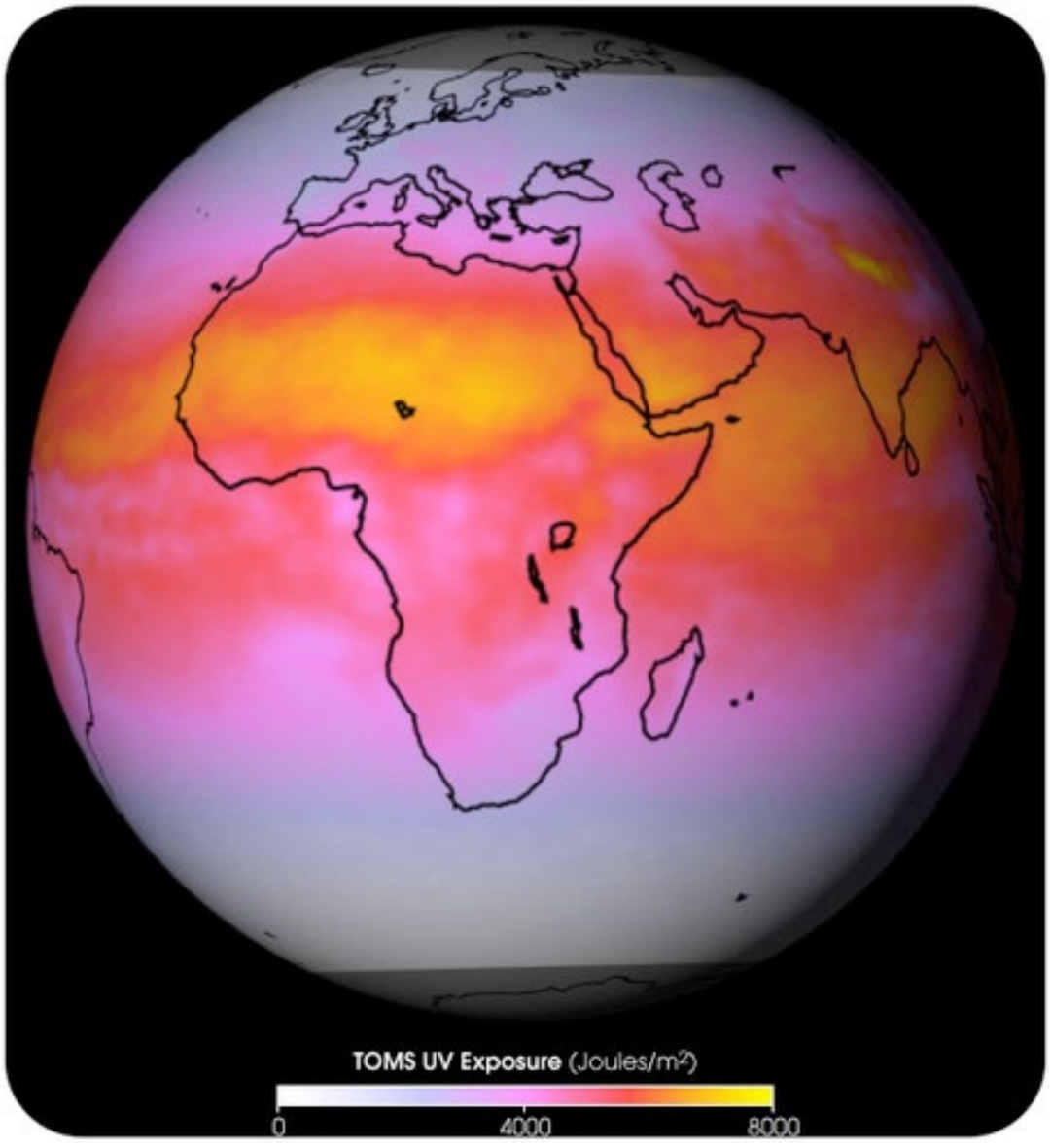


Figure 22.10

Even with the ozone layer, UVB radiation still manages to reach Earth's surface, especially where solar radiation is high.

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°C (-130°F).

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** below). 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. Stranger yet, an unprotected traveler's blood would boil at normal body temperature because the pressure is so low.

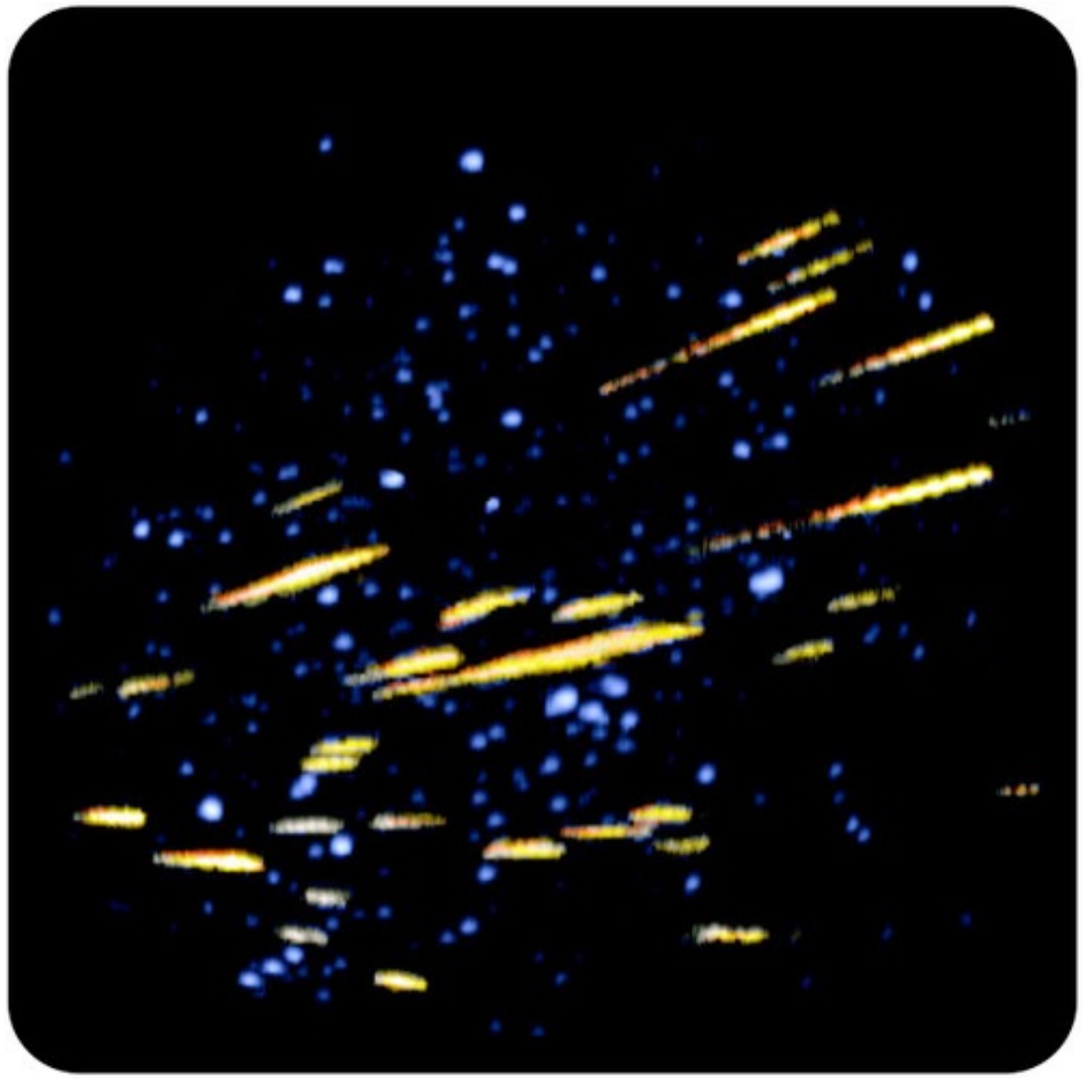


Figure 22.11

Meteors burn in the mesosphere even though the gas is very thin; these burning meteors are shooting stars.

Thermosphere and Beyond



Figure 22.12

The International Space Station (ISS) orbits within the upper part of the thermosphere, at about 320 to 380 km above the Earth.

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 (**Figure** above).

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.

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.

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** below). 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.

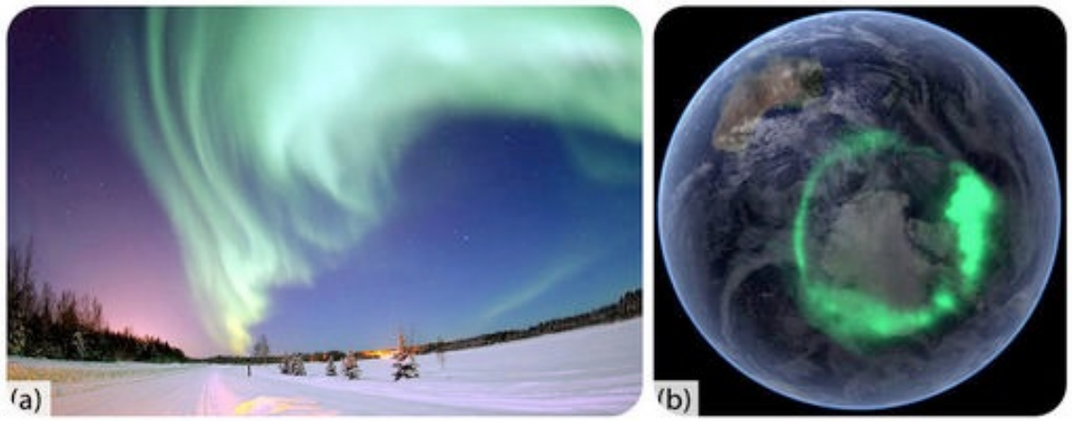
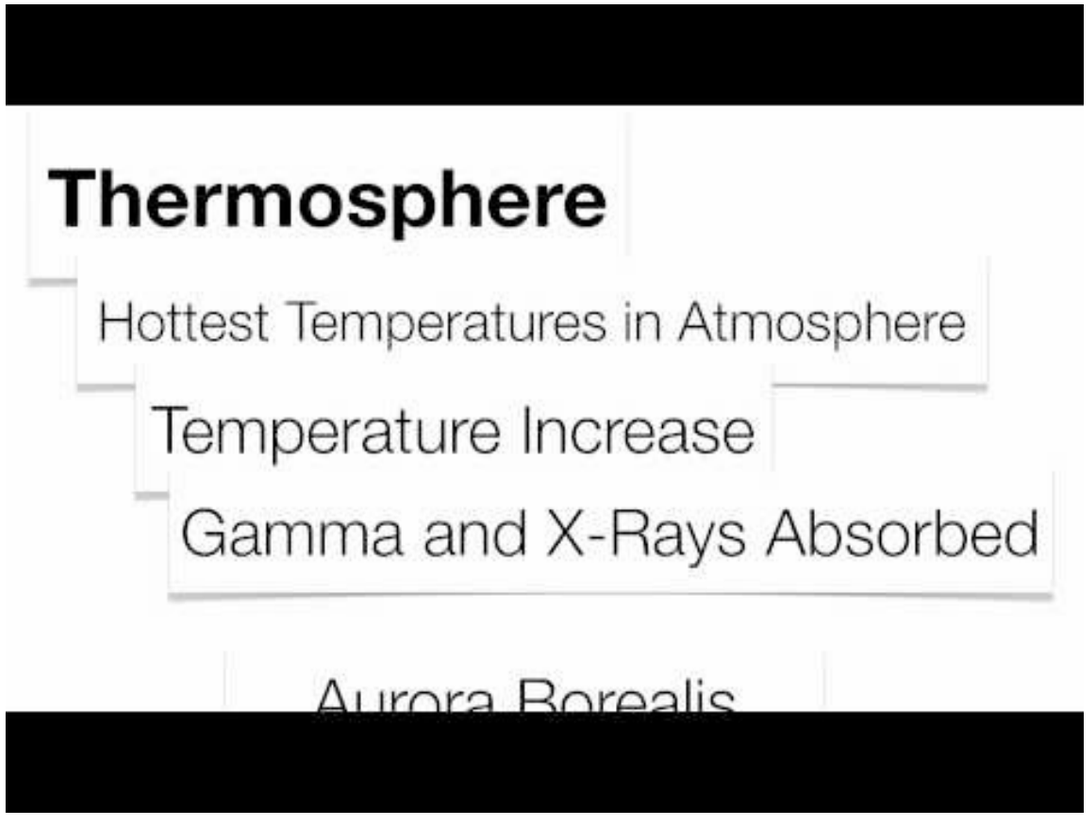


Figure 22.13

(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.

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.

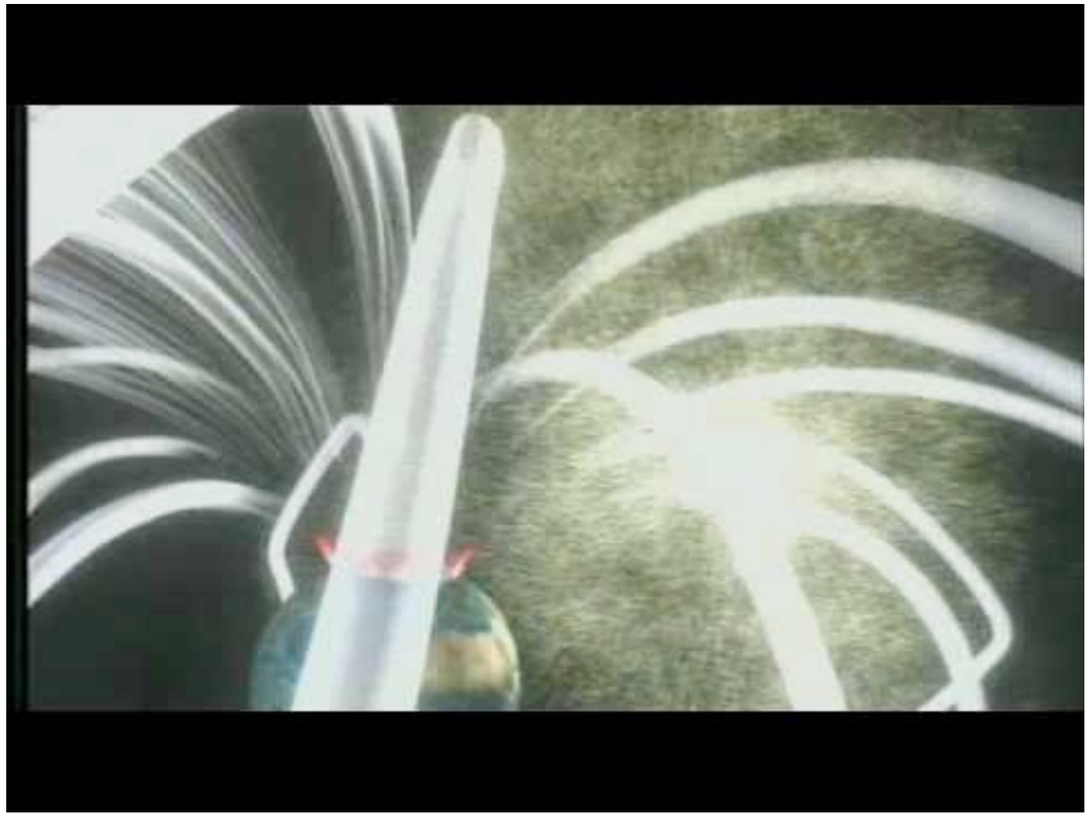
This video is very thorough in its discussion of the layers of the atmosphere. Remember that the chemical composition of each layer is nearly the same except for the ozone layer that is found in the stratosphere **(8a)** : http://www.youtube.com/watch?v=S-YAKZoy1A0 (6:44).



Click on the image above for more content

KQED: Illuminating the Northern Lights

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. Learn more at: http://science.kqed.org/quest/video/illuminating-the-northern-lights/ .



Click on the image above for more content

Lesson Summary

- Features of the atmosphere change with altitude: density decreases, air pressure decreases, temperature changes vary.
- Different temperature gradients create different layers within the atmosphere.
- The lowest layer is the troposphere where most of the atmospheric gases and all of the planet's weather are located. The troposphere is heated from the ground, so temperature decreases with altitude. Because warm air rises and cool air sinks, the troposphere is unstable.
- In the stratosphere, temperature increases with altitude. The stratosphere contains the ozone layer, which protects the planet from the Sun's harmful UV radiation.

Review Questions

1. Give a detailed explanation of why warm air rises.

2. Why doesn't air temperature change uniformly with altitude? Give examples.

3. Describe how the ground acts as the heat source for the troposphere. What is the source of energy and what happens to that energy?

4. How stable is an inversion and why? How does an inversion form?

5. Phoenix, Arizona, is a city in the Southwestern desert. Summers are extremely hot. Winter days are often fairly warm but winter nights can be quite chilly. In December, inversions are quite common. How does an inversion form under these conditions and what are the consequences of an inversion to this sprawling, car-dependent city?

6. Why can't air from the troposphere and the stratosphere mix freely?

7. What is the heat source for the stratosphere? How is that heat absorbed?

8. Describe ozone creation and loss in the ozone layer. Does one occur more than the other?

9. How and where are "shooting stars" created?

10. Why would an unprotected traveler's blood boil in the mesosphere?

Further Reading / Supplemental Links

NASA, The Mystery of the Aurora: http://www.youtube.com/watch?v=PaSFAbATPvk .

Points to Consider

- How does solar energy create the atmosphere's layers?
- How does solar energy create the weather?
- What would happen to life on Earth if there was less ozone in the ozone layer?

Section 3

Energy in the Atmosphere

Energy in the Atmosphere

Lesson Objectives

- Describe how energy is transmitted.
- Describe the Earth's heat budget and what happens to the Sun's energy.
- Discuss the importance of convection in the atmosphere.
- Describe how a planet's heat budget can be balanced.
- Describe the greenhouse effect and why it is so important for life on Earth.

Vocabulary

- albedo
- electromagnetic waves
- greenhouse effect
- insolation
- insulation
- latent heat
- reflection
- specific heat
- temperature

Introduction

Wind, precipitation, warming, and cooling depend on how much energy is in the atmosphere and where that energy is located. Much more energy from the Sun reaches low latitudes (nearer the equator) than high latitudes (nearer the poles). These differences in **insolation** –- the amount of solar radiation that reaches a given area in a given time -- cause the winds, affect climate, and drive ocean currents. Heat is held in the atmosphere by greenhouse gases.

Energy, Temperature, and Heat

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** below).

- The wavelengths humans can see are known as "visible light." These wavelengths appear to us as the colors of the rainbow. What objects can you think of that radiate visible light? Two include the Sun and a light bulb.
- 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.

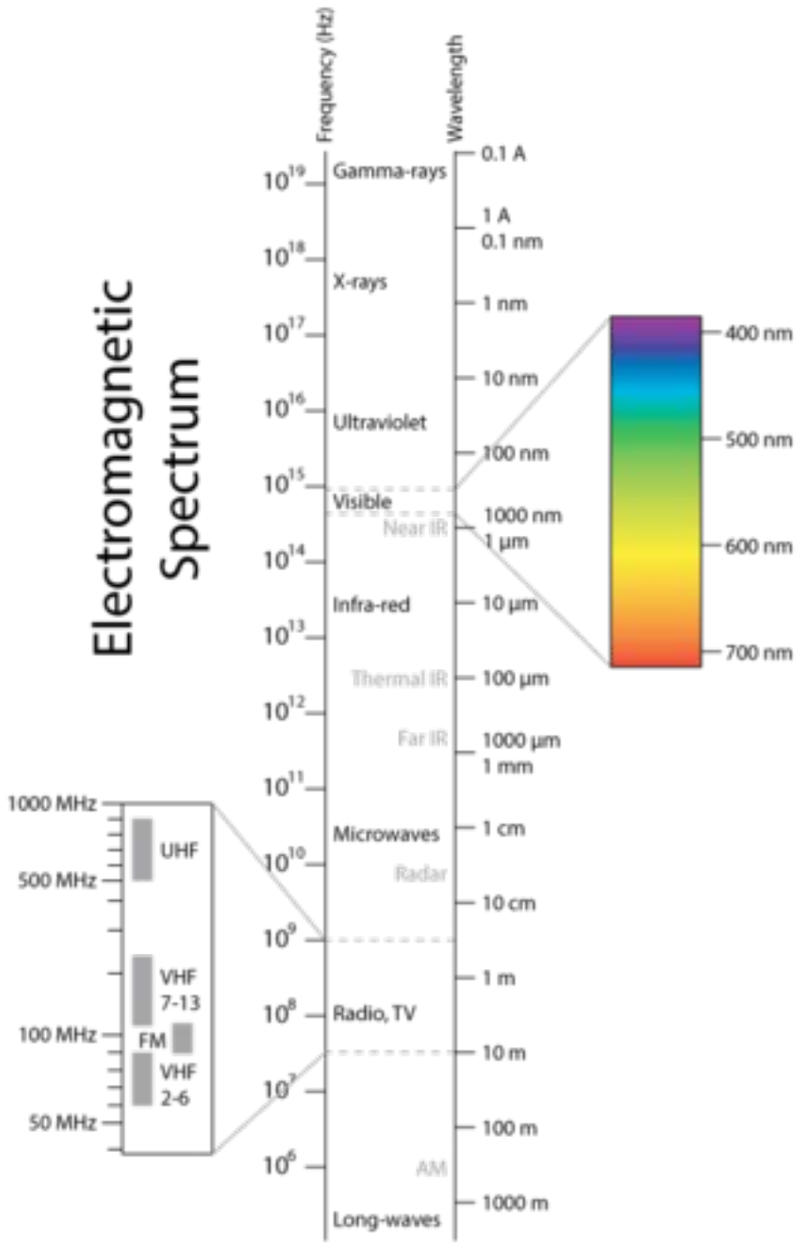


Figure 22.14

The electromagnetic spectrum; short wavelengths are the fastest with the highest energy.

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.

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.

Which has higher heat and which has higher temperature: a candle flame or a bathtub full of hot water?

•The flame has higher temperature, but less heat, because the hot region is very small.
•The bathtub has lower temperature but contains much more heat because it has many more vibrating atoms. The bathtub has greater total energy.

Heat

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°C (212°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°C (1.8°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.

Energy From the Sun

Most of the energy that reaches the Earth's surface comes from the Sun (**Figure** below). About 44% of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths.

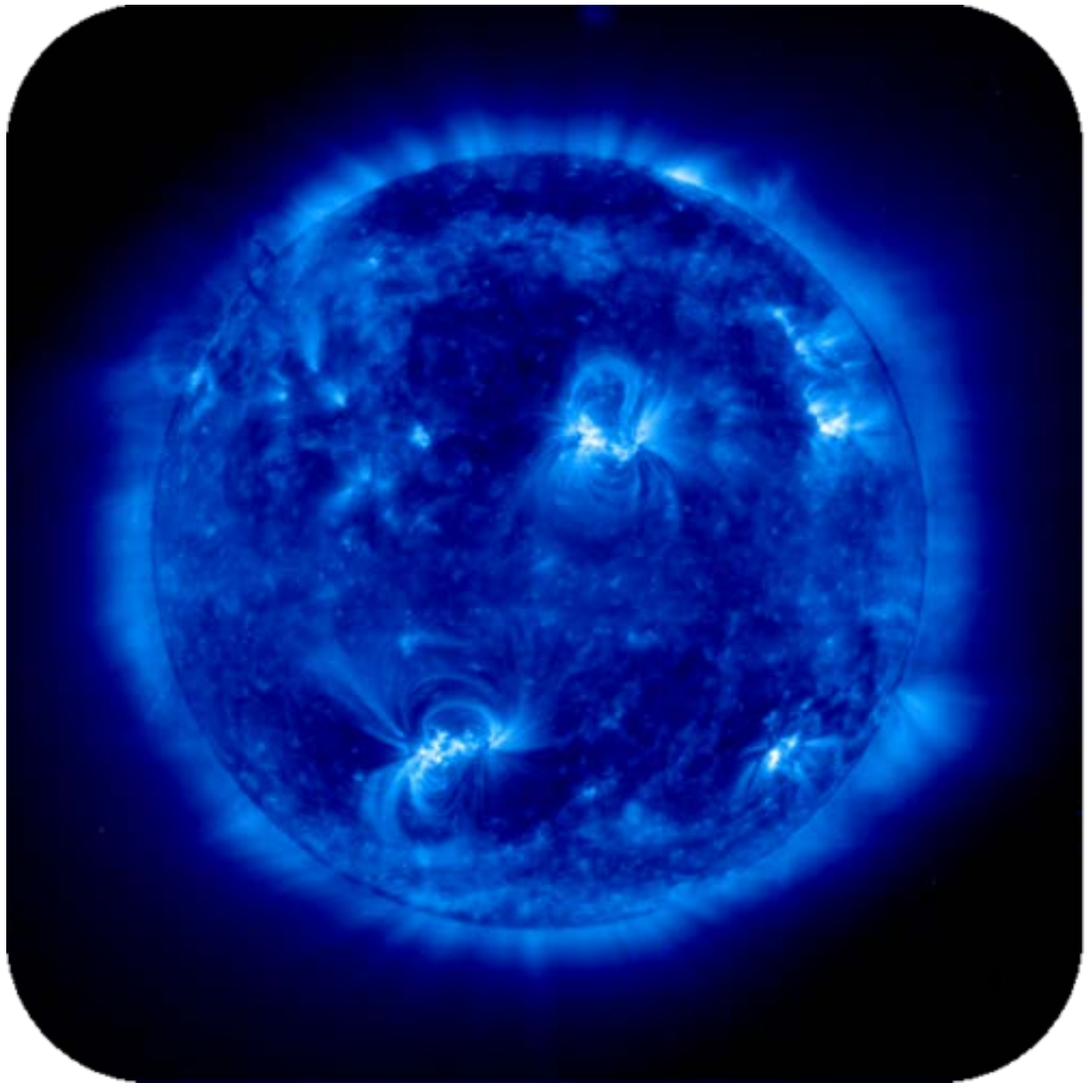


Figure 22.15

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.

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** below).

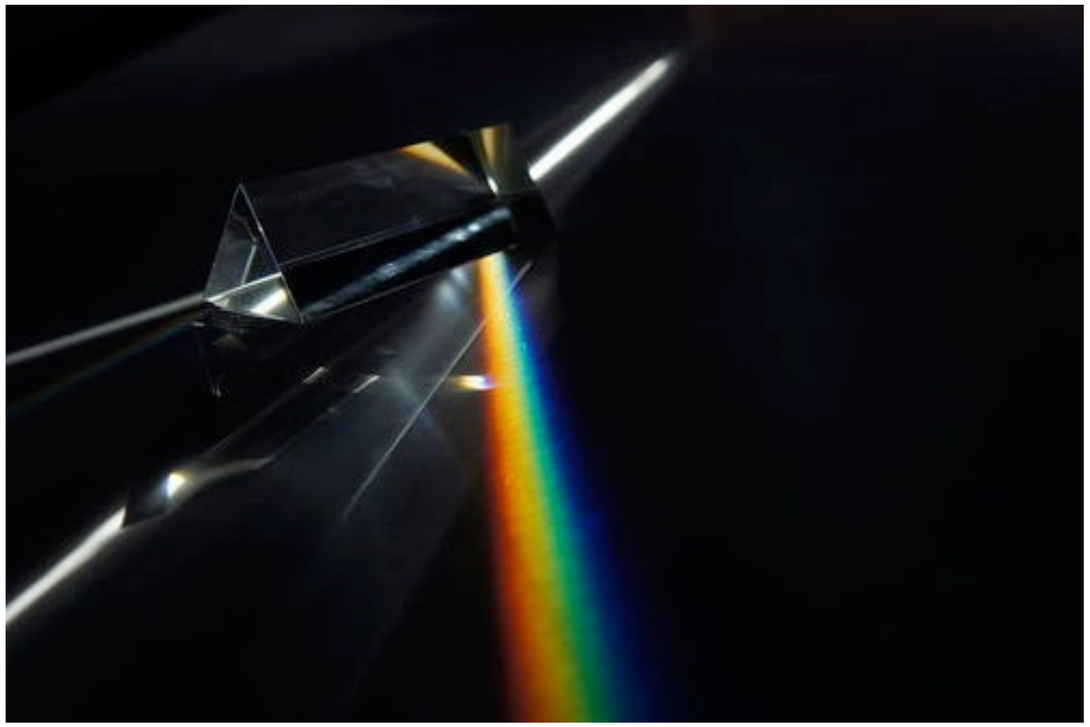


Figure 22.16

A prism breaks apart white light.

Of the solar energy that reaches the outer atmosphere, 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.

The remaining solar radiation is the longest wavelength, infrared. Most objects radiate infrared energy, which we feel as heat (**Figure** below).

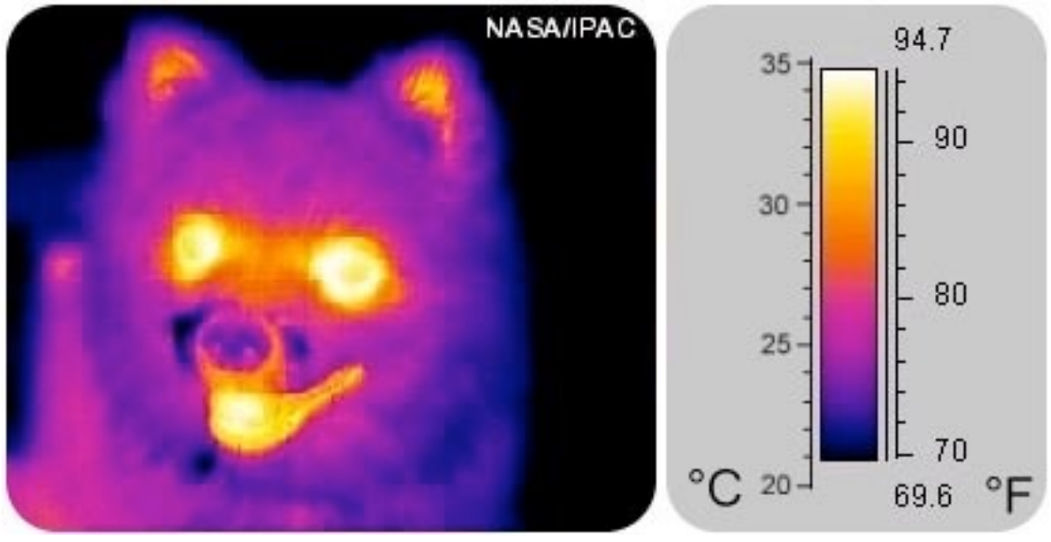


Figure 22.17

An infrared sensor detects different amounts of heat radiating from a dog.

Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases (**Figure** below). Ozone completely removes UVC, most UVB, and some UVA from incoming sunlight. O_2, CO_2 and H_2O also filter out some wavelengths.

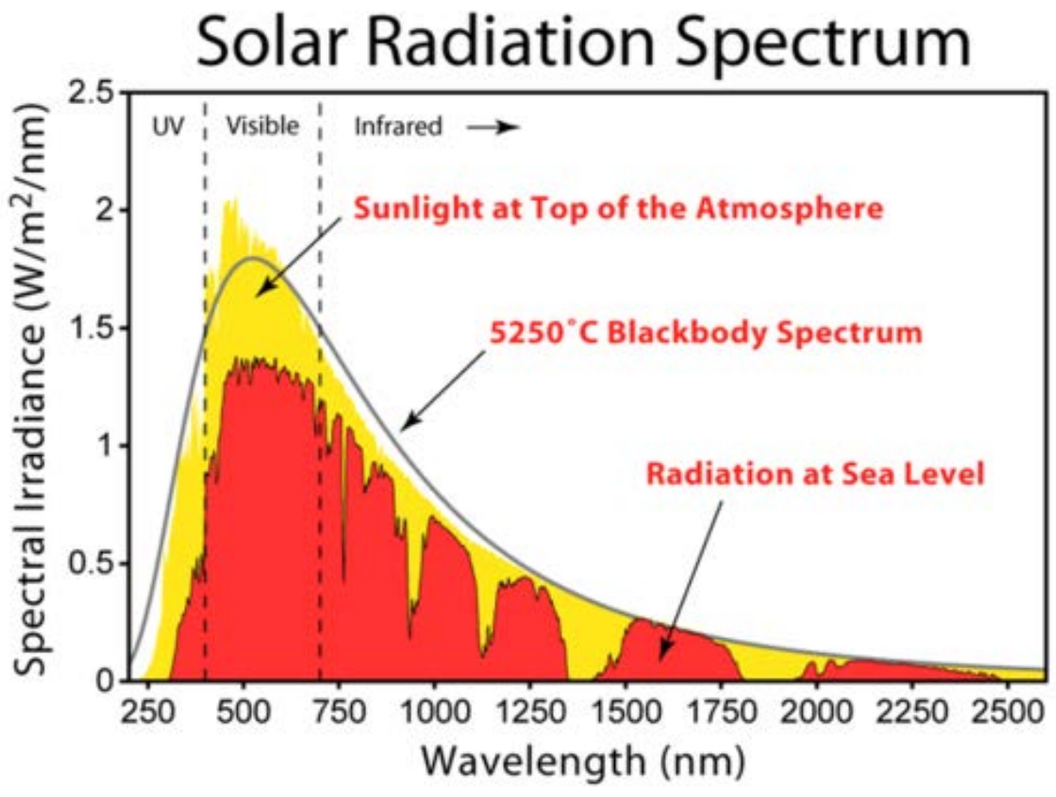


Figure 22.18

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.

Solar Radiation on Earth

Different parts of the Earth receive different amounts of solar radiation. Which part of the planet receives the most insolation? 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° 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** below). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5°N); 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.

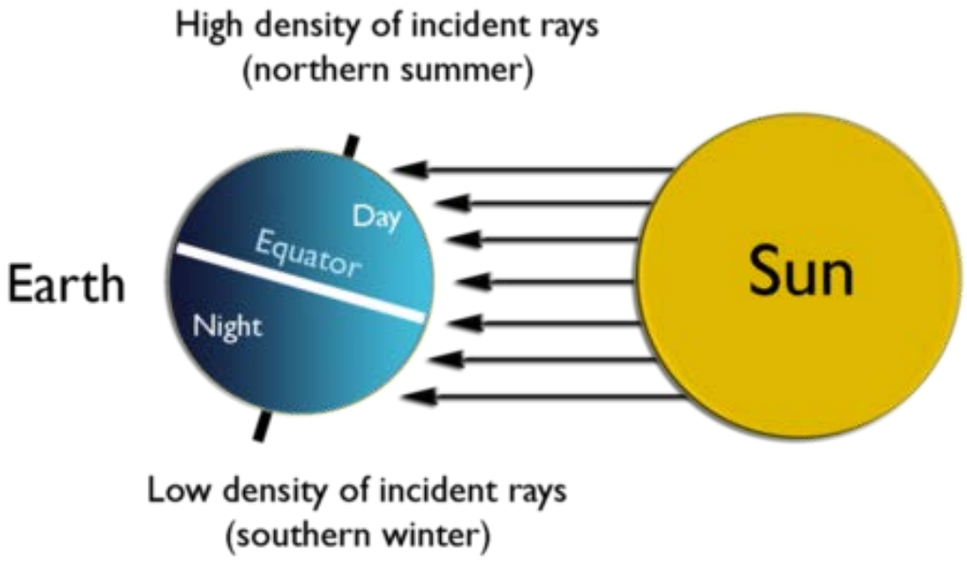


Figure 22.19

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** below). 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.

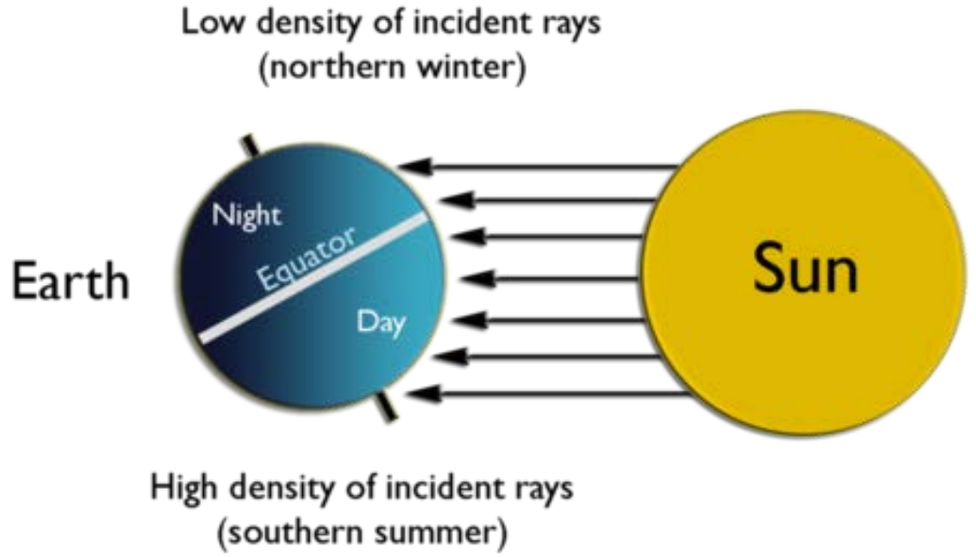


Figure 22.20

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

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an "equinox" (**Figure** below). 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.

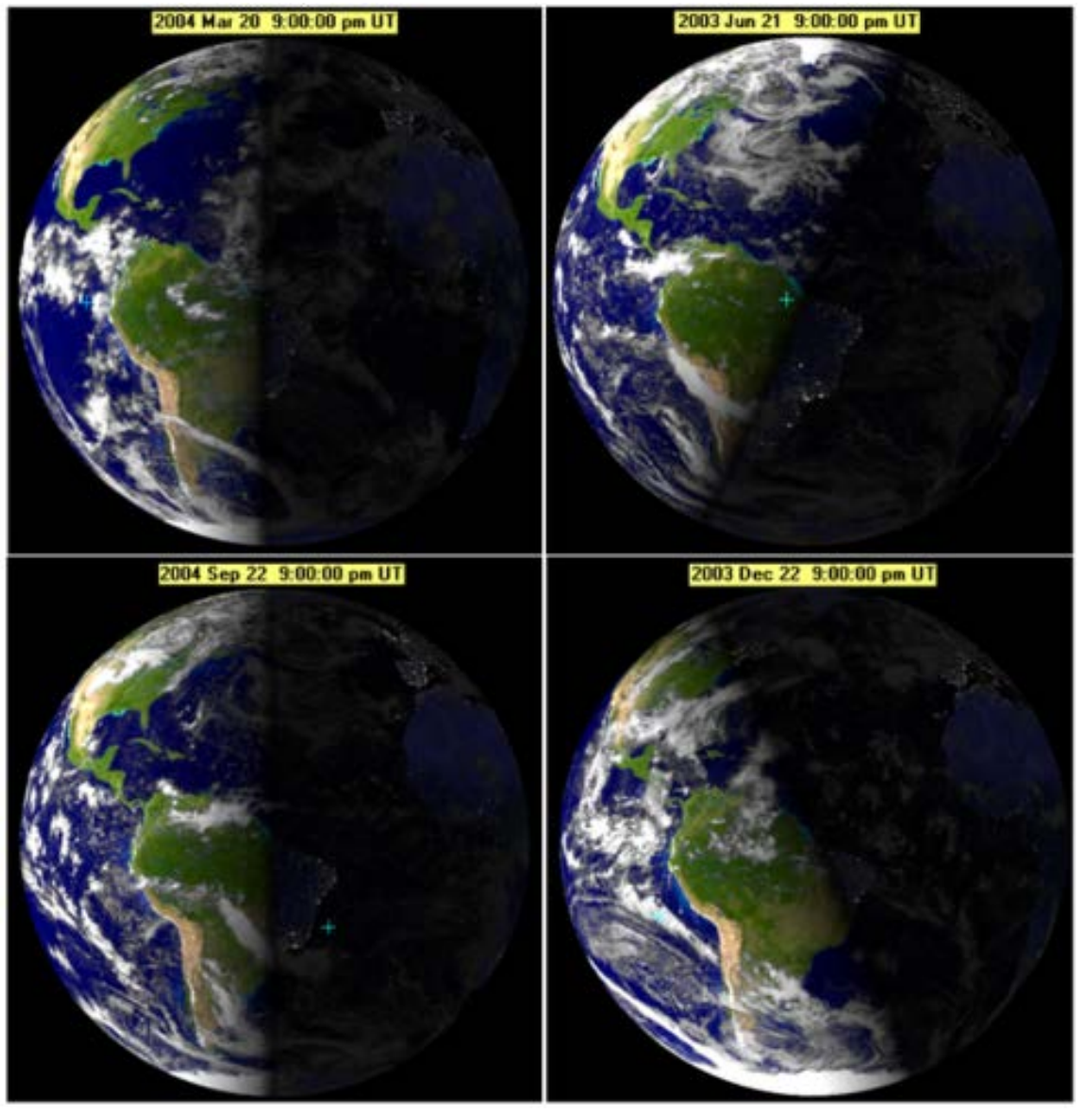


Figure 22.21

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.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth (Plate Tectonics chapter) 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; 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** below).

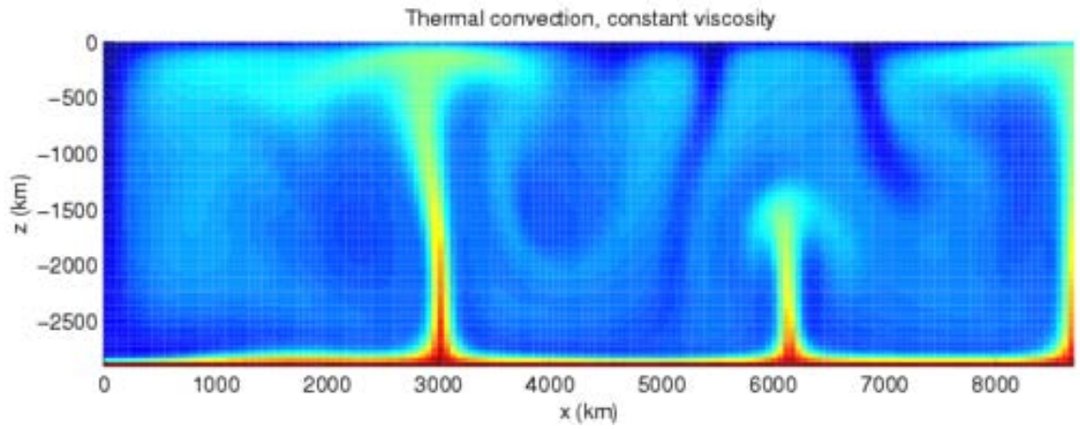


Figure 22.22

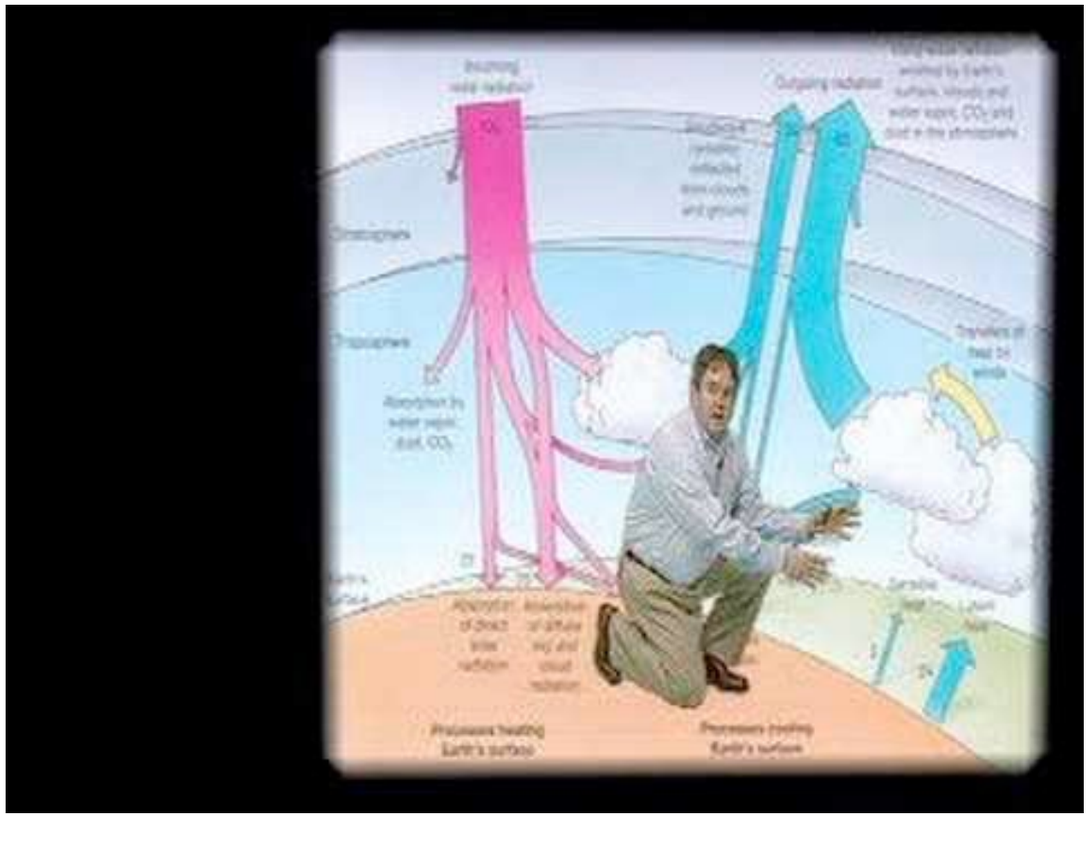
Thermal convection where the heat source is at the bottom and there is a ceiling at the top.

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 (5:40).



Click on the image above for more content

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 (**Figure** below). Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See **Table** below

	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.

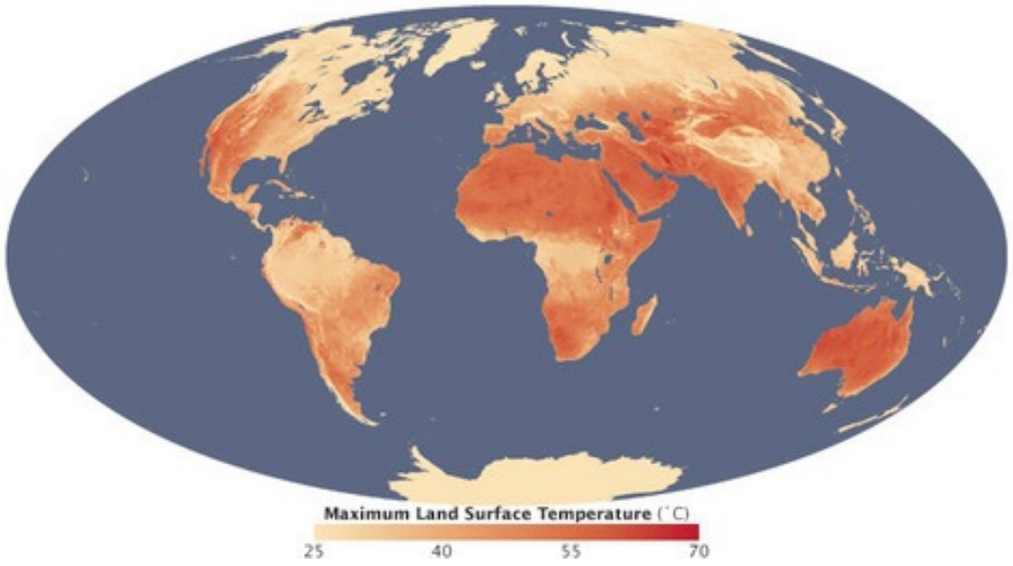


Figure 22.23

The maximum land surface temperature of the Earth, showing a roughly gradual temperature gradient from the low to the high latitudes.

The difference in solar energy received at different latitudes drives atmospheric circulation.

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 radiation 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** below). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

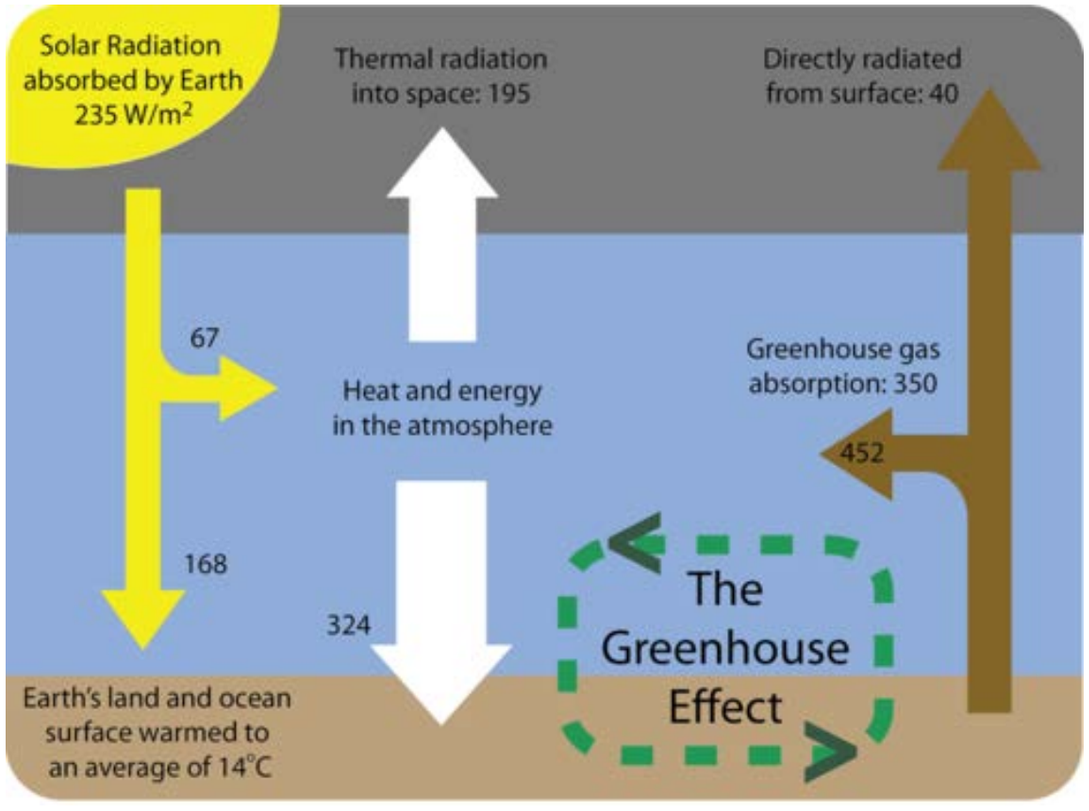


Figure 22.24

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.

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** below shows how each greenhouse gas naturally enters the atmosphere.

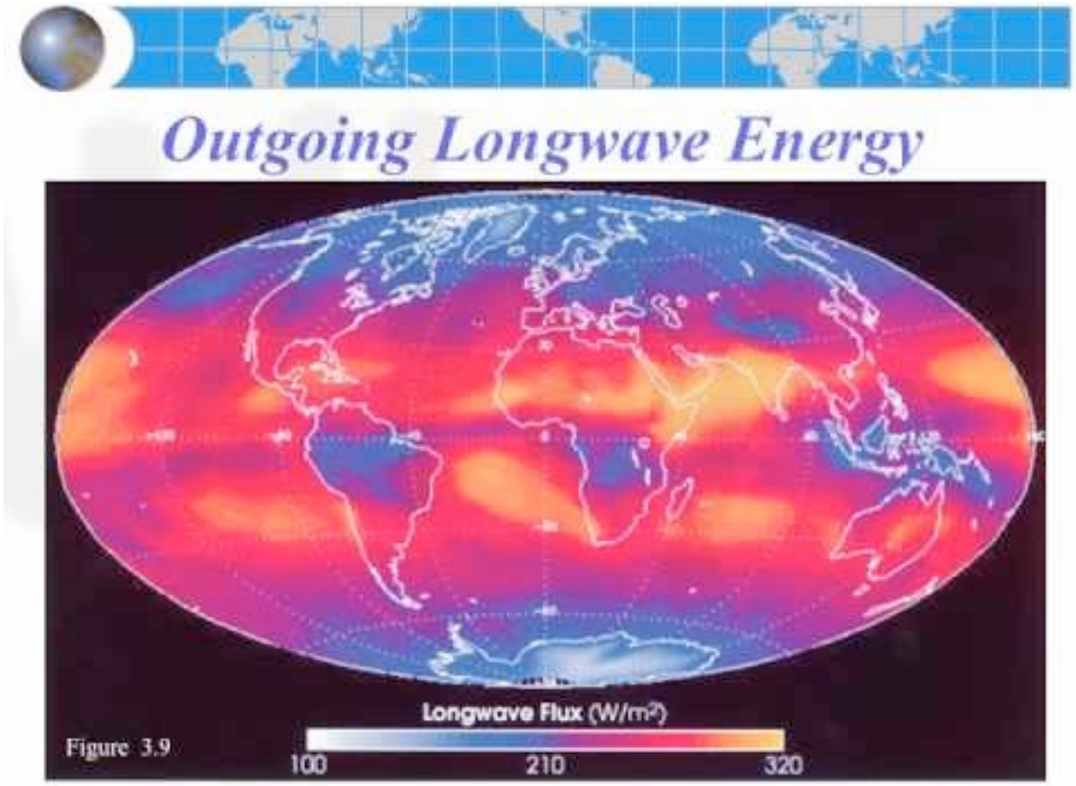
Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

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 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).



Click on the image above for more content

Lesson Summary

•All materials contain energy, which can radiate through space as electromagnetic waves. The wavelengths of energy that come from the Sun include visible light, which appears white but can be broken up into many colors.
•Ultraviolet waves are very high energy. The highest energy UV, UVC and some UVB, gets filtered out of incoming sunlight by ozone.
•More solar energy reaches the low latitudes and the redistribution of heat by convection drives the planet's air currents.

Review Questions

1. What is the difference between temperature and heat?

2. Give a complete description of these three categories of energy relative to each other in terms of their wavelengths and energy: infrared, visible light, and ultraviolet.

3. Why do the polar regions have high albedo?

4. Give an example of the saying “energy can’t be created or destroyed.”

5. Describe what happens to the temperature of a pot of water and to the state of the water as the dial on the stove is changed from no heat to the highest heat.

6. Describe where the Sun is relative to the Earth on summer solstice, autumnal equinox, winter solstice and spring equinox. How much sunlight does the North Pole get on June 21? How much does the South Pole get on that same day?

7. What is the difference between conduction and convection?

8. What is a planet’s heat budget? Is Earth’s heat budget balanced or not?

9. On a map of average annual temperature, why are the lower latitudes so much warmer than the higher latitudes?

10. Why is carbon dioxide the most important greenhouse gas?

11. How does the amount of greenhouse gases in the atmosphere affect the atmosphere’s temperature?

Points to Consider

•How does the difference in solar radiation that reaches the lower and upper latitudes explain the way the atmosphere circulates?
•How does the atmosphere protect life on Earth from harmful radiation and from extreme temperatures?
•What would the consequences be if the Earth’s overall heat budget were not balanced?

Section 4

Air Movement

Air Movement

Lesson Objectives

•List the properties of the air currents within a convection cell.
•Describe how high and low pressure cells create local winds and explain how several types of local winds form.
•Discuss how global convection cells lead to the global wind belts.

Vocabulary

•advection
•Chinook winds (Foehn winds)
•haboob
•high pressure zone
•jet stream
•katabatic winds
•land breeze
•low pressure zone
•monsoon
•mountain breeze
•polar front
•rainshadow effect
•Santa Ana winds
•sea breeze
•valley breeze

Introduction

A few basic principles go a long way toward explaining how and why air moves: Warm air rising creates a **low pressure zone** at the ground. 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. Where it reaches the ground, it creates a **high pressure zone** . Air flowing from areas of high pressure to low pressure creates winds. Warm air can hold more moisture than cold air. Air moving at the bases of the three major convection cells in each hemisphere north and south of the equator creates the global wind belts.

Air Pressure and Winds

Within the troposphere are convection cells (**Figure** below).

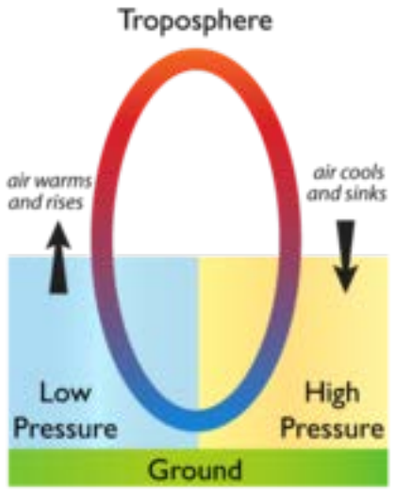


Figure 22.25

Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

Air that moves horizontally between high and low pressure zones makes wind. The greater the pressure difference between the pressure zones the faster the wind moves.

Convection in the atmosphere creates the planet's weather. 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.

Air moving between large high and low pressure systems creates the global wind belts that profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

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 .

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 (**Figure** below). Where is the high pressure zone and where is the low pressure zone? Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10°C (9 to 18°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.

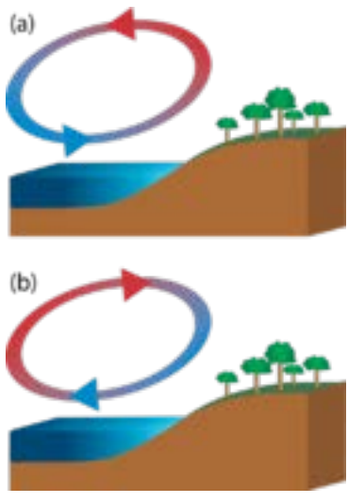


Figure 22.26

How do sea and land breezes moderate coastal climates?

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.

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 are occur where very hot summer lands are next to the sea. Thunderstorms are common during monsoons (**Figure** below).



Figure 22.27

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°C (36°F) in an hour and they rapidly decrease humidity. Snow on the leeward side of the mountain disappears 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** below), which creates many of the world's deserts.

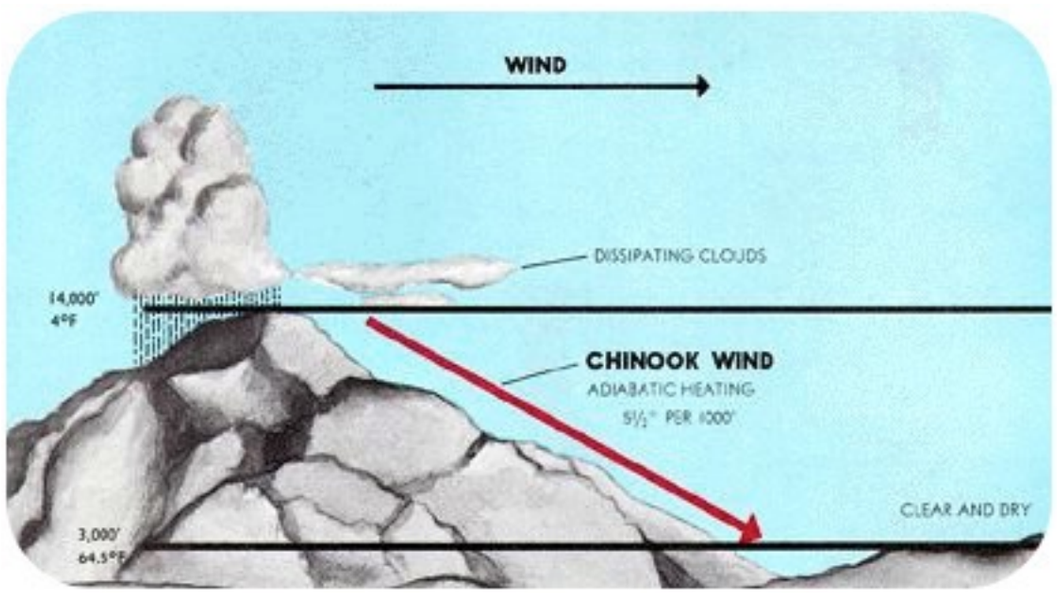


Figure 22.28

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** below).



Figure 22.29

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** below).



Figure 22.30

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** below). A **haboob** forms in the downdrafts on the front of a thunderstorm.



Figure 22.31

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.

Atmospheric Circulation

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.

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. Coriolis Effect was described in the Earth's Oceans chapter.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis Effect (**Figure** below). 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°N 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° and 30°N.

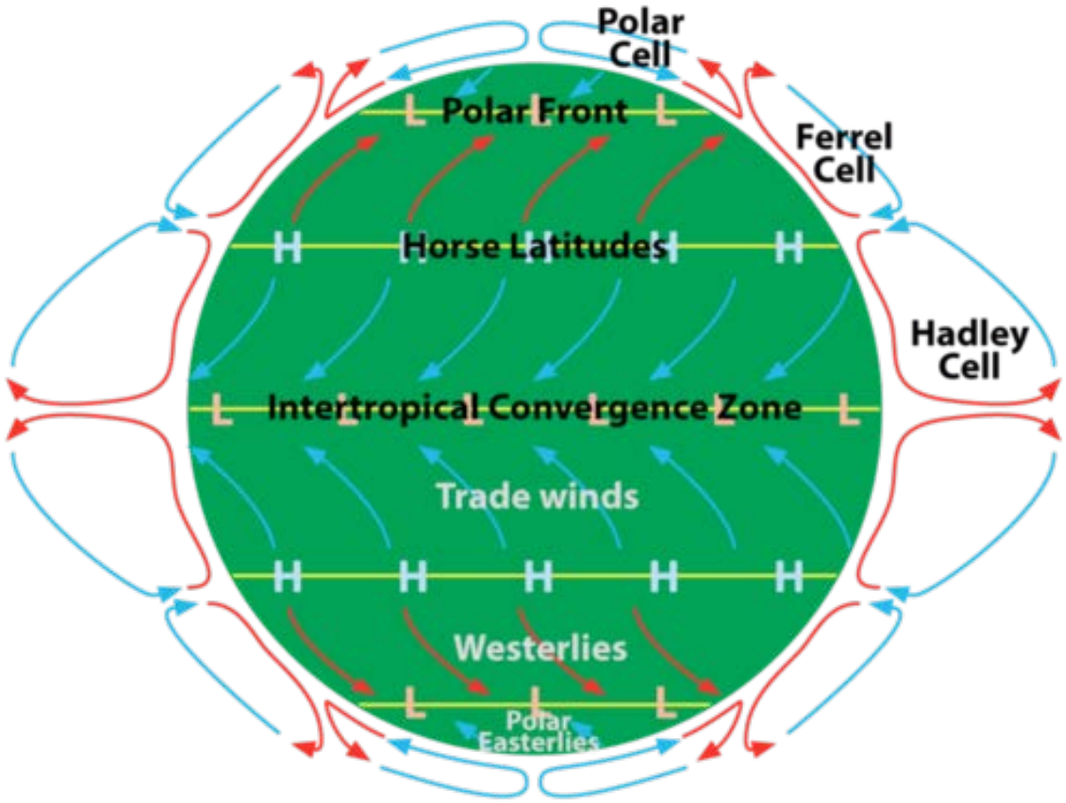


Figure 22.32

The atmospheric circulation cells, showing direction of winds at Earth's surface.

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30°N and 50° to 60°N. 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°N to 60°N and the North Pole, where cold air descends.

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.

Global Wind Belts

Global winds blow in belts encircling the planet. The global wind belts are enormous and the winds are relatively steady (**Figure** below). These winds are the result of air movement at the bottom of the major atmospheric circulation cells, where the air moves horizontally from high to low pressure.

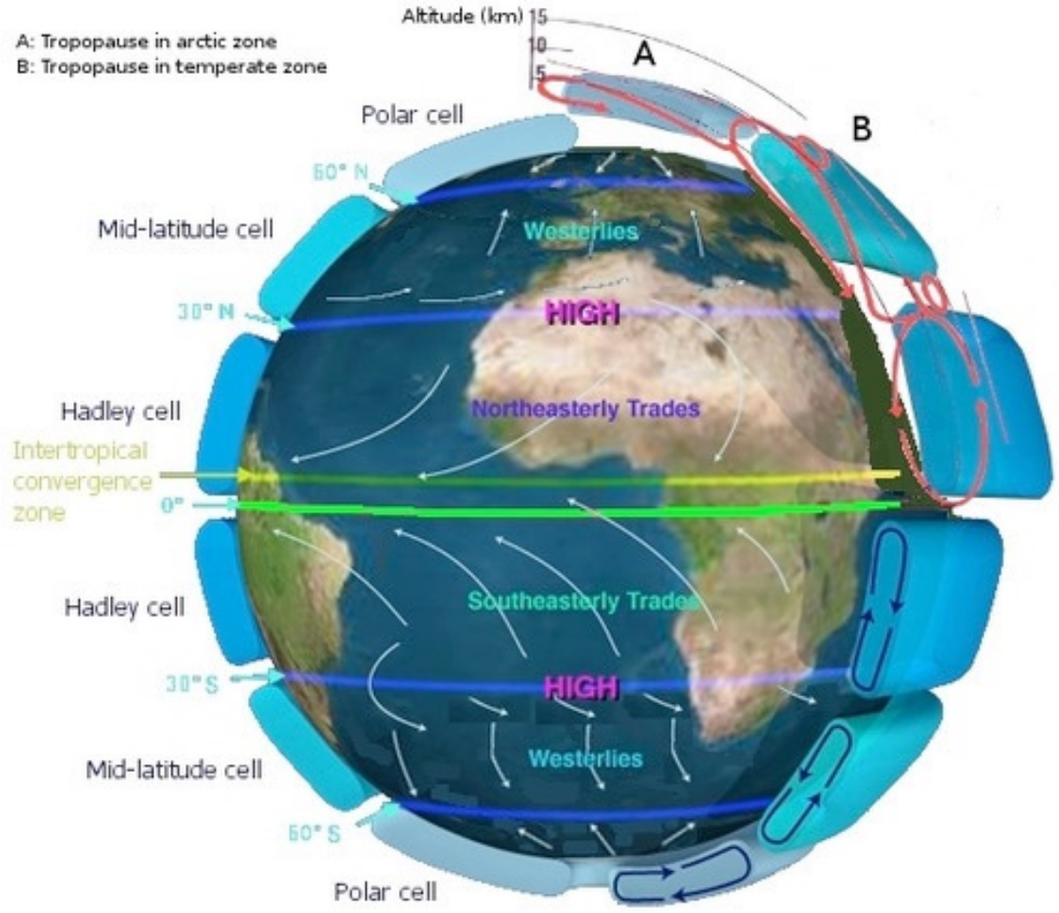


Figure 22.33

The major wind belts and the directions that they blow.

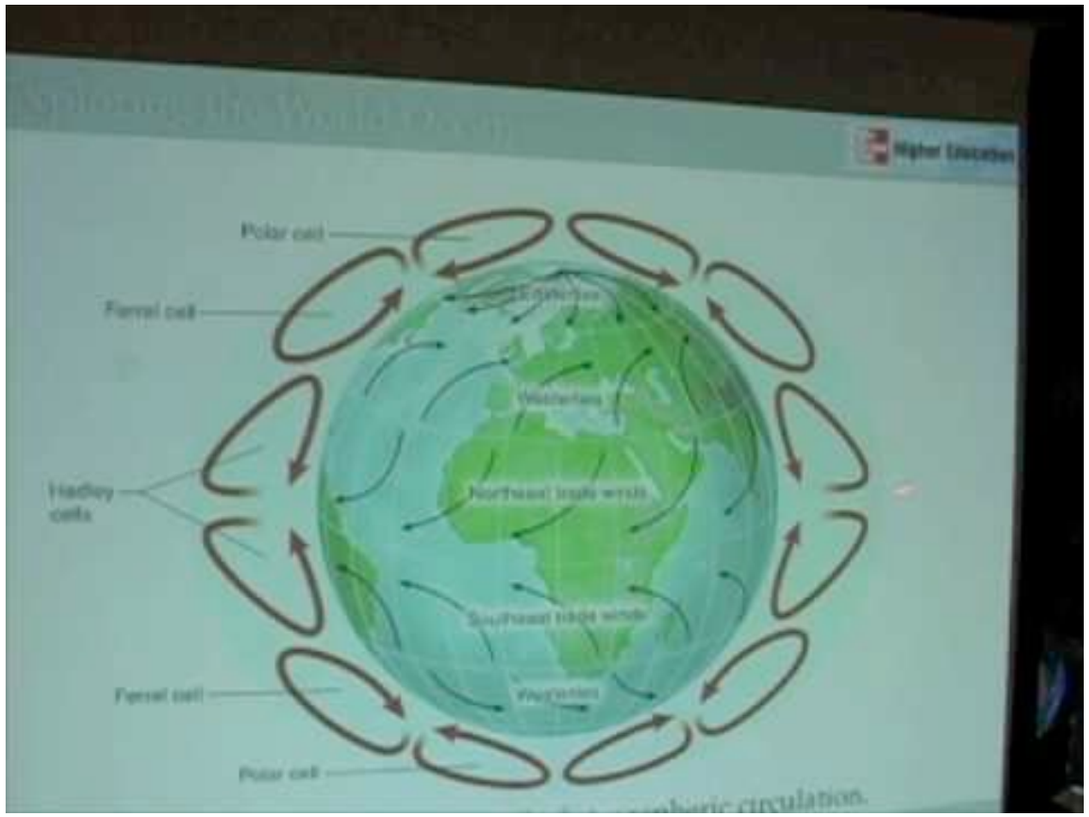
Global Wind Belts

Let's look at the global wind belts in the Northern Hemisphere.

- 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. Why do you think a flight across the United States from San Francisco to New York City takes less time than the reverse trip?
- 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 (8:45).



Click on the image above for more content

Global Winds and Precipitation

Besides their effect on the global wind belts, the high and low pressure areas created by the six atmospheric circulation cells determine in a general way the amount of precipitation a region receives. In low pressure regions, where air is rising, rain is common. In high pressure areas, the sinking air causes evaporation and the region is usually dry. More specific climate effects will be described in the chapter about climate.

Polar Fronts and Jet Streams

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.

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** below).

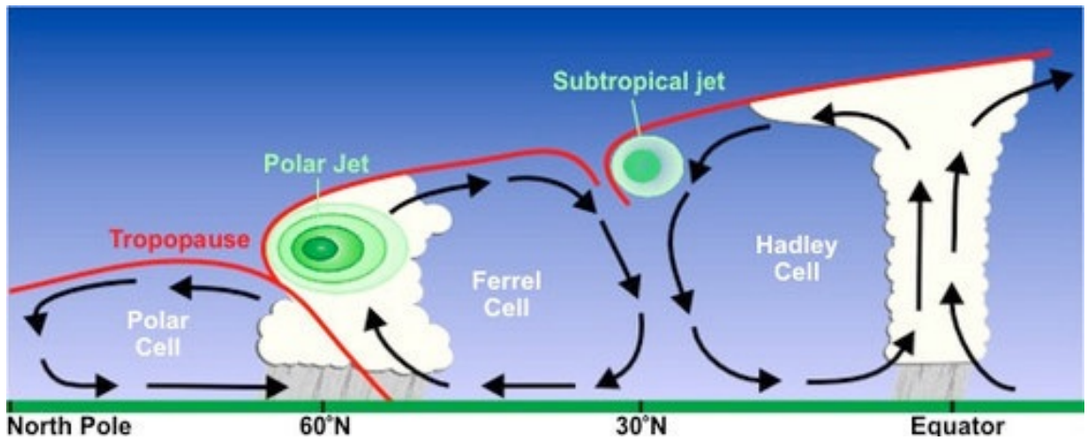


Figure 22.34

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°N and 50° to 75°N.

Lesson Summary

- Winds blow from high pressure zones to low pressure zones. The pressure zones are created when air near the ground becomes warmer or colder than the air nearby.
- Local winds may be found in a mountain valley or near a coast.
- The global wind patterns are long-term, steady winds that prevail around a large portion of the planet.
- The location of the global wind belts has a great deal of influence on the weather and climate of an area.

Review Questions

1. Draw a picture of a convection cell in the atmosphere. Label the low and high pressure zones and where the wind is.

2. Under what circumstances will winds be very strong?

3. Given what you know about global-scale convection cells, where would you travel if you were interested in experiencing warm, plentiful rain?

4. Describe the atmospheric circulation for two places where you are likely to find deserts, and explain why these regions are relatively warm and dry.

5. How could the Indian monsoons be reduced in magnitude? What effect would a reduction in these important monsoons have on that part of the world?

6. Why is the name "snow eater" an apt description of Chinook winds?

7. Why does the Coriolis Effect cause air to appear to move clockwise in the Northern Hemisphere? When does Coriolis Effect cause air to appear to move counterclockwise?

8. Sailors once referred to a portion of the ocean as the doldrums. This is a region where there is frequently no wind, so ships would become becalmed for days or even weeks. Where do you think the doldrums might be relative to the atmospheric circulation cells?

9. Imagine that the jet stream is located further south than usual for the summer. What is the weather like in regions just north of the jet stream, as compared to a normal summer?

10. Give a general description of how winds form.

Further Reading / Supplemental Links

High and Low Pressure Systems animations, Bureau of Meteorology, Australian Government http://www.bom.gov.au/lam/Students_Teachers/pressure.shtml

Points to Consider

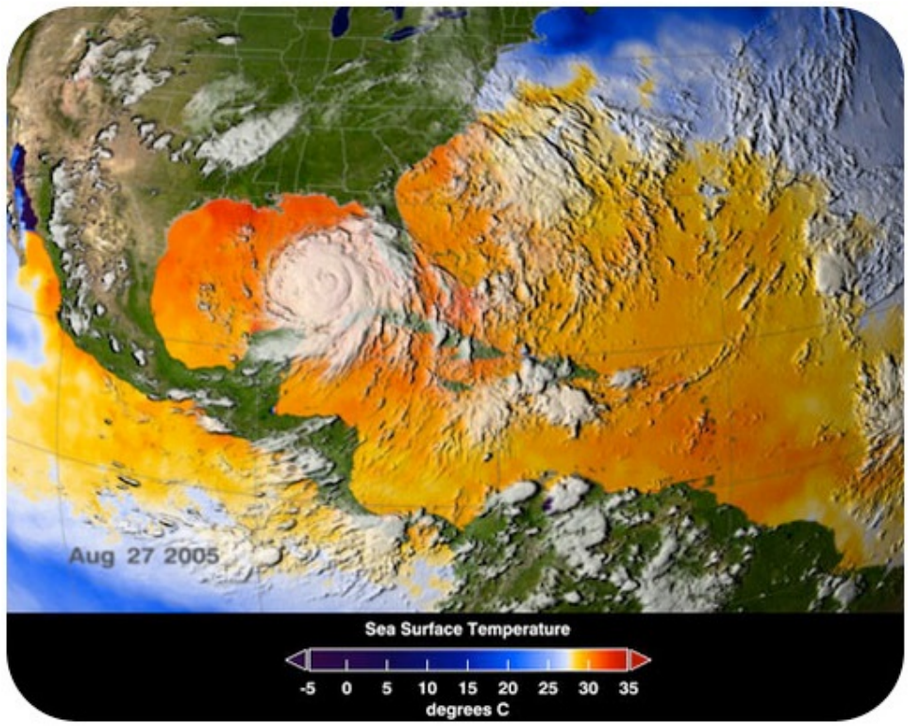
- How do local winds affect the weather in an area?
- How do the global wind belts affect the climate in an area?
- What are the main principles that control how the atmosphere circulates?

References

1.Courtesy of the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE. http://commons.wikimedia.org/wiki/File:Seawifs_global_biosphere.jpg . Public Domain
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13.(a) Courtesy of Senior Airman Joshua Strang, United States Air Force; (b) Courtesy of NASA. (a) hhttp://commons.wikimedia.org/wiki/File:Polarlicht_2.jpg; (b) http://earthobservatory.nasa.gov/IOTD/view.php?id=6226 . Public Domain
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31.User:Junebug172/Wikipedia. http://commons.wikimedia.org/wiki/File:Haboob2.jpg . Public Domain
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Ch. 20: Weather



A hurricane feeds off warm water. This NASA map of sea surface temperature shows just how warm the water was in the tropical Atlantic and the Gulf of Mexico in August 2005 when Hurricane Katrina made its way towards the Gulf Coast.

The storm began over the southeastern Bahamas on August 23 and moved over south Florida the next day as a Category 1 hurricane. The storm killed nine people and caused about $600 million in damage. As the storm traveled west over the Gulf of Mexico, the water was abnormally warm, as high as 89°F (32°C). On August 27, the storm was upgraded to Category 3 and the next day it received the highest designation, Category 5. Winds of 175 mph (280 kph) and gusts of 215 mph (344 kph) were reported. The residents of New Orleans were advised to evacuate the city and fortunately many did.

By the time Hurricane Katrina hit land it had been downgraded to a Category 4 storm. New Orleans was not hit head-on, but by the weaker side of the storm. Initial reports were that the city had been spared. What people didn't know initially was that storm surge had collapsed several sections of the levee that protected the city. Soon 80% of the city was submerged; around 1,300 people were dead (2,500 throughout the region) and one million people were homeless.

Courtesy of NASA/SVS. www.nasa.gov/vision/earth/lookingatearth/h2005_katrina.html. Public Domain.

Section 1

Weather and Atmospheric

Weather and Atmospheric Water

Lesson Objectives

- Discuss the difference between weather and climate.
- Describe the relationship between air temperature and humidity, including the concept of dew point.
- List the basics of the different cloud types and what they indicate about current and future weather.
- Explain how the different types of precipitation form.

Vocabulary

- cloud
- condensation nuclei
- dew point
- precipitation
- relative humidity
- saturated
- specific humidity

Introduction

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. In this chapter, you will learn about many of these features in more detail.

What is Weather and Climate?

Weather is what is going on in the atmosphere at a particular place at a particular time. Weather can change rapidly. A location's weather depends on:

- air temperature
- air pressure
- fog
- humidity
- cloud cover
- precipitation
- wind speed and direction

All of these 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.

Climate is the average of a region's weather over time. 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.

Humidity

Humidity is the amount of water vapor in the air in a particular spot.

The actual amount of water vapor in the air at a given time and place is called the **specific humidity** . It is expressed as the number of grams of water vapor per kilogram of air. On a humid summer day, for example, the specific humidity may be about 20 grams per kilogram.
There is no limit to the amount of water vapor that can be present in the air. To understand how this works, consider the water and air inside a fish tank with a glass lid. Some water molecules have enough energy to escape from the surface and enter the air as water vapor. In other words, they evaporate. At the same time, other water vapor molecules lose energy and return to the liquid state through condensation. As temperatures hold steady, the rate of condensation increases as the amount of water vapor in the air increases. When there is so much water vapor in the air that the rate of condensation equals the rate of evaporation, the air is **saturated** . If any additional water evaporates into saturated air, an equal amount will condense. This fact explains why water droplets may form on the lid of the fish tank. These drops confirm that as water continues to evaporate, an equal amount of water condenses from the saturated air.
The amount of water vapor present in saturated air depends on the temperature of the air. The warmer the air, the more water vapor it can contain. The water vapor capacity of air roughly doubles for every rise in temperature of about 11°C.

When meteorologists refer to **relative humidity** , they are telling us how near the air is to its maximum capacity for holding water vapor. Relative humidity is the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. Relative humidity is usually expressed as a percent. Saturated air has a relative humidity of 100 percent; air that contains no water vapor has a relative humidity of 0 percent.

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.

To calculate the relative humidity of a kilogram of air, divide its specific humidity by its maximum capacity.

Relative Humidity = Specific humidity/maximum capacity x 100%

Relative Humidity = 11g/kg /22g/kg x 100%

Relative Humidity = 0.5 x 100%

Relative Humidity = 50%

The above equation shows that if air holds 11 grams per kilogram of water vapor and it can contain at most 22 grams per kilogram, then it holds half of the water vapor it can contain. This, its relative humidity is 50 percent.

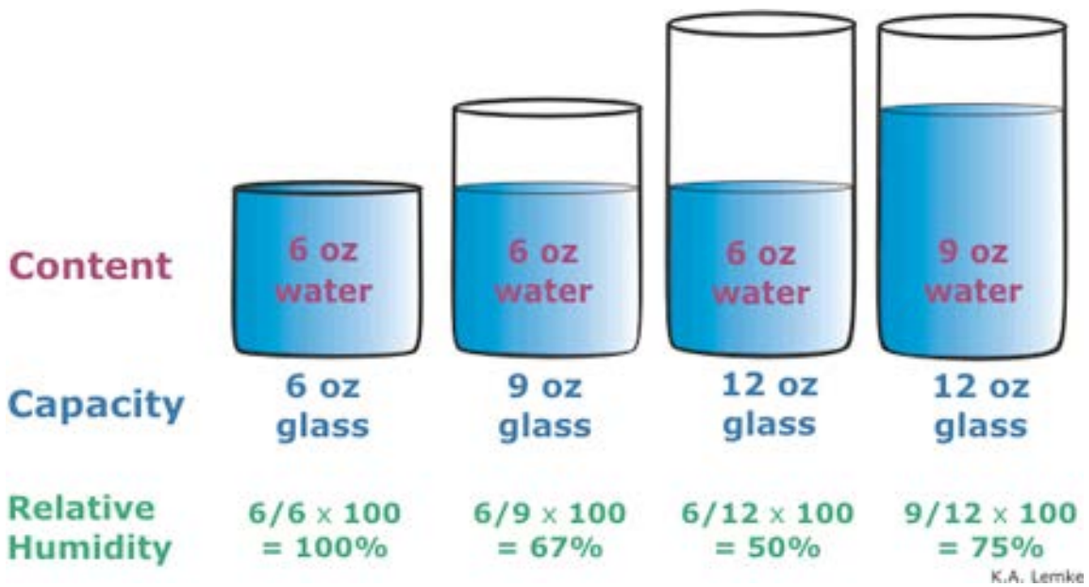


Figure 23.1

Measuring Humidity

Humidity is typically measured with a psychrometer, an instrument that works on the principle that evaporation causes cooling. A psychrometer consists of two thermometers. One is a dry-bulb thermometer that shows the air temperature. The other is a wet-bulb thermometer that has a water–soaked wick wrapped around it's bulb. Fans are set to circulate air past the two thermometers. The wet-bulb thermometer usually shows a lower temperature than the dry-bulb thermometer, because water evaporating from the wick cools the wet-bulb. The dryer the air, the greater the cooling from evaporation, and the greater the difference in the readings. If both the wet-bulb and dry-bulb thermometers read the same, this shows that no water is evaporating from the wet-bulb, and the air is saturated.

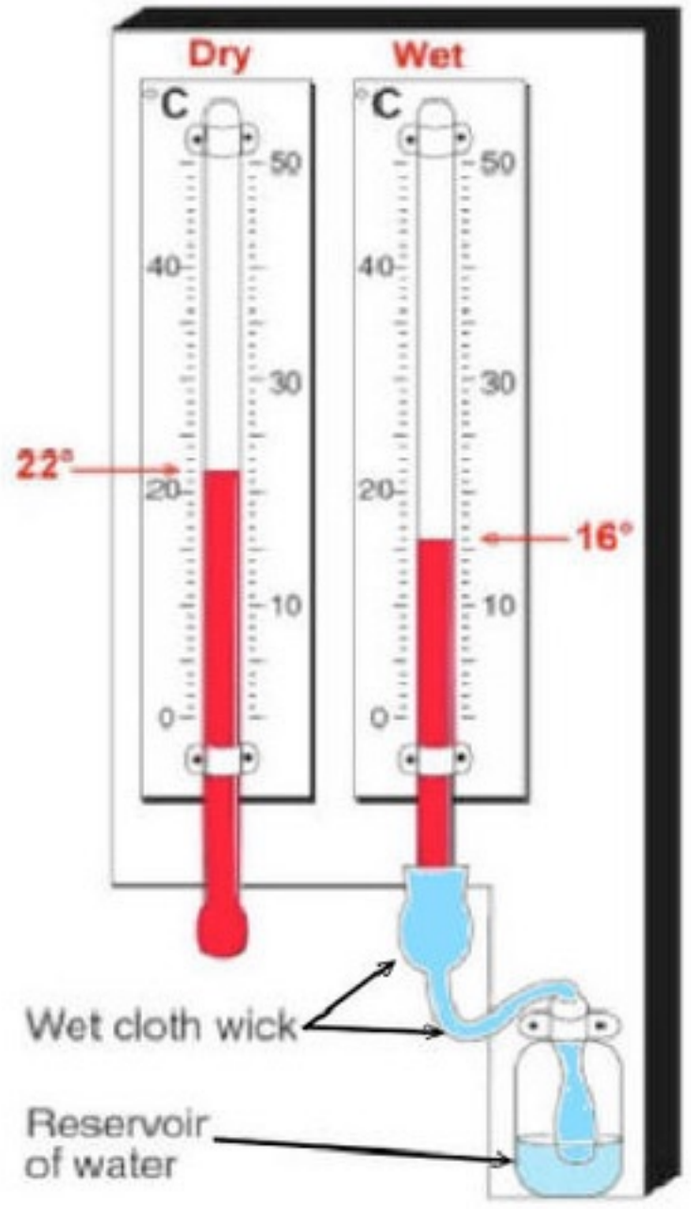


Figure 23.2

Dew Point

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity (**Figure** below). 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.

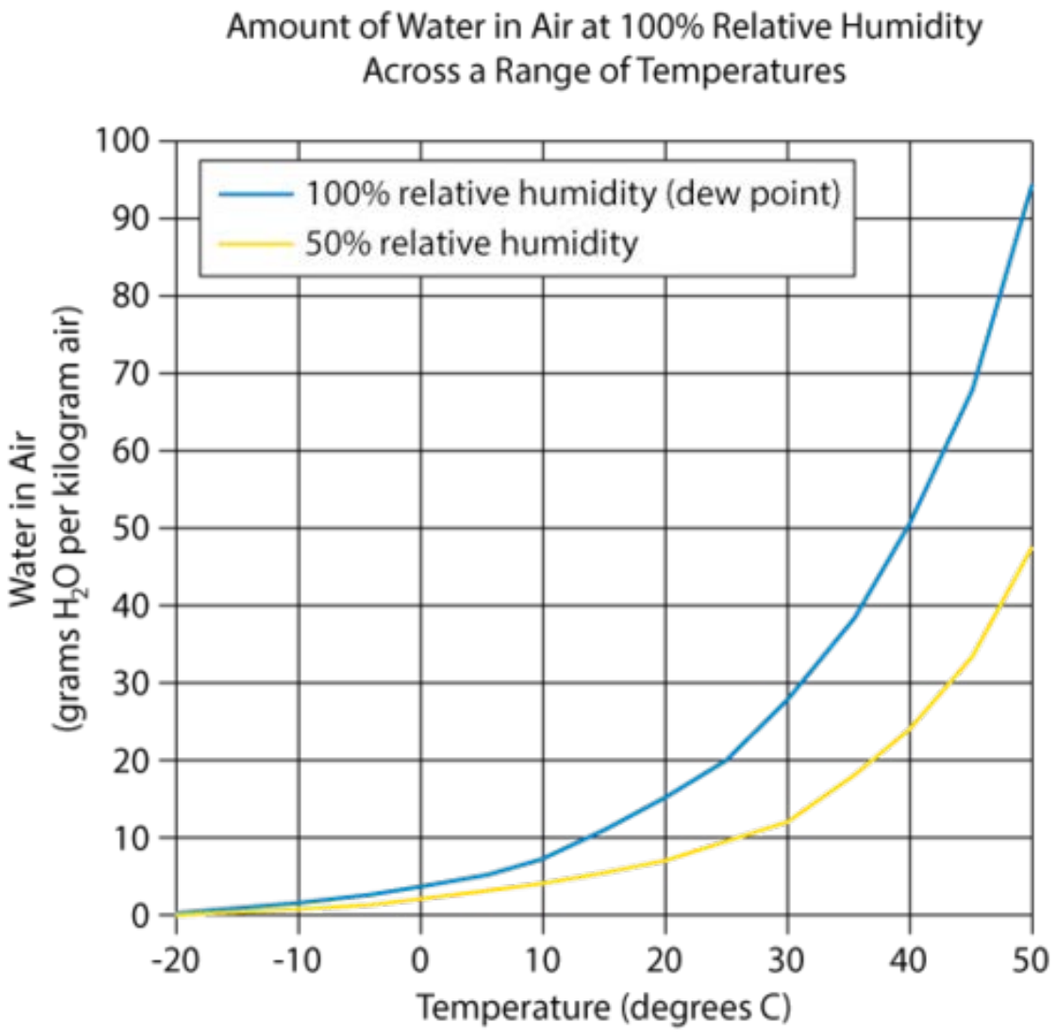


Figure 23.3

This diagram shows the amount of water air can hold at different temperatures. The temperatures are given in degrees Celsius.

The dewpoint is a measure of the amount of water vapor in the air. The more I want to Weber the air contains, Balestier has to cool in order for condensation to start, so the higher the dew point.
Two conditions are necessary for water vapor to condense: (1) there must be a material for water vapor to condense onto and (2) air must cool below its dew point. When fog or clouds form, the water vapor is condensing on tiny particles called **condensation nuclei** . Even when air is cooled below its dew point, condensation to fog or clouds may not occur if there are no condensation nuclei available. Air cooled below its dew point is said to be supersaturated.
Condensation nuclei are usually substances such as salt, sulfate particles, or nitrate particles. Salt enters the air when fine sea spray evaporates. The sulfates and nitrates come from natural sources and from the burning of fuels. Condensation nuclei are so tiny that one puff of smoke contains millions of them. Just as these particles are necessary for the formation of fog or clouds, ice nuclei are required for the formation of ice crystals. Some types of bacteria and clay particles contaminated with organic material make good ice nuclei.
Air may cool, or lose heat, through the following ways:
1. contact with a colder surface
2. radiation of heat
3. mixing with colder air
4. expansion as it rises

Clouds

Like fog, clouds form when the air cools below its the point. **Clouds** can form at any altitude in the troposphere. At temperatures above freezing, clouds are made of water droplets. Below freezing, clouds are usually mixtures of snow crystals and supercooled water, which is water that has cooled below 0°C without freezing. When supercooled droplets contact ice nuclei, they form snow and ice

crystals. At temperatures below -20°C, clouds are made up of mostly snow and ice crystals.

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.

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 can remain 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.

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.

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** below).

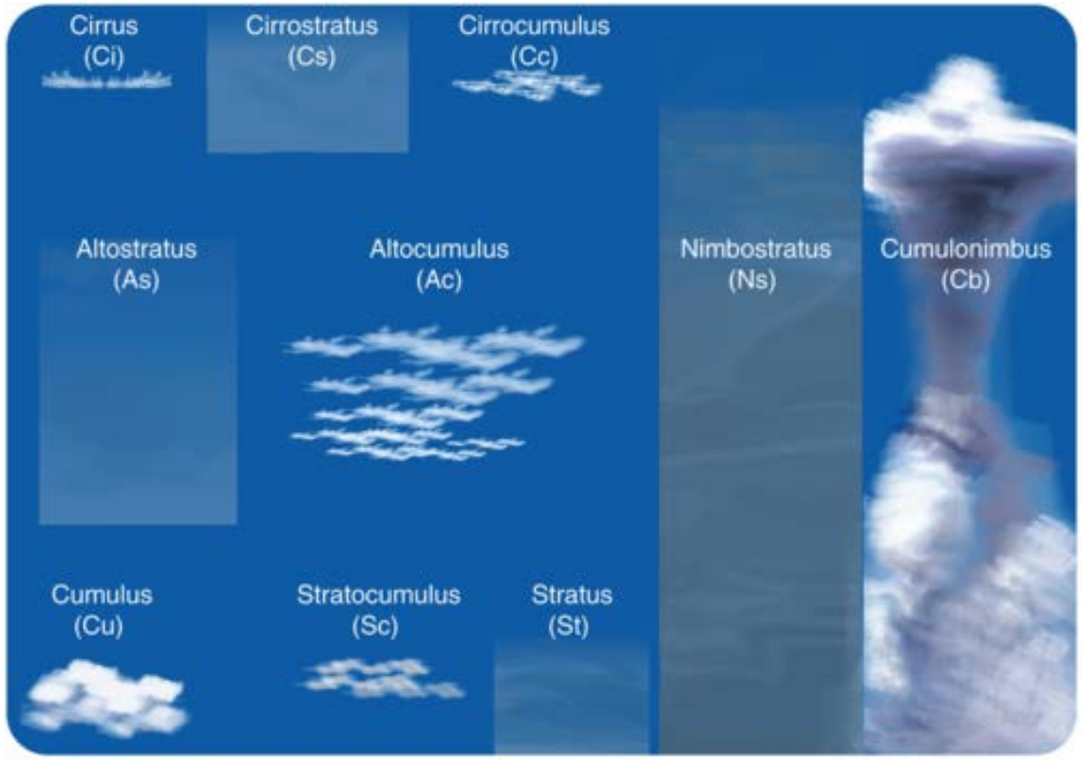


Figure 23.4

The four cloud types and where they are found in the atmosphere.

High Clouds

High clouds (**Figure** below) 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.

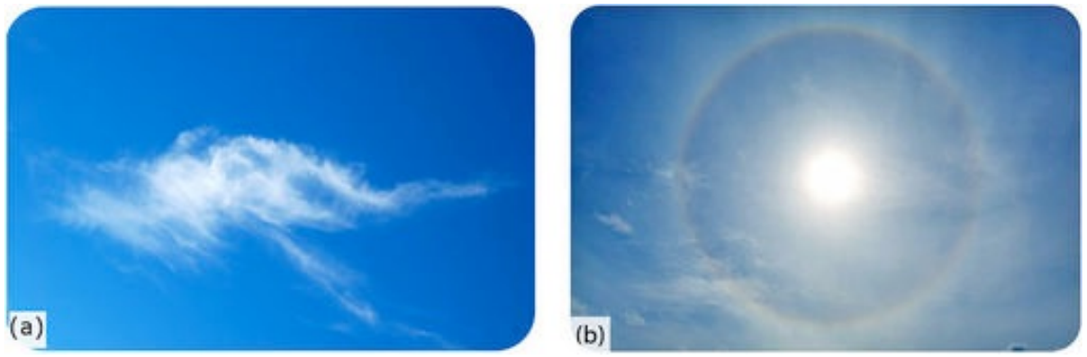


Figure 23.5

(a) Cirrus clouds are thin wisps of ice crystals found at high altitudes. (b) Cirrostratus clouds are thin white sheets of ice crystals that are sometimes invisible unless backlit by the Sun or Moon.

Cirrocumulus clouds are small, white puffs that ripple across the sky, often in rows. Cirrus clouds may indicate that a storm is coming.

Middle Clouds

Middle clouds, including altocumulus and altostratus clouds, may be made of water droplets, ice crystals or both, depending on the air temperatures (**Figure** below).



Figure 23.6

Altocumulus clouds are white to puffy stripes rolling across the sky. They may precede a thunderstorm.

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

Low clouds (**Figure** below) are nearly all water droplets. Stratus, stratocumulus and nimbostratus clouds are common low clouds.



Figure 23.7

(a) Stratus clouds are gray sheets that cover the entire sky and may produce a steady drizzle. Stratus clouds with the Alps in the distance. (b) Stratocumulus clouds are rows of large, low puffs that may be white or gray. These clouds rarely bring precipitation.

Nimbostratus clouds are thick and dark. They bring steady rain or snow.

Vertical Clouds

Clouds with the prefix 'cumulo-' (**Figure** below) 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.



Figure 23.8

(a) Cumulus clouds resemble white or light gray cotton and have towering tops and may produce light showers. Anvil-shaped cumulus clouds floating over New Jersey. (b) A cumulonimbus cloud grows when vertical air currents are strong as in a thunderstorm. This one is lit up by lightning.

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** below) is a cloud located at or near the ground . When humid air near the ground cools below its dew point, fog is formed. The several types of fog that each form 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.
- Warm humid air travels up a hillside and cools below its dew point to create upslope fog



Figure 23.9

(a) Tule fog in the Central Valley of California. (b) Advection fog in San Francisco. (c) Steam fog over a lake. (d) Upslope fog in Teresópolis city, Rio de Janeiro State, Brazil.

KQED: Science on the SPOT: The Science of 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://science.kqed.org/quest/video/science-on-the-spot-science-of-fog/ .



Click on the image above for more content

Precipitation

Precipitation (**Figure** below) is an extremely important part of weather. When the water droplets or ice crystals in cloud grow heavy enough to fall, precipitation occurs. **Precipitation** is any form of water that falls from a cloud to Earth's surface. Rain, snow, sleet, and hail are all examples of precipitation.

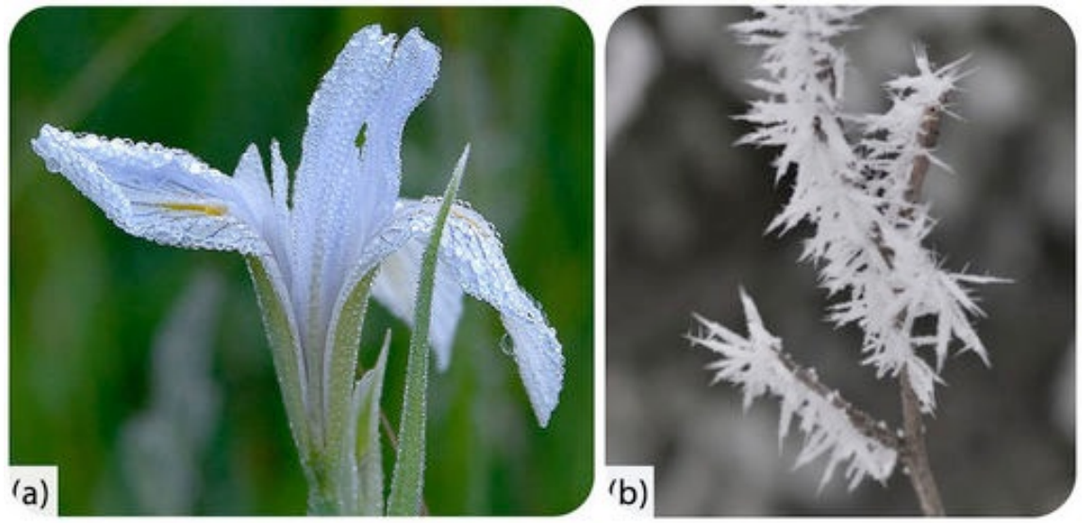


Figure 23.10

(a) Dew forms when moist air cools below its dew point on a cold surface, such as a flower. (b) Frost is dew that forms when the air temperature is below freezing; hoar frost.

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** below). 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 a snowflake.

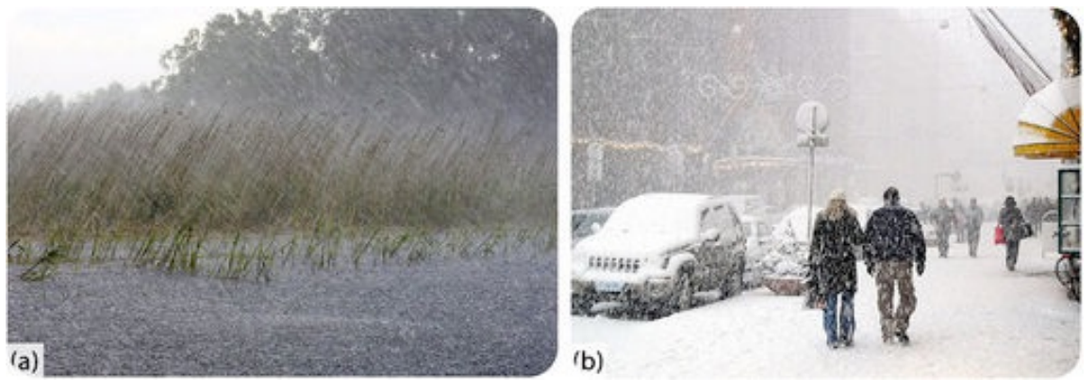


Figure 23.11

(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** below).



Figure 23.12

(a) Sleet is rain that becomes ice as it hits a layer of freezing air near the ground. (b) If a frigid raindrop freezes on the frigid ground, it forms glaze. (c) Hail forms in cumulonimbus clouds with strong updrafts. An ice particle travels until it finally becomes too heavy and it drops. This large hail stone is about 6 cm (2.5 inches) in diameter.

Click the link to examine hail forming.

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 .

Lesson Summary

- Different air temperatures create convection cells.
- Air rising in a convection cell may cool enough to reach its dew point and form clouds or precipitation if the humidity is high enough.
- Clouds or fog may form if warmer air meets a colder ground surface. Air temperature and humidity also determine what sorts of clouds and precipitation form.
- Different factors play a role in creating pleasant or uncomfortable weather, such as when it might be warm and dry or hot and humid.

Review Questions

1. What factors need to be included in a thorough weather report?

2. If Phoenix, Arizona, experiences a cool, wet day in June (when the weather is usually hot and dry), does that mean the region's climate is changing?

3. What happens when a batch of air reaches its dew point? What is the temperature?

4. What effect do clouds have on weather?

5. You are standing in a location that is clear in the morning, but in the afternoon there are thunderstorms. There is no wind during the day, so the thunderstorms build directly above you. Describe how this happens.

6. What are the four different cloud groups and how are they classified?

7. How does sleet form? How does glaze form?

8. What circumstances must be present for enormous balls of hail to grow and then fall to the ground?

Points to Consider

- When thinking about the weather, what factors do you consider important?
- How do air temperature, humidity, and pressure differences create different weather?
- Think about the types of weather described in this lesson. Imagine types of weather that you have not experienced, look at photos, and ask friends and relatives who've lived in other places what their weather is like.

Section 2

Changing Weather

Changing Weather

Lesson Objectives

•Describe the characteristics of air masses and how they get those characteristics.
•Discuss what happens when air masses meet.
•List the differences between stationary, cold, warm, and occluded fronts.

Vocabulary

•air mass
•cold front
•front
•occluded front
•squall line
•stationary front
•warm front

Introduction

The weather in a location often depends on what type of air mass is over it. Another key factor is whether the spot is beneath a front, the meeting place of two air masses. The characteristics of the air masses and their interactions determine whether the weather over an area is constant, or whether there are rapid changes.

Air Masses

An **air mass** is a batch of air that has nearly the same temperature and humidity (**Figure** below). 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.

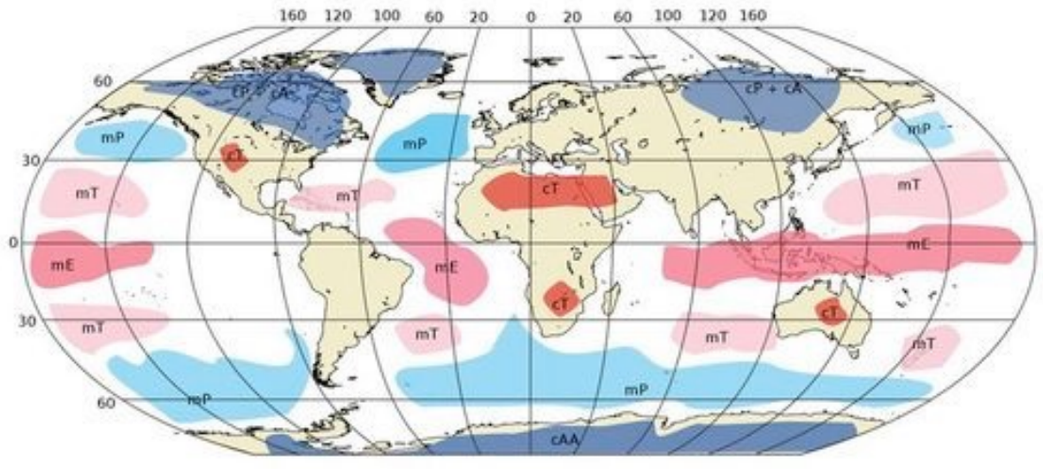


Figure 23.13

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.

Meteorologist specify air masses according to where they originate. The temperature of each type of air masses depends on whether the air masses originates in arctic, polar, or tropical region. The humidity depends on whether the air mass comes from land (continental) or sea (maritime). What does an air mass with the symbol cP mean? The symbol cP 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 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.

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 towards balancing out the planet's temperatures.

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 .

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.

The rest of this section will be devoted to four types of fronts. Three of these fronts move and one is 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** below). 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.

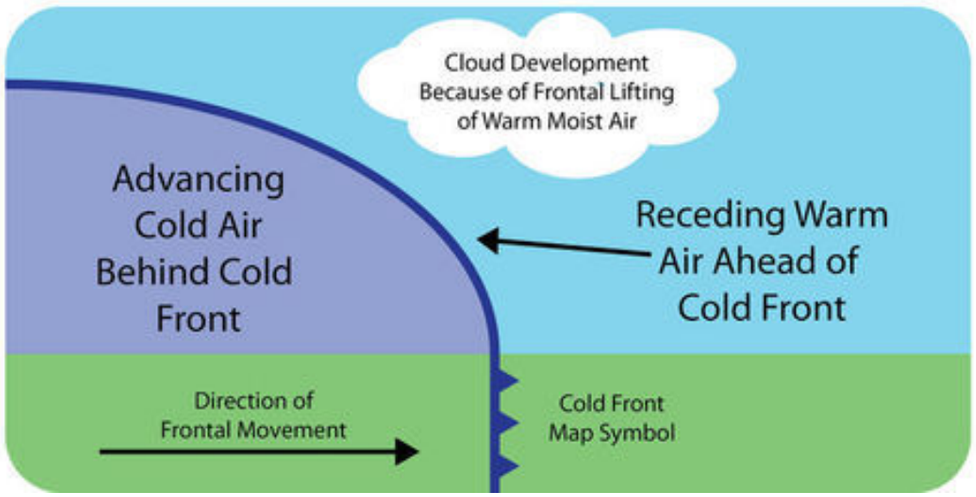


Figure 23.14

The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

Cold Fronts

When a cold air mass takes the place of a warm air mass, there is a **cold front** (**Figure** below).



The map symbol for a cold front is blue triangles that point in the direction the front is moving.

Figure 23.15

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** above). 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** below). 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.



Figure 23.16

A squall line.

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.

Warm Fronts

At a **warm front** , a warm air mass slides over a cold air mass (**Figure** below). When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable.

The map symbol for a warm front is red half-circles that point in the direction the front is moving.

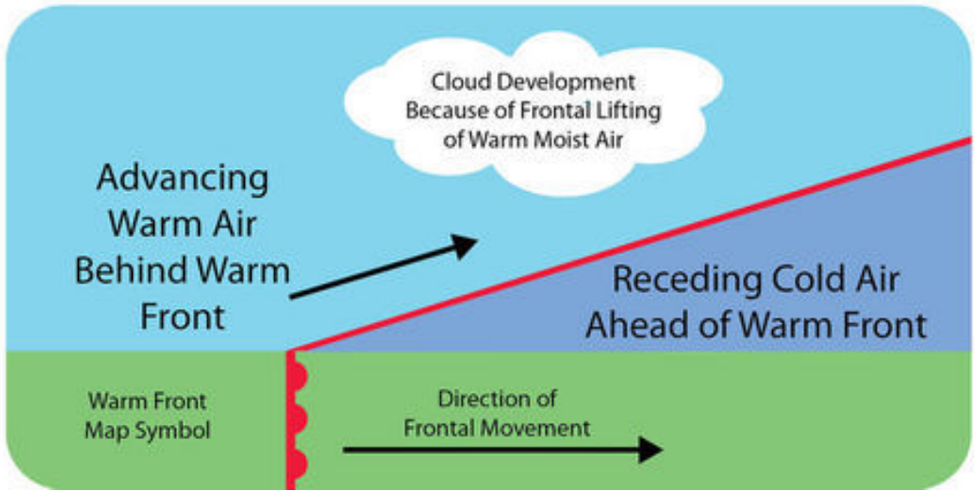


Figure 23.17

Warm air moves forward to take over the position of colder air.

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** below).

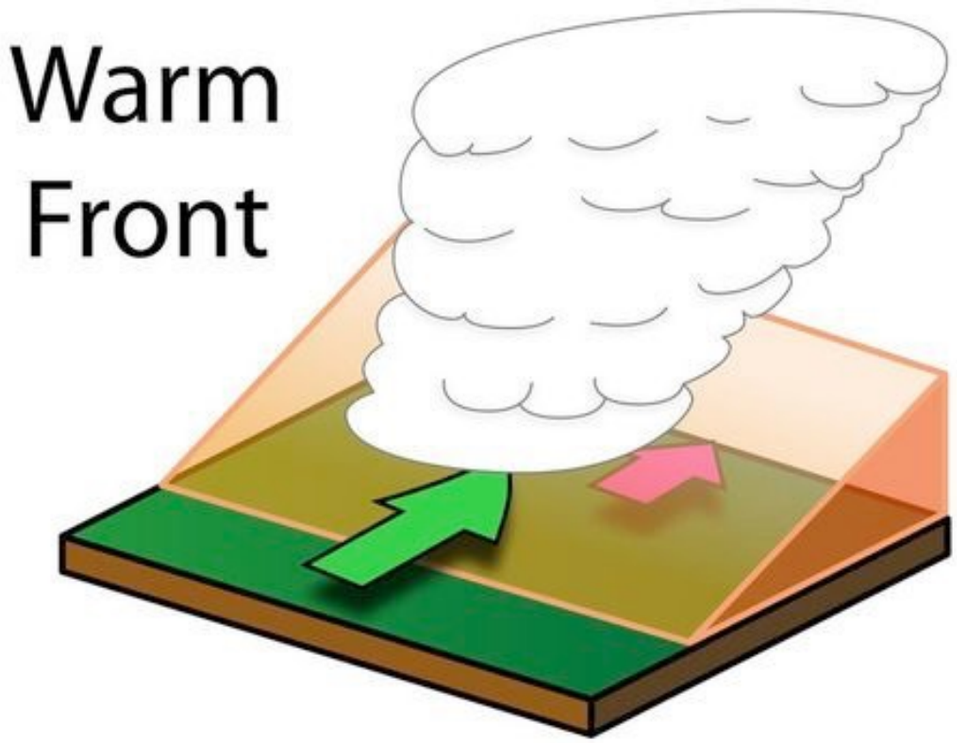


Figure 23.18

Cumulus clouds build at a warm front.

Occluded Front

An **occluded front** usually forms around a low pressure system (**Figure** below). 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.



Figure 23.19

The map symbol for an occluded front is mixed cold front triangles and warm front domes.

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** below).

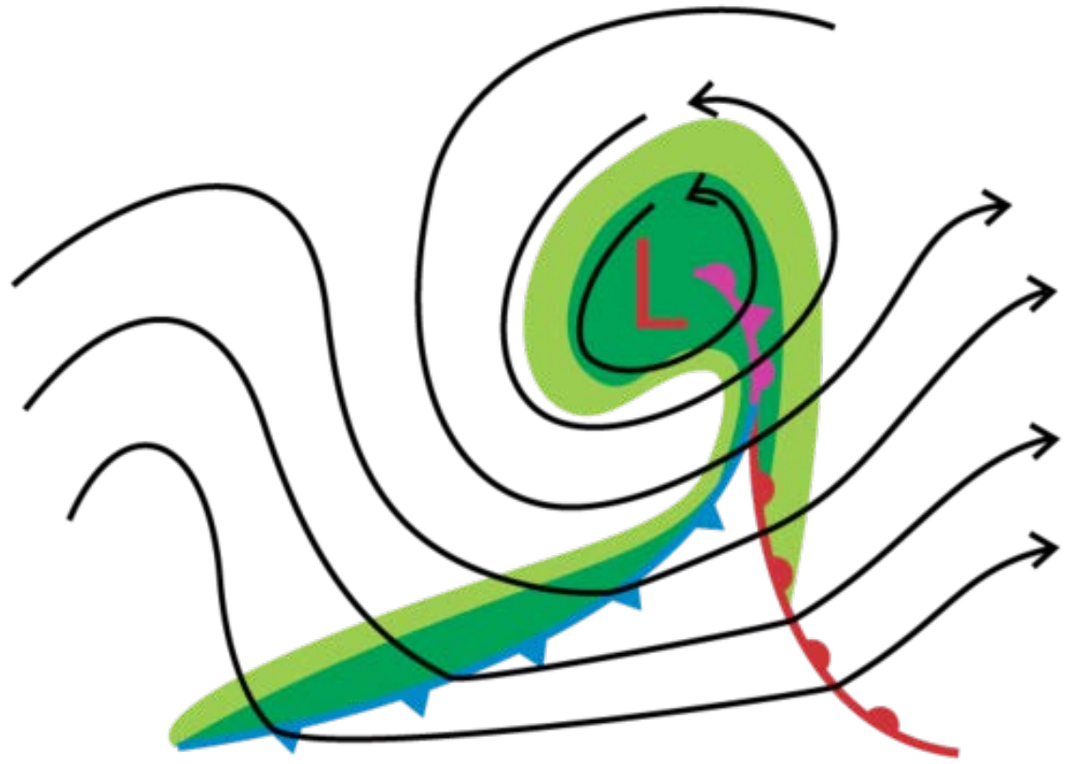


Figure 23.20

An occluded front with the air masses from front to rear in order as cold, warm, cold.

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.

Weather is explored in this video at National Geographic Video, Natural disaster, Landslides, and more: Weather 101

Lesson Summary

•An air mass takes on the temperature and humidity characteristics of the location where it originates. Air masses meet at a front.
•Stationary fronts become trapped in place; the weather they bring lasts for many days.
•At a cold front, a cold air mass forces a warm air mass upwards.
•At a warm front, the warm air mass slips above the cold air mass.
•In an occluded front, a warm front overtakes a cold front, which creates variable weather.

Review Questions

1. What type of air mass is created if a batch of air sits over the equatorial Pacific Ocean for a few days? What is the symbol for this type of air mass?

2. What conditions must be present for air to sit over a location long enough to acquire the characteristics of the land or water beneath it?

3. How does latitude affect the creation of air masses in tropical, temperate, and polar zones?

4. Why are the directions fronts move in the Southern Hemisphere a mirror image of the directions they move in the Northern Hemisphere?

5. How is a stationary front different from a cold or warm front?

6. What sorts of weather will you experience as a cold front passes over you?

7. What sorts of weather will you experience as a warm front passes over you?

8. How does an occlusion form?

9. What situation creates a cold occlusion and what creates a warm occlusion?

Further Reading / Supplemental Links

•Cold Front animation, Goddard Space Flight Center: http://svs.gsfc.nasa.gov/vis/a000000/a002200/a002203/index.html
•The University of Illinois online guide to weather basics: http://ww2010.atmos.uiuc.edu/%28Gl%29/guides/mtr/af/frnts/wfrnt/prcp.rxml

Points to Consider

•How do the various types of fronts lead to different types of weather?
•Why are some regions prone to certain types of weather fronts and other regions prone to other types of weather fronts?
•Why does the weather sometimes change so rapidly and sometimes remain very similar for many days?

Storms

Storms

Lesson Objectives

- Describe how atmospheric circulation patterns cause storms to form and travel.
- Understand the weather patterns that lead to tornadoes, and identify the different types of cyclones.
- Know what causes a hurricane to form, what causes it to disappear, and what sorts of damage it can do.
- Know the damage that heat waves and droughts can cause.

Vocabulary

- anticyclone
- blizzard
- cyclone
- heat wave
- hurricane
- lake-effect snow
- lightning
- mid-latitude cyclone
- nor'easter
- thunder
- thunderstorm
- tornado
- tropical depression

Introduction

Weather happens every day, but only some days have storms. Storms vary immensely depending on whether they're warm or cold, coming off the ocean or off a continent, occurring in summer or winter, and many other factors. The effects of storms also vary depending on whether they strike a populated area or a natural landscape. Hurricane Katrina is a good example, since the flooding after the storm severely damaged New Orleans, while a similar storm in an unpopulated area would have done little damage.

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.

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** below).

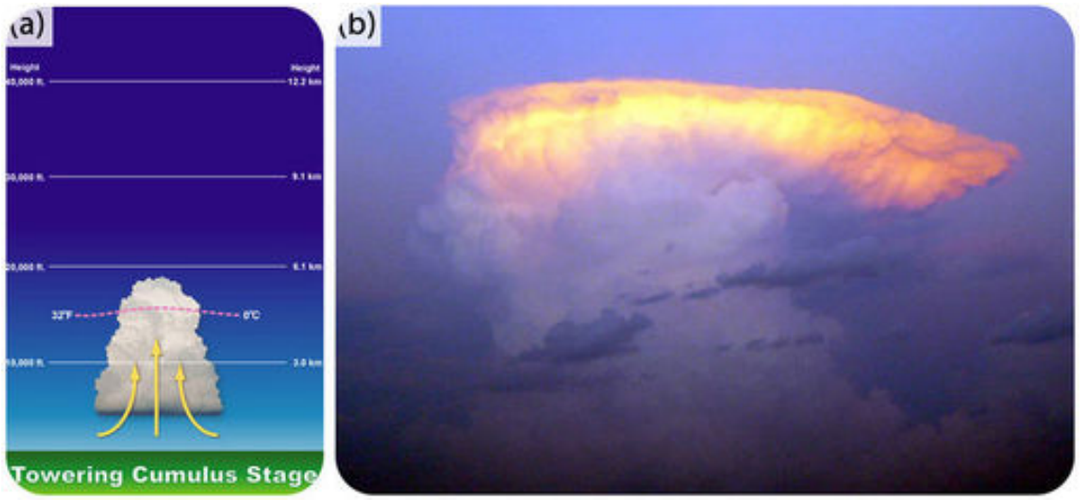


Figure 23.21

(a) As temperatures increase, warm, moist air rises. These updrafts first form cumulus and then cumulonimbus clouds. (b) 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** below).

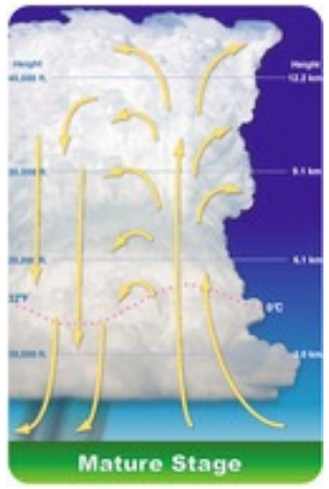


Figure 23.22

A mature thunderstorm with updrafts and downdrafts that reach the ground.

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.

With severe thunderstorms, the downdrafts are so intense that when they hit the ground it sends warm air from the ground 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.

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** below).

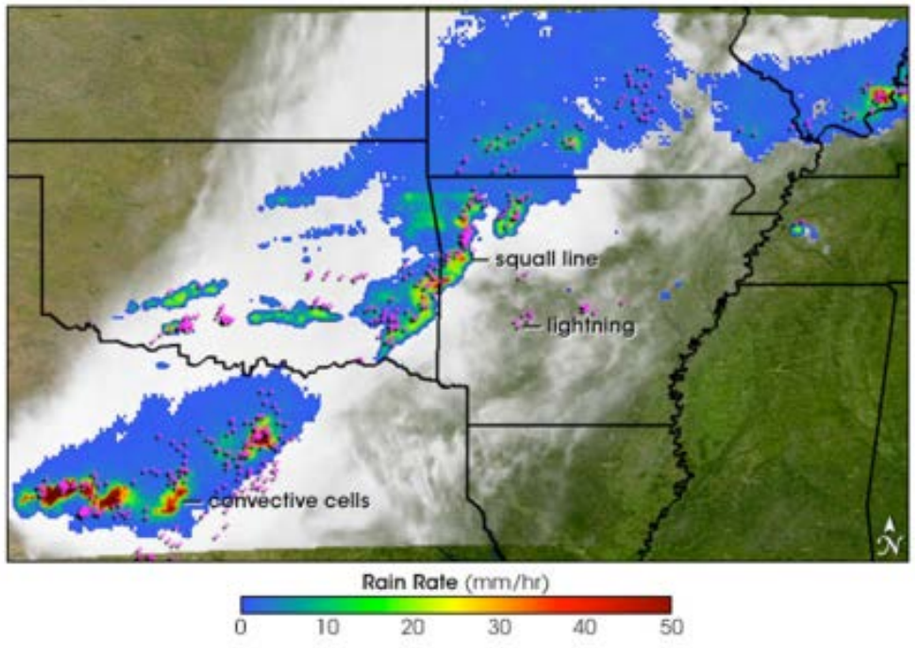


Figure 23.23

Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning** , may result (**Figure** below). The electrical discharge may be between one part of the cloud and another, two clouds, or a cloud and the ground.

A key ingredient of thunderstorms is explored in this National Geographic Video, Natural Disaster, Landslides, and more: Lightning 101 (2:38) (http://video.nationalgeographic.com/video/environment/environment-natural-disasters/landslides-and-more/lightning/).



Figure 23.24

Lightning behind the town of Villalonga, Spain.

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.

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** below).



Figure 23.25

Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

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 .

Tornadoes

Tornadoes , also called twisters, are fierce products of severe thunderstorms (**Figure** below). As air in a thunderstorm rises, the surrounding air races in to fill the gap, forming a funnel.



Figure 23.26

A tornado is a funnel shaped, whirling column of air extending downward from a cumulonimbus cloud. The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

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** below).



Figure 23.27

This tornado struck Seymour, Texas, in 1979.

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** below). 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.



Figure 23.28

Tornado damage at Ringgold, Georgia in April 2011.

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** below).

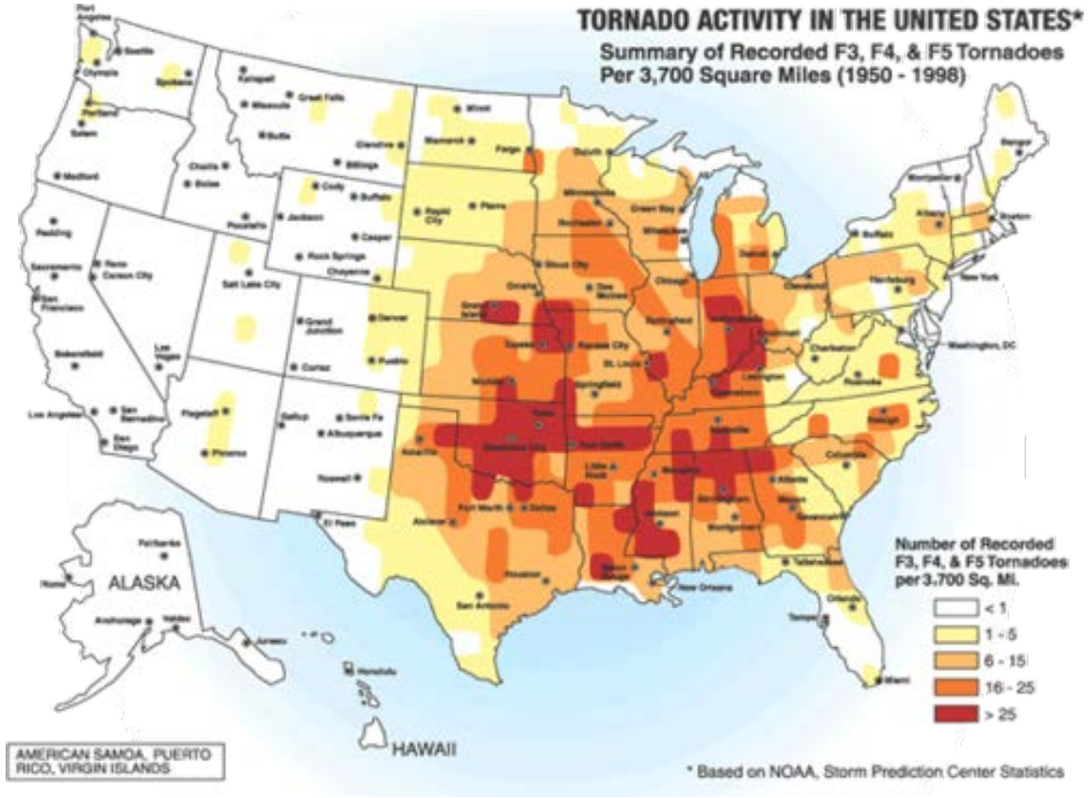


Figure 23.29

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 late April 2011, the situation was ripe for the deadliest set of tornadoes in 25 years. In addition to the meeting of cP and mT mentioned above, the jet stream was blowing strongly in from the west. The result was more than 150 tornadoes reported throughout the day (**Figure** below).

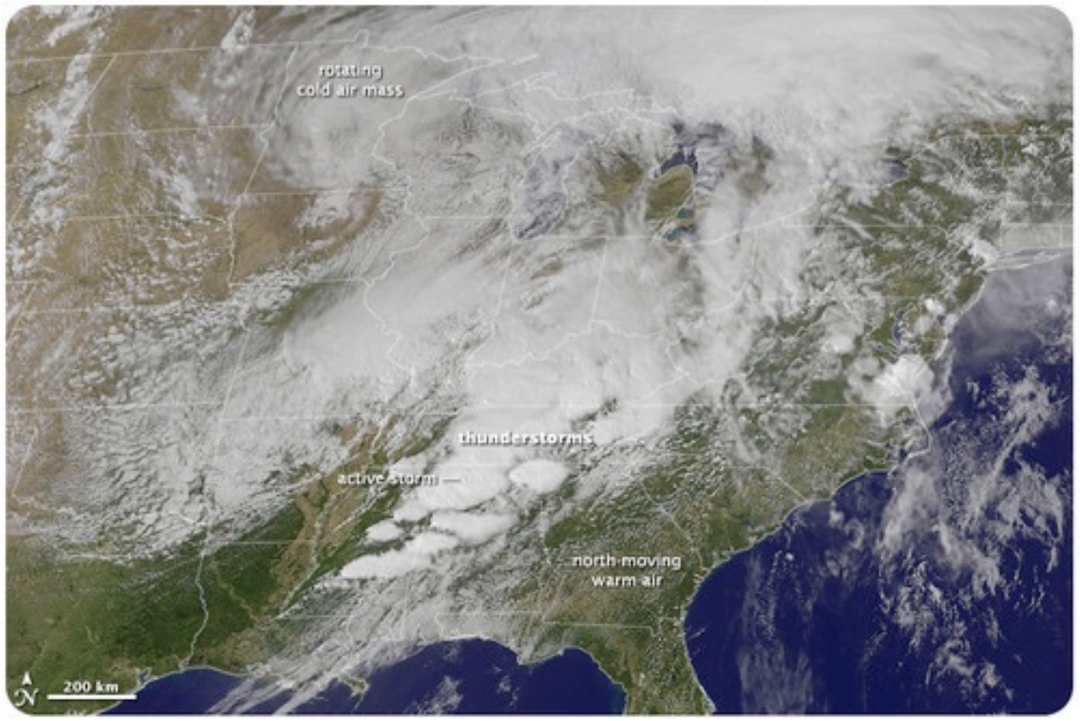


Figure 23.30

The severe thunderstorms pictured in this satellite image spawned the deadliest set of tornadoes in more than 25 years on 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.

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 .

The intensity of tornadoes is measured on the Fujita Scale (see **Table** below), which assigns a value based on wind speed and damage.

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	254-333	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

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.

There are two types of cyclones: middle latitude (mid-latitude) cyclones and tropical cyclones. Mid-latitude cyclones are the main cause of winter storms in the middle latitudes. Tropical cyclones are also known as hurricanes.

An **anticyclone** is the opposite of a cyclone. An anticyclone's winds rotate clockwise in the Northern Hemisphere around a center of high pressure. Air comes in from above and sinks to the ground. High pressure centers generally have fair weather.

Mid-Latitude Cyclones

Mid-latitude cyclones , sometimes called extratropical 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** below).

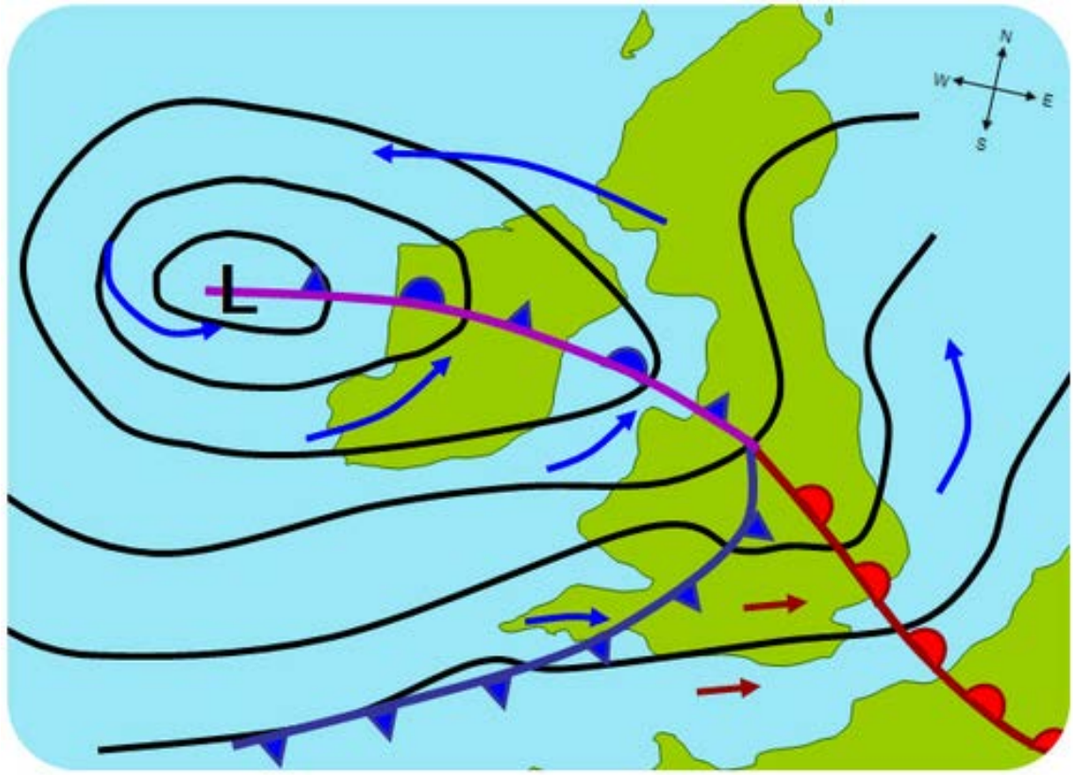


Figure 23.31

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.

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.

Like tropical cyclones, they can cause extensive beach erosion and flooding.

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** below).

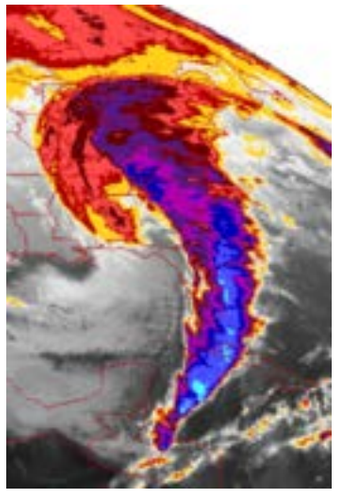


Figure 23.32

The 1993 "Storm of the Century" was a nor'easter that covered the entire eastern seaboard of the United States.

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 .

Hurricanes

Tropical cyclones have many names. They are called **hurricanes** in the North Atlantic and eastern Pacific oceans, typhoons in the western Pacific Ocean, tropical cyclones in the Indian Ocean, and willi-willi's in the waters near Australia (**Figure** below). By any name, they are the most damaging storms on Earth.

Hurricanes arise in the tropical latitudes (between 10 ◦ and 25 ◦ N) in summer and autumn when sea surface temperature are 28 ◦ C (82 ◦ F) 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 ◦ C (82 ◦ F) 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.

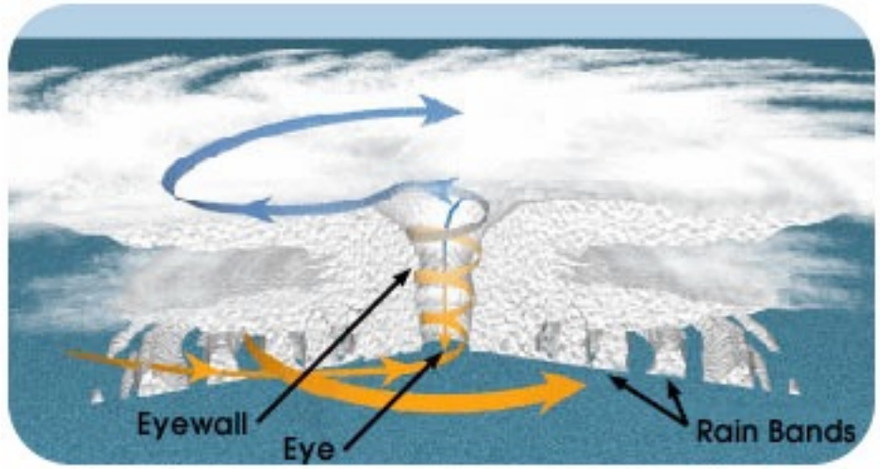


Figure 23.33

A cross-sectional view of a hurricane.

Hurricanes are huge with 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.

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (**Table** below).

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
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

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.

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.

Hurricanes typically last for 5 to 10 days. Over cooler water or land, the hurricane’s latent heat source shut downs and the storm weakens. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

Hurricanes are explored in a set of National Geographic videos found at National Geographic Video, Natural disaster, Hurricanes:

- “Hurricanes 101” is an introduction to the topic.
- “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.

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.

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 .

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** below) and (**Figure** below).

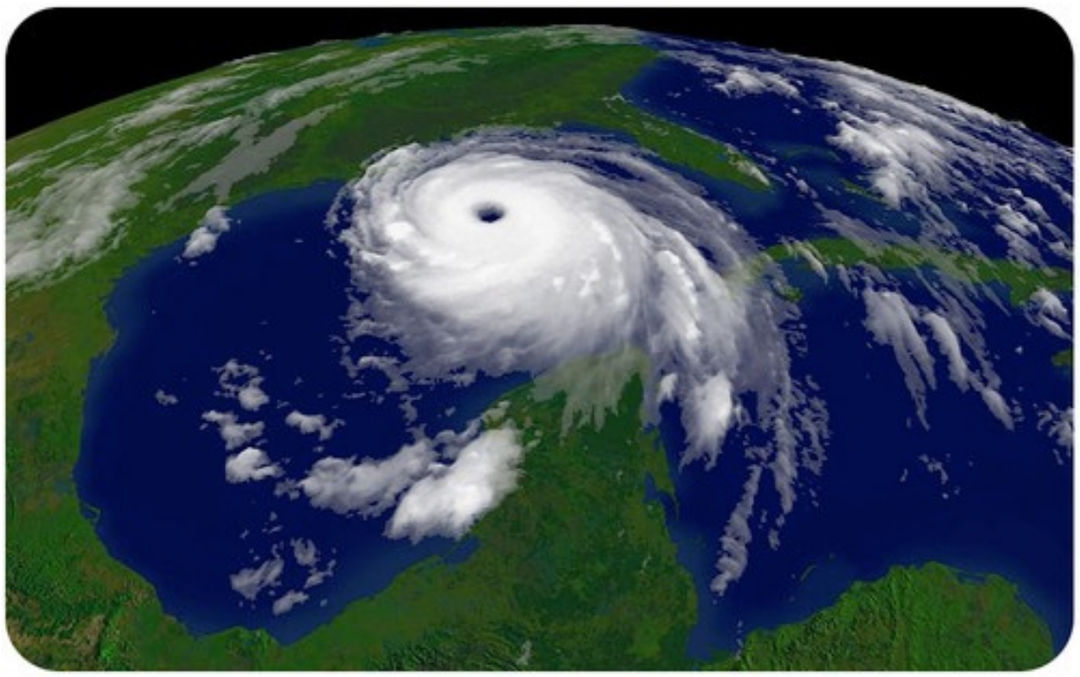


Figure 23.34

Hurricane Katrina nears its peak strength as it travels across the Gulf of Mexico.

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 .



Figure 23.35

Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.



Blizzards and Lake-Effect Snow

A **blizzard** is distinguished by certain conditions (**Figure** below):

- Temperatures below –7 ◦C (20 ◦F); –12 ◦C (10 ◦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.

Figure 23.36

A near white out in a blizzard in Washoe Valley, Nevada.

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** below). 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 23.37

Blizzard snows blanket the East Coast of the United States in February 2010.

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** below).

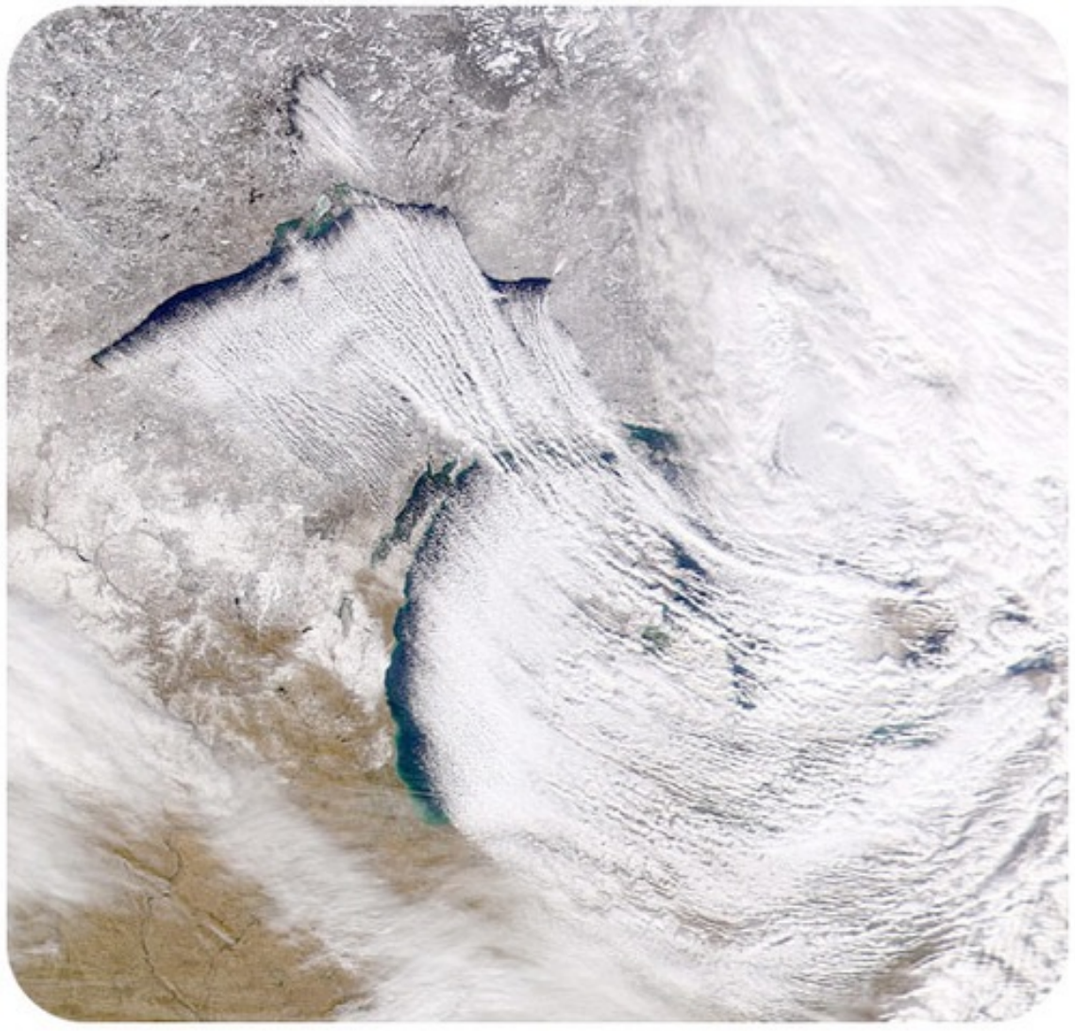


Figure 23.38

Frigid air travels across the Great Lakes and dumps lake-effect snow on the leeward side.

Heat Wave

Even more insidious are the deadliest weather phenomena, a **heat wave** . A heat wave is different for different locations; it is a long period of hot weather, at least 86 ◦F (30 ◦C) for at least three days

in cooler locations but much more in hotter locations. Heat waves have increased in frequency and duration in recent years.

What do you think caused the heat wave in the image below (**Figure** below)? A high pressure zone kept the jet stream further north than normal for August.

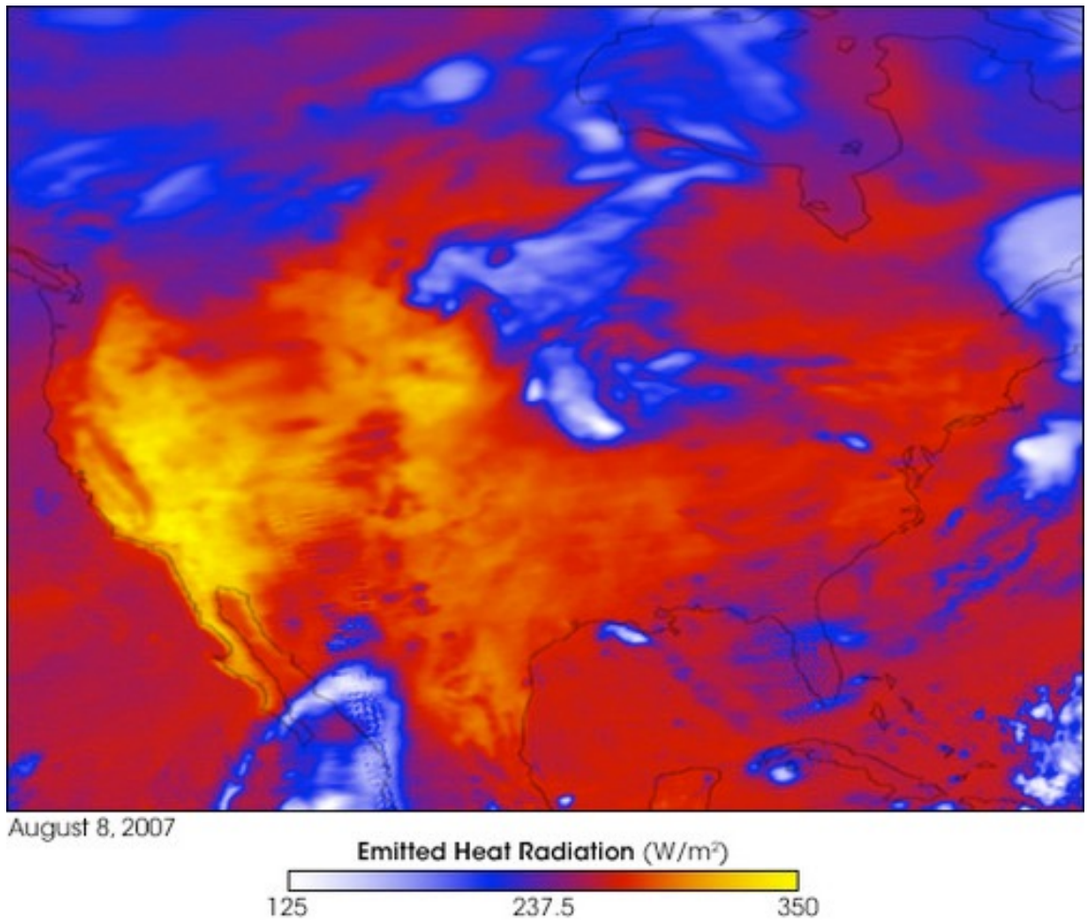


Figure 23.39

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.

Lesson Summary

- Thunderstorms arise over warm ground when updrafts form cumulonimbus clouds that rain and hail.
- Tornadoes form most commonly from thunderstorms. They are relatively short-lived and small, but they do an enormous amount of damage where they strike.
- Cyclones of all sorts are large and damaging; they include nor'easters and hurricanes.

Review Questions

1. Describe in detail how a thunderstorm forms and where the energy to fuel it comes from. Start with a warm day and no clouds.

2. How does a thunderstorm break apart and disappear?

3. Why does a thunderstorm get more severe rather than losing energy and disappearing?

4. What are lightning and thunder?

5. Discuss the pros and cons of living in an area that is prone to tornadoes versus one that is prone to hurricanes.

6. Where are tornadoes most common in the United States?

7. What is a cyclone? What are the two types of cyclone and how do they differ?

8. Describe in detail how a hurricane forms.

9. What level is the most damaging hurricane on the Saffir-Simpson scale? What sorts of damage do you expect from such a strong hurricane?

10. What causes damage from hurricanes?

11. What could have been done in New Orleans to lessen the damage and deaths from Hurricane Katrina?

12. Do you think New Orleans should be rebuilt in its current location?

13. Where do blizzards develop?

Further Reading / Supplemental Links

Hunt for the Supertwister from PBS: http://access.ncsa.illinois.edu/Stories/supertwister/index.htm

Points to Consider

- Why is predicting where tornadoes will go and how strong they will be so difficult?
- How would the damage done by Hurricane Katrina have been different if the storm had taken place 100 years ago?
- What knowledge do meteorologists need to better understand storms?

Section 4

Weather Forecasting

Weather Forecasting

Lesson Objectives

- List some of the instruments that meteorologists use to collect weather data.
- Describe how these instruments are used to collect weather data from many geographic locations and many altitudes.
- Discuss the role of satellites and computers in modern weather forecasting.
- Describe how meteorologists develop accurate weather forecasts.

Vocabulary

- barometer
- isobars
- isotachs
- isotherms
- radar
- radiosonde
- thermometer
- weather map

Introduction

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! This is because forecasters now use advanced technologies to gather weather data, along with the world's most powerful computers. Together, the data and computers produce complex models that more accurately represent the conditions of the atmosphere. These models can be programmed to predict how the atmosphere and the weather will change. Despite these advances, weather forecasts are still often incorrect. Weather is extremely difficult to predict because it is a complex and chaotic system.

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 (**Figure** below). A barometer may contain water, air, or mercury, but like thermometers, barometers are now mostly digital.

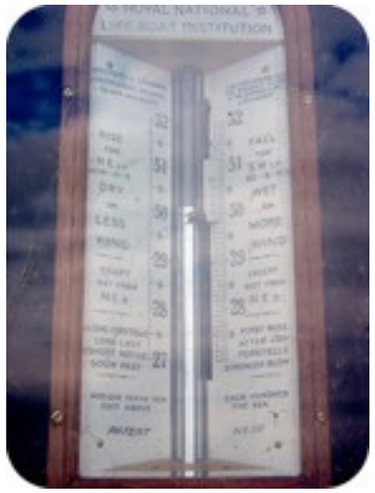


Figure 23.40

Barometers use mercury columns to measure air pressure.

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** below).



Figure 23.41

A land-based weather station. Weather stations are located on land, the surface of the sea, and in orbit all around the world.

According to the WMO, 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 (**Figure** below). 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.



Figure 23.42

A weather balloon with a radiosonde beneath it. The radiosonde is the bottom piece and the parachute that will bring it to the ground is above it.

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** below). 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.

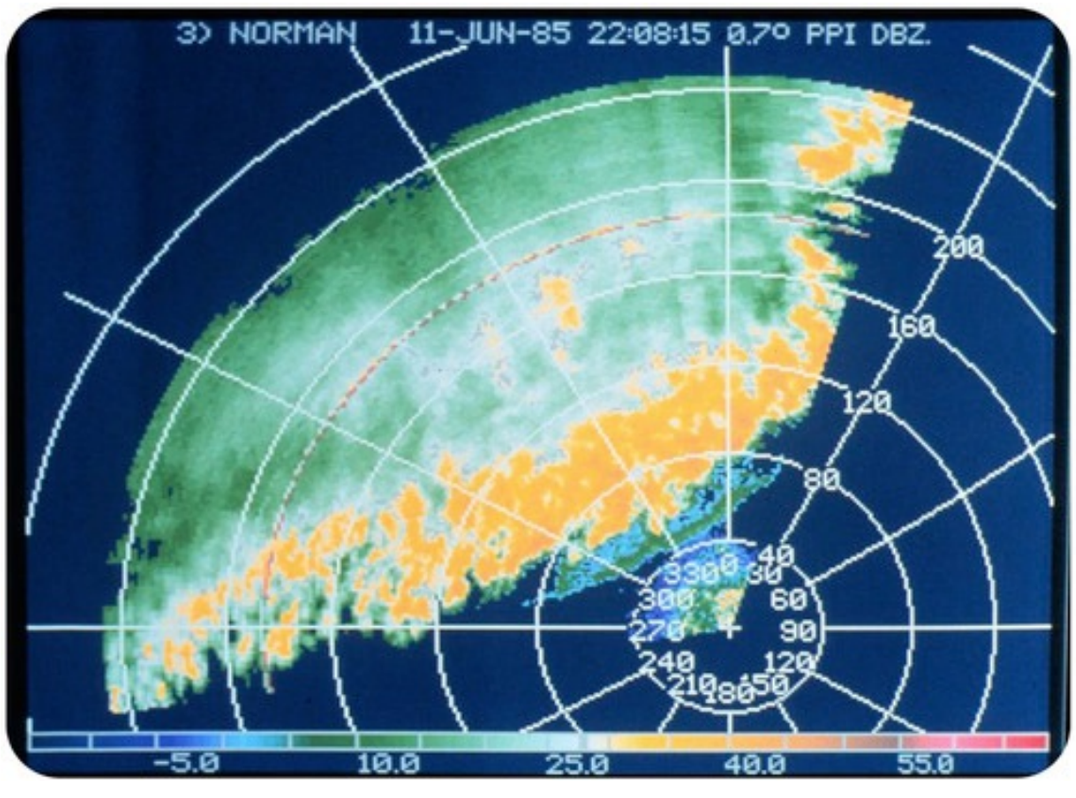


Figure 23.43

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** below).

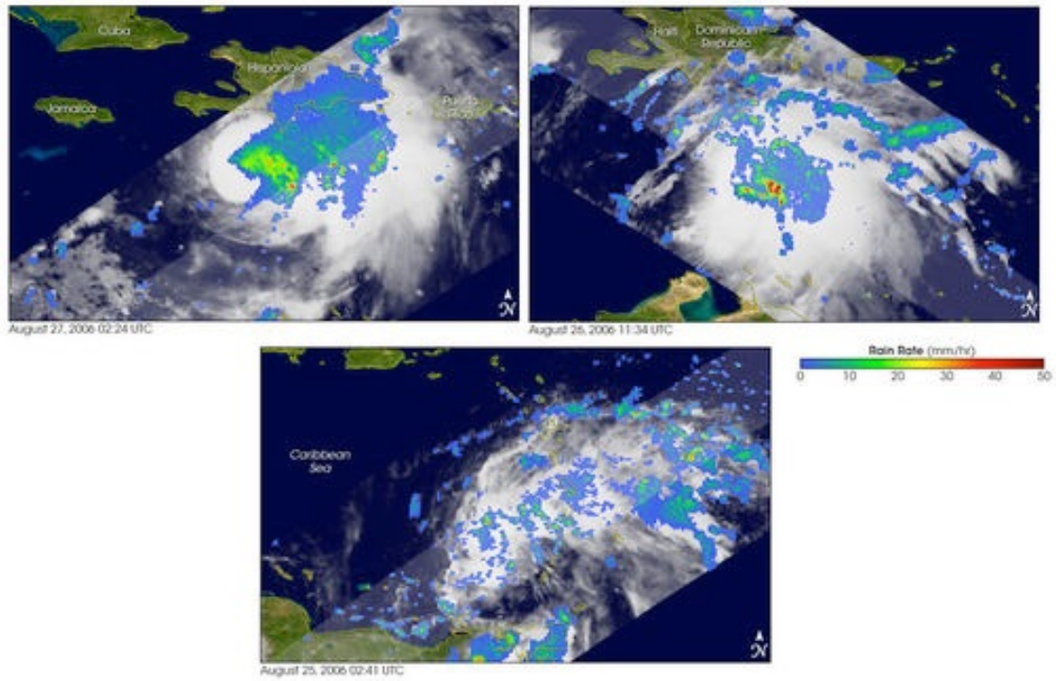


Figure 23.44

Infrared data superimposed on a satellite image shows rainfall patterns in Hurricane Ernesto in 2006.

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 .

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** below). 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.

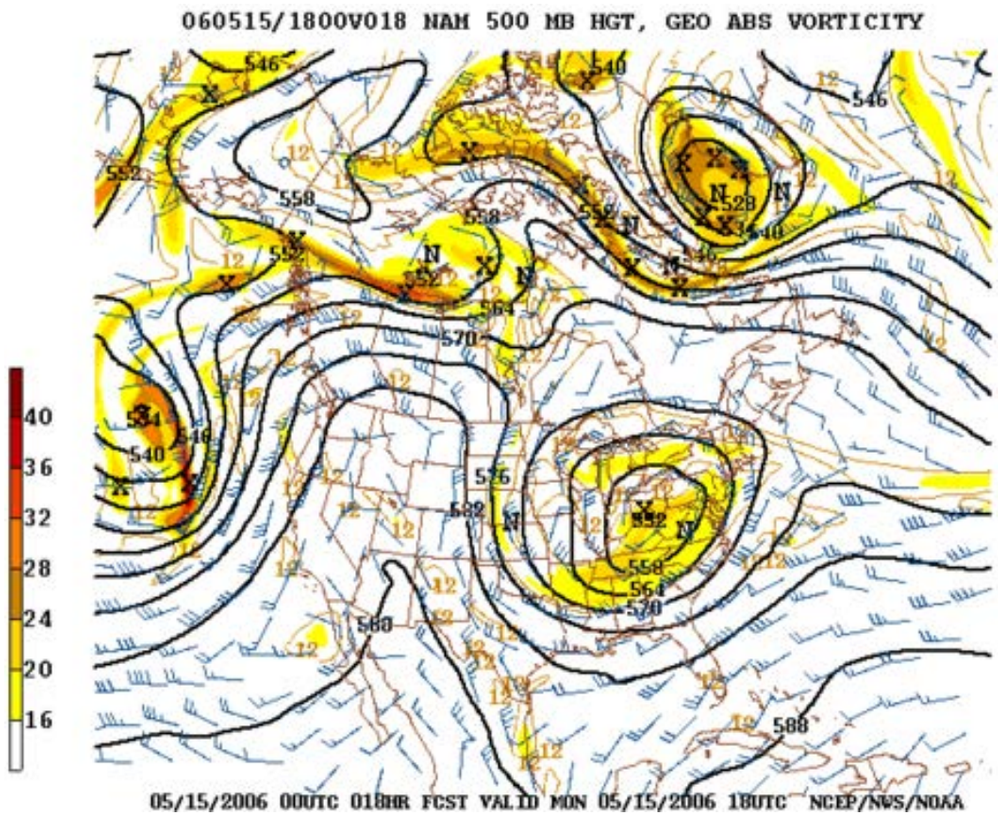


Figure 23.45

A weather forecast using numerical weather prediction.

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** below).



Figure 23.46

By predicting Hurricane Rita's path, it is likely that lives were saved.

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** below).

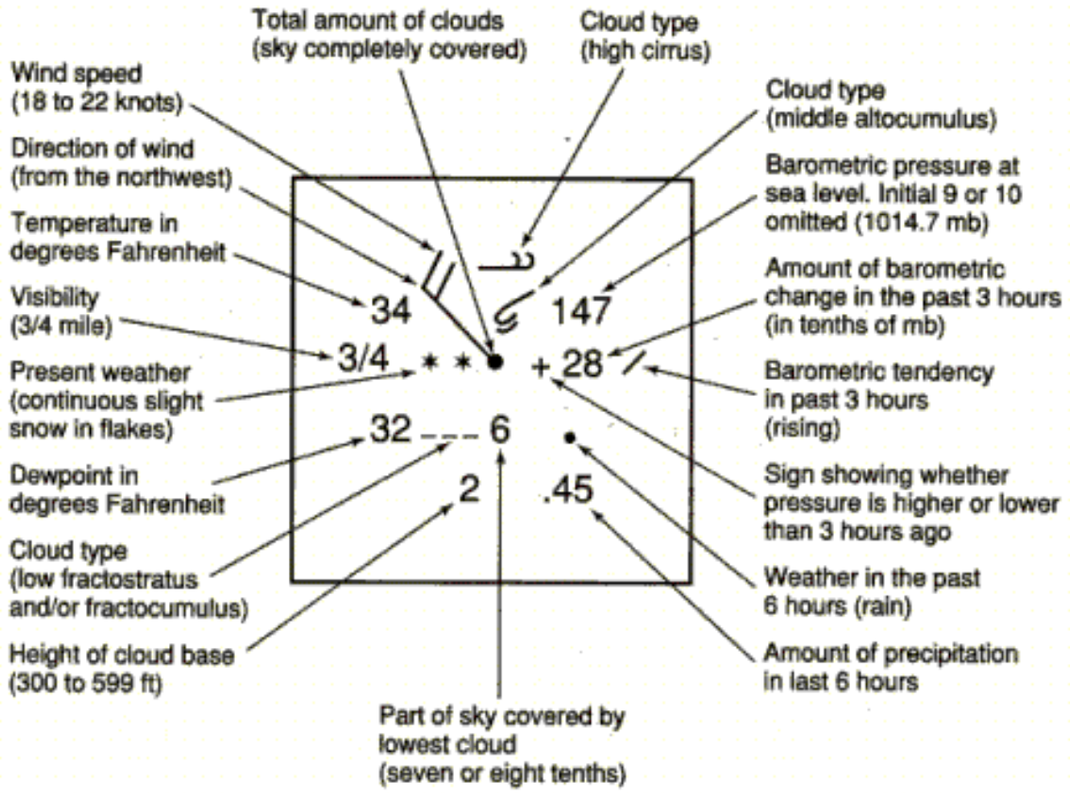


Figure 23.47

Explanation of some symbols that may appear on a weather map.

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:

•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 ◦C (32 ◦F) 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** below). Closed isobars represent the locations of high and low pressure cells.

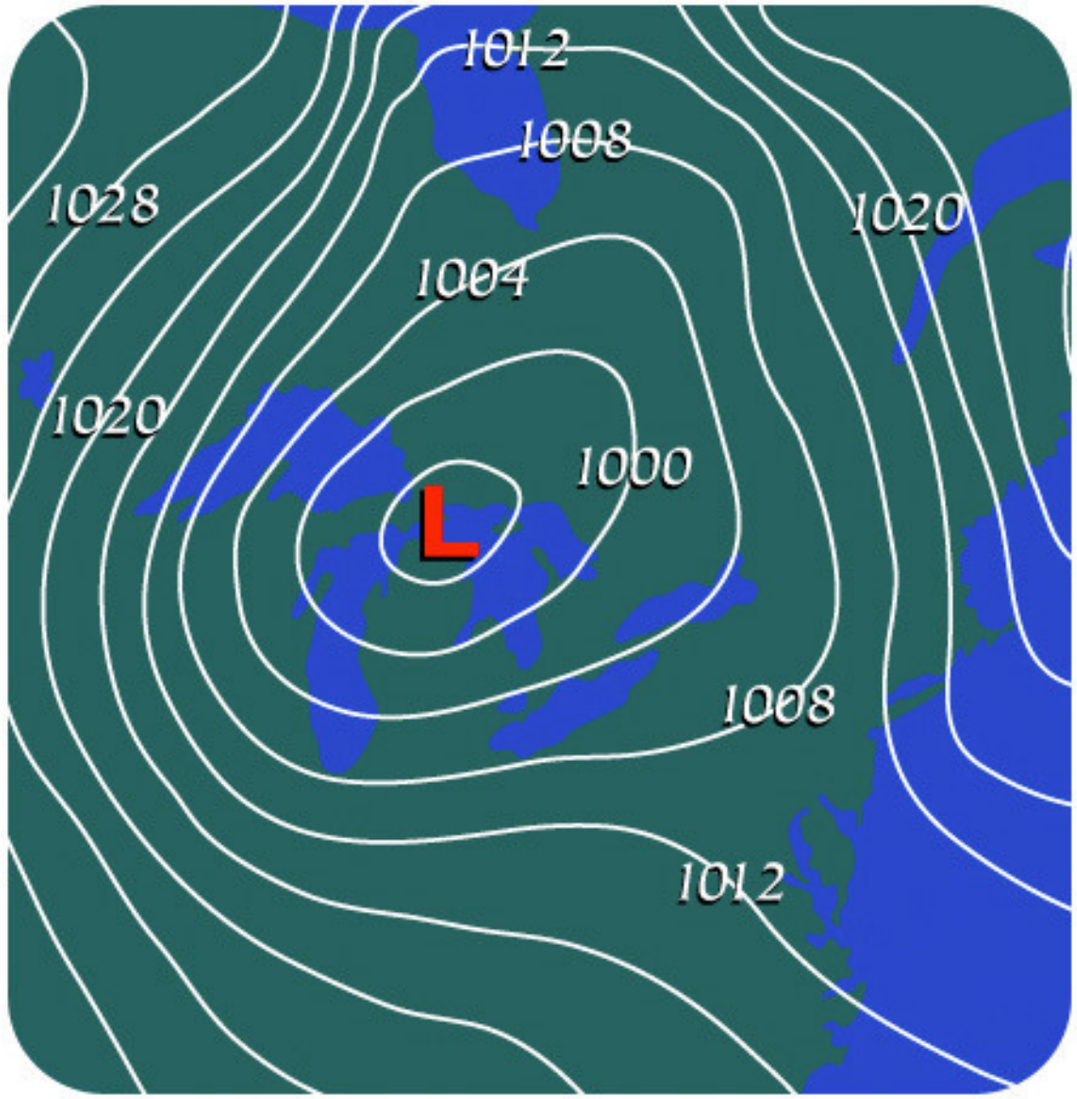


Figure 23.48

Isobars can be used to help visualize high pressure (H) and low pressure (L) 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** below).

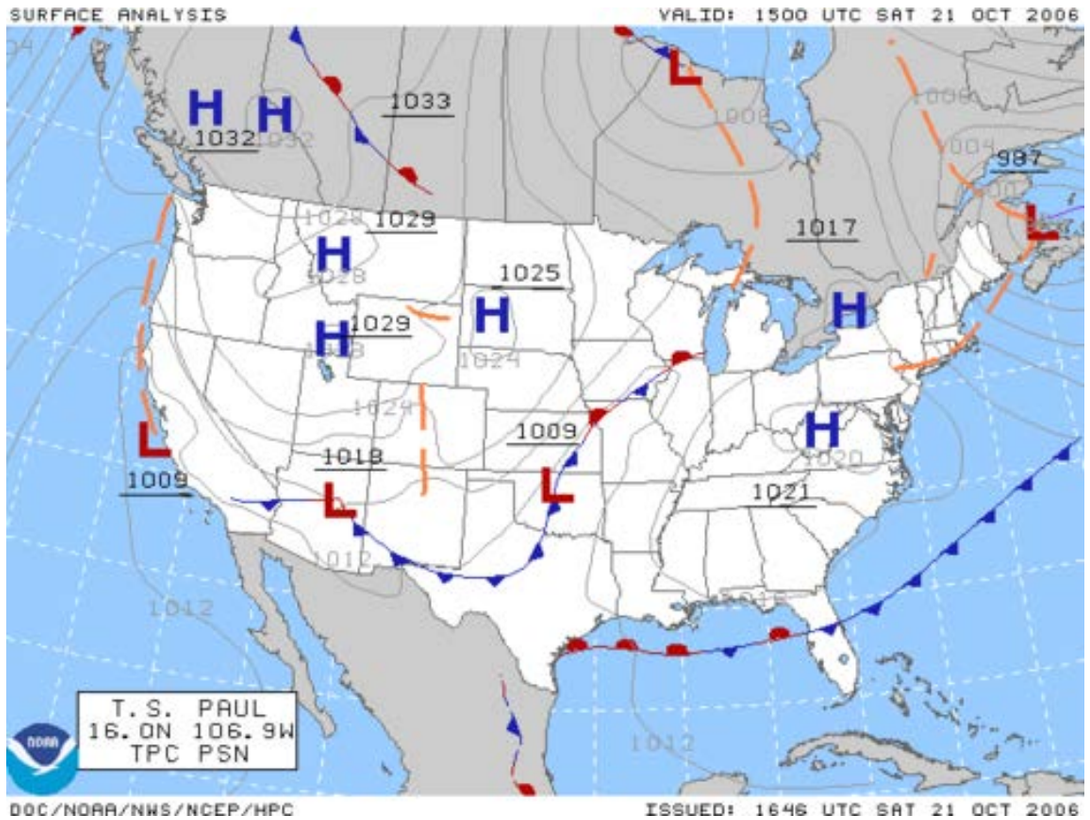


Figure 23.49

Surface analysis maps may show sea level mean pressure, temperature, and amount of cloud cover.

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 .

Lesson Summary

- Weather forecasts are more accurate than ever before. Older instruments and data collection methods, such as radiosondes and weather balloons, are still used.
- Satellites and computers create much more detailed and accurate forecasts.
- Forecasts are often wrong, particularly those that predict the weather for several days.

Review Questions

1. What types of instruments would you expect to find at a weather station and what do these instruments measure?

2. How does a thermometer work?

3. How could a barometer at a single weather station predict an approaching storm?

4. Why are weather balloons important for weather prediction? What information do they give that isn't obtainable in other ways?

5. How does radar work, and what is its value in weather prediction?

6. Imagine that your teacher asks you to predict what the weather will be like tomorrow. You can go outside or use a telephone, but can't use a TV or computer. What method will you use?

7. Same as above only now you have access to electronics but not weather forecasts. You can look at weather maps and radar images but not look at interpretations made by a meteorologist. What method will you use?

8. No rain is in the forecast, but it's pouring outside. How could the NWP weather forecast have missed this weather event?

9. What does it mean to say that weather is a chaotic system? How does this affect the ability to predict the weather?

Further Reading / Supplemental Links

- National Doppler Radar Sites http://radar.weather.gov/
- Google Earth Visualizations, Barnabu http://www.barnabu.co.uk/global-cloud-animations-update/

Points to Consider

- With so much advanced technology available, what is the role of meteorologists in creating accurate weather forecasts?
- With so much advanced technology available, why are weather forecasts so often wrong?
- What advances do you think will be necessary for meteorologists to create accurate weather forecasts one- to two-weeks in advance of a major weather event?

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Ch. 21: Ecosystems and Human Populations



A lot of information is shown in this image of Earth's city lights. Although there is a map underlying the lights, why is it possible to see the outlines of the continents in many locations anyway? What does this tell about where cities are located? What geographical features can you locate? Can you find the Nile River? The Himalaya Mountains? The Sahara Desert?

What characteristics do the regions with the brightest lights share? What is different about them? How do they differ from the regions that are dark? What characteristics do those dark regions share and what is different about them?

The regions with the brightest lights are the most urbanized. Do they have the largest populations? Do they have the largest population densities? The brightest lights are found in the eastern half of the United States, Europe, and Japan. But the nations with the highest populations are China and India and the highest population densities are in some tiny countries such as Bangladesh, Taiwan, South Korea, and parts of Africa.

Can you locate your town?

Can you locate your town?

Courtesy of Craig Mayhew and Robert Simmon, NASA GSFC. earthobservatory.nasa.gov/IOTD/view.php?id=896. Public Domain.

Section 1

Ecosystems

Ecosystems

Lesson Objectives

•Discuss the importance of chemical and physical factors to living organisms.
•Describe the role of different species in an ecosystem.
•Describe the function of an ecosystem, and how different species fill different roles in different ecosystems.
•Describe energy transfer from the lowest to the highest trophic level in a chain, including energy loss at every trophic level.
•Discuss how materials are cycled between trophic levels and how they can enter or leave a food web at any time.

Vocabulary

•abiotic
•biotic
•carnivore
•commensalism
•community
•competition
•consumer
•decomposer
•ecosystem
•food chain
•food web
•habitat
•herbivore
•mutualism
•niche
•nutrients
•omnivore
•parasitism
•population
•predator
•prey
•producer
•scavenger
•species
•symbiosis
•trophic level

Introduction

An **ecosystem** is made up of the living creatures and the nonliving things that those creatures need within an area. Energy moves through an ecosystem in one direction. Nutrients cycle through different parts of the ecosystem and can enter or leave the ecosystem at many points.

Biological Communities

A **population** consists of all individuals of a single **species** that occur 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 . An ecosystem is all of the living things in a community and the physical and chemical factors that they interact with.

In an Ecosystem

The living organisms within an ecosystem are its **biotic** factors (**Figure** below). Living things include bacteria, algae, fungi, plants , and animals, including invertebrates, animals without backbones, and vertebrates, animals with backbones.



Figure 24.1

(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. Abiotic factors also include environmental features that are not materials or living things, such as living space and the right temperature range.

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** below). Every species fills a niche, and niches are almost always filled in an ecosystem.



Figure 24.2

The top carnivore niche is filled by lions on the savanna, wolves in the tundra, and tuna in the oceans.

Habitat

An organism’s **habitat** is where it lives (**Figure** below). The important characteristics of a habitat include climate, the

availability of food, water, and other resources, as well as other factors, such as weather.



Figure 24.3

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.

Roles in Ecosystems

There are many different types of ecosystems, some of which were described in the biomes discussion in the Climate chapter (**Figure** below). As with biomes, climate conditions determine which ecosystems are found in which location. A particular biome encompasses all of the ecosystems that have similar climate and organisms.



Figure 24.4

Coral reefs are complex and beautiful ecosystems.

Different organisms live in each different type of ecosystems. Lizards thrive in deserts, but no reptiles can survive at all in polar ecosystems. 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, described in the Earth's Atmosphere chapter and elsewhere.
- Chemosynthesis: bacteria at hydrothermal vents as discussed in the Earth's Oceans chapter.

Organisms that use the food energy that was created by producers are named **consumers** . There are many types of consumers.

- **Herbivores** eat producers directly (**Figure** below). 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.



Figure 24.5

Deer are herbivores.

Feeding Relationships

There are many types of feeding relationships (**Figure** below) between organisms: **predators** that feed on **prey** , **scavengers** , **and decomposers** .



Figure 24.6

(a) A predator is an animal that kills and eats another animal, known as its prey. (b) Scavengers are animals, such as vultures and hyenas, that eat organisms that are already dead. (c) Decomposers break apart dead organisms or the waste material of living organisms, returning the nutrients to the ecosystem. Bacteria and fungi are decomposers.

Flow of Energy in Ecosystems

Remember from the Earth's Atmosphere chapter that 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** below)?

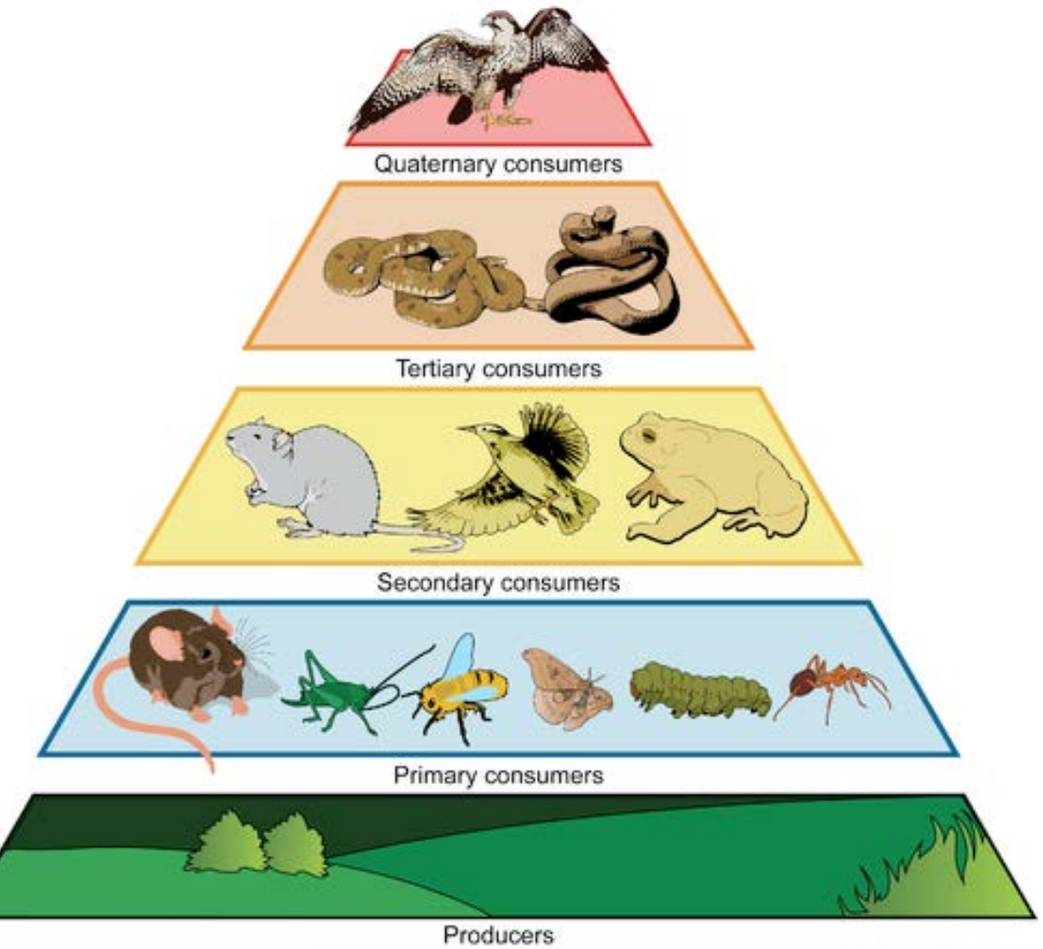


Figure 24.7

Producers are always the first trophic level, herbivores the second, the carnivores that eat herbivores the third, and so on.

Most of the energy – about 90% – at a trophic level 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** below). In this simple depiction, all organisms eat at only one trophic level (**Figure** below).



Figure 24.8

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?

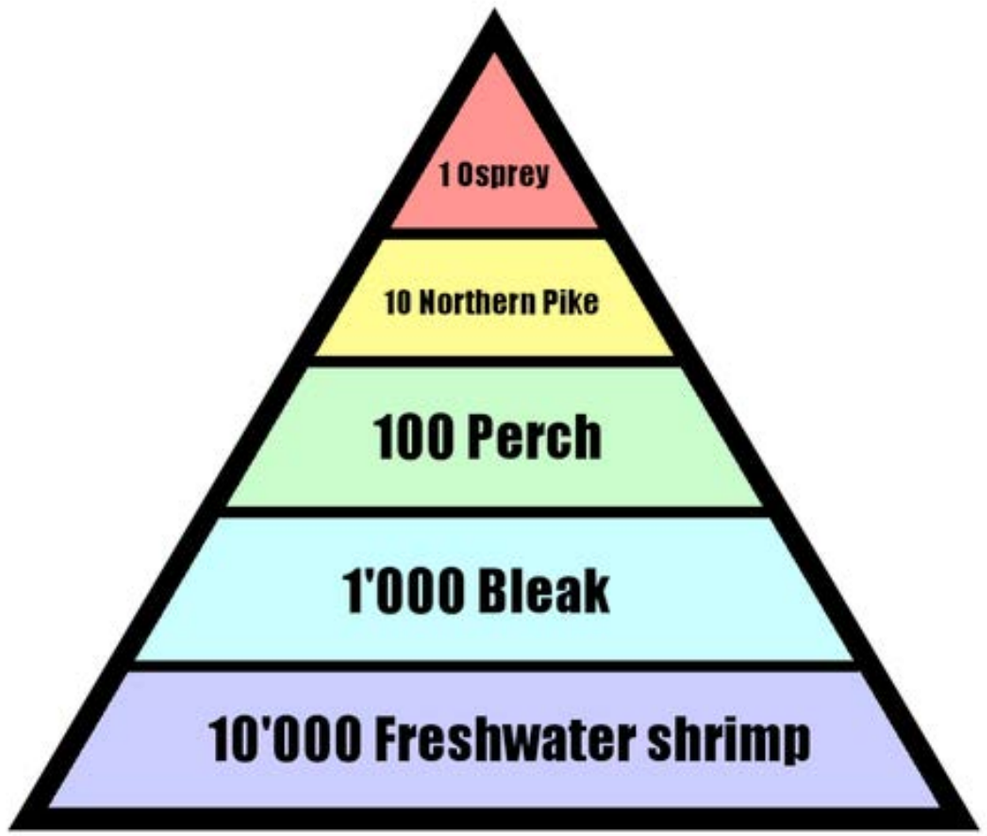


Figure 24.9

What are the consequences of the loss of energy at each trophic level? Each trophic level can support fewer organisms. How many osprey are there relative to the number of shrimp?

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** below).



Figure 24.10

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** below) recognizes that many organisms eat at multiple trophic levels.

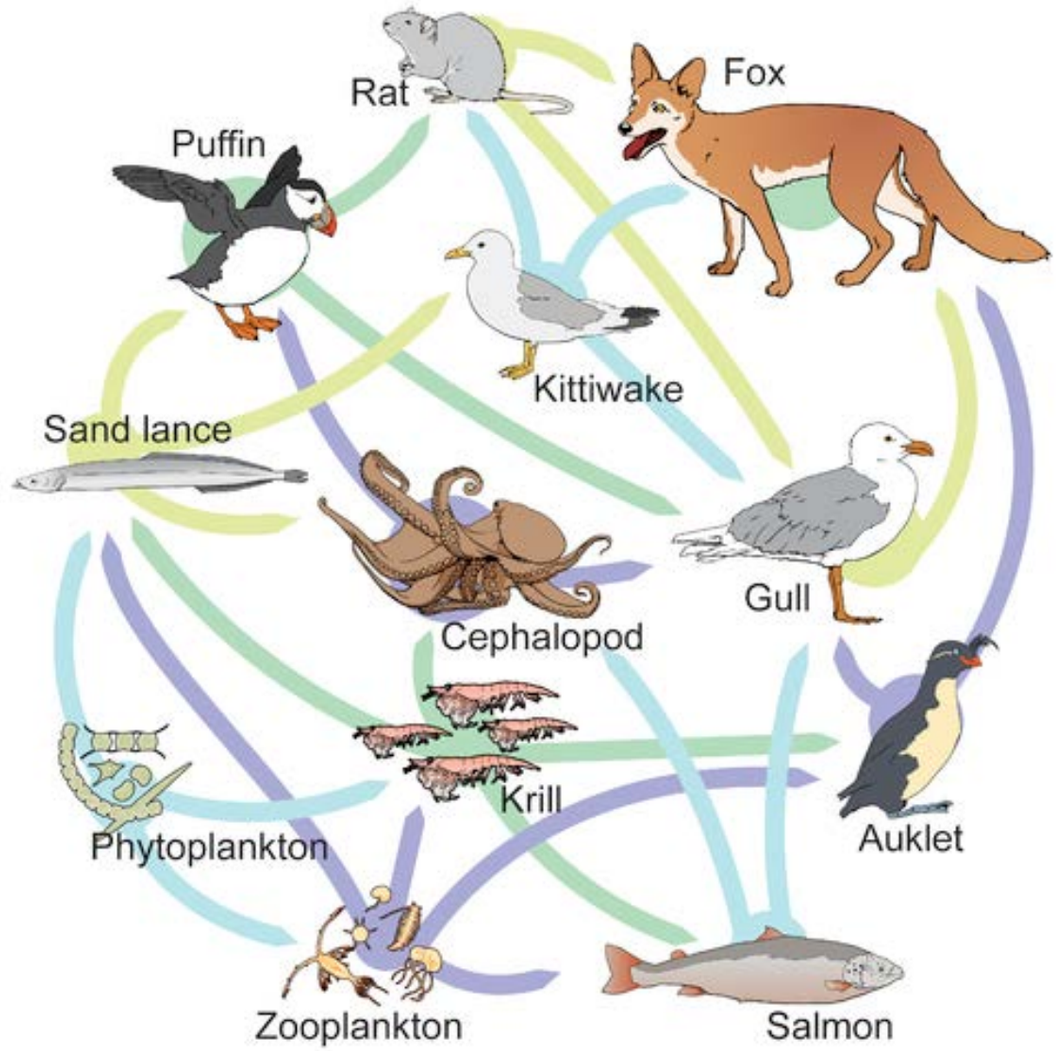


Figure 24.11

A food web includes the relationships between producers, consumers, and decomposers.

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.

Where do humans fit into these 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. That means that we are top predators.

Flow of Matter in Ecosystems

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.

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** below).

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. Decaying leaves may be transported out of an ecosystem by a stream. Wind or water carries nutrients out of an ecosystem.

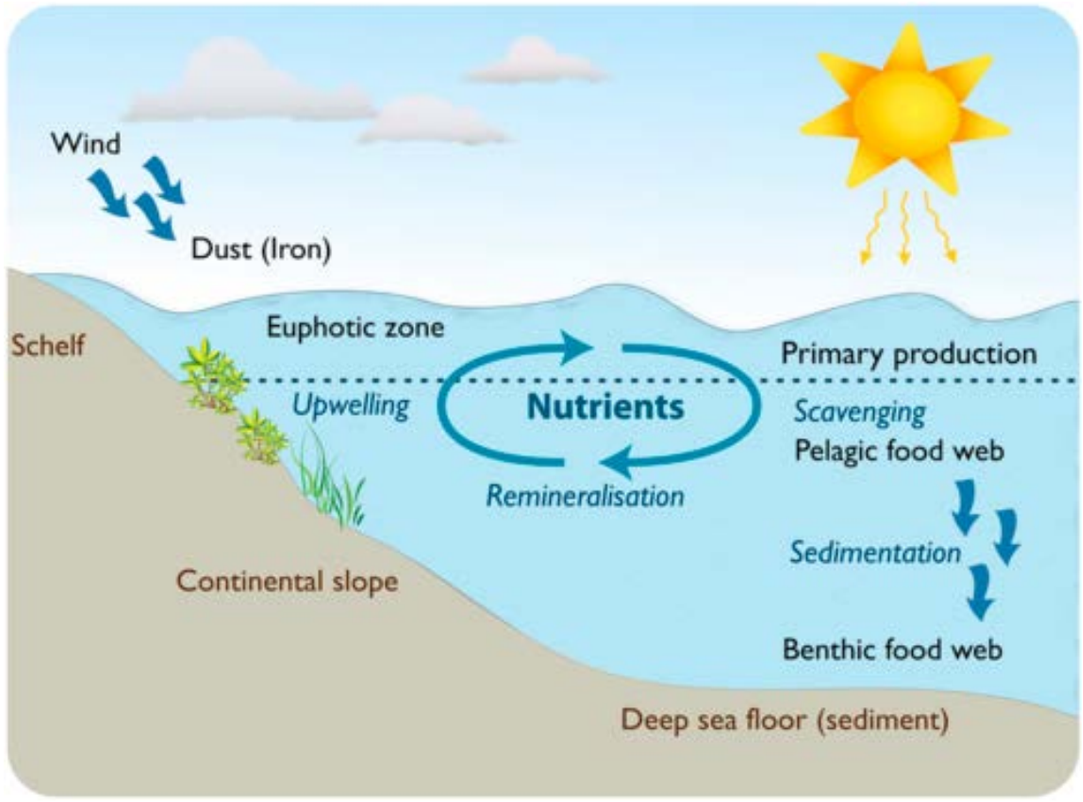


Figure 24.12

Nutrients cycle through ocean food webs.

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.

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.
- 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 caption in the **Figure** below .



Figure 24.13

(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.

Lesson Summary

- Each species fills a niche within an ecosystem. Each ecosystem has the same niches, although the same species don't always fill them.
- Each ecosystem has producers, consumers, and decomposers. Decomposers break down dead tissue to make nutrients available for living organisms.
- Energy is lost at each trophic level, so top predators are scarce.
- Feeding relationships are much more complicated than a food chain, since some organisms eat from multiple trophic levels.
- Food webs are needed to show all the predator/prey interactions in an ecosystem.

Review Questions

1. What is the difference between a population, a community, and an ecosystem?

2. What is the difference between a niche and a habitat?

3. Why are the roles in different ecosystems the same but the species that fill them often different?

4. Why are there no producers in the deep sea ecosystem? Without producers, where does the energy come from? What is the ultimate source of the energy?

5. Is a predator an herbivore, carnivore, or omnivore? How about a prey?

6. Biologists have been known to say that bacteria are the most important living things on the planet. Why would this be true?

7. Why are you so much more likely to see a rabbit than a lion when you're out on a hike?

8. How much energy is available to organisms on the 5th trophic level compared with those on the 1st? How does this determine how long a food chain can be?

9. Why is a food web a better representation of the feeding relationships of organisms than a food chain?

10. Why is energy only transferred in one way in an ecosystem, but nutrients cycle around?

11. Why does a predator kill its prey but a parasite rarely kills its host?

Points to Consider

- What happens if two species attempt to fill the same niche?
- There is at least one exception to the rule that each ecosystem has producers, consumers, and decomposers. Excluding hydrothermal vents, what does the deep sea ecosystem lack?
- Where do humans fit into a food web?
- Most humans are omnivores, but a lot of what we eat is at a high trophic level. Since ecosystems typically can support only a few top predators relative to the number of lower organisms, why are there so many people?

Section 2

The Carbon Cycle and the

The Carbon Cycle and the Nitrogen Cycle

Lesson Objectives

- Describe the short term cycling of carbon through the processes of photosynthesis and respiration.
- Identify carbon sinks and carbon sources.
- Describe short term and long term storage of carbon.
- Describe how human actions interfere with the natural carbon cycle.
- Describe the nitrogen cycle.

Vocabulary

- carbohydrate
- carbon sink
- carbon source
- deforestation

Introduction

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 and is found throughout the environment (**Figure** below). The element moves through organisms and then returns to the environment. When all this happens in balance, the ecosystem remains in balance too. In this section, let's follow the path of a carbon atom over many years and see what happens.

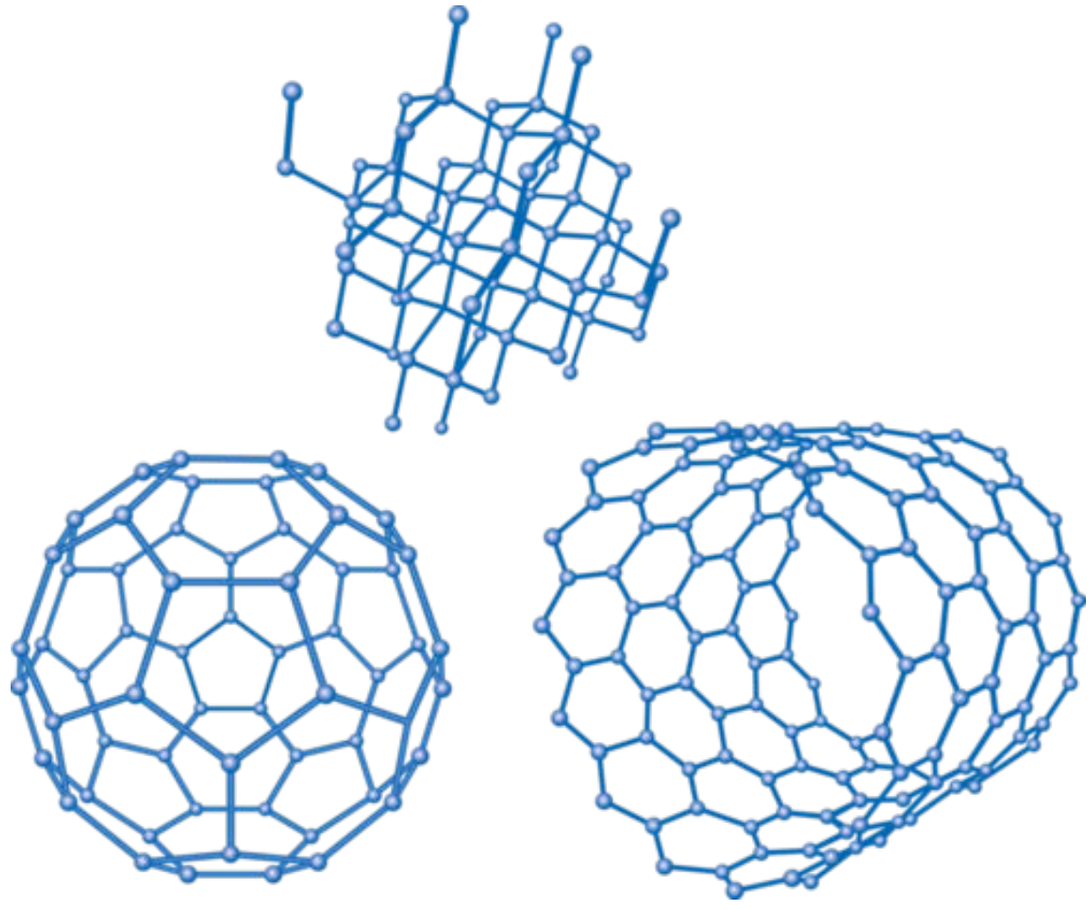


Figure 24.14

These are some of the structures that carbon takes.

Nitrogen is also a very important element, used as a nutrient for plant and animal growth. First, the nitrogen must be converted to a useful form. Without "fixed" nitrogen, plants, and therefore animals, could not exist as we know them.

Short Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide (CO_2) in the atmosphere.

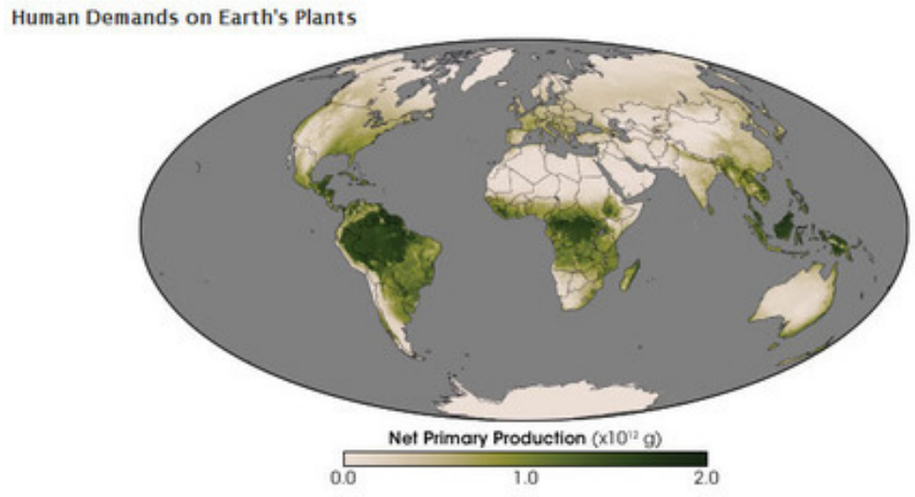


Figure 24.15

The production of food energy by land plants.

Through photosynthesis, the inorganic carbon in carbon dioxide plus water and energy from sunlight is transformed into organic carbon (food) (**Figure** above) with oxygen given off as a waste product. The chemical equation for photosynthesis is below:

$$6\ CO_2 + 6\ H_2O + \text{Energy from sunlight} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

carbon dioxide water glucose (sugar) oxygen

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:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{useable energy}$$

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2.

Do plants create energy? It is important to 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** below).

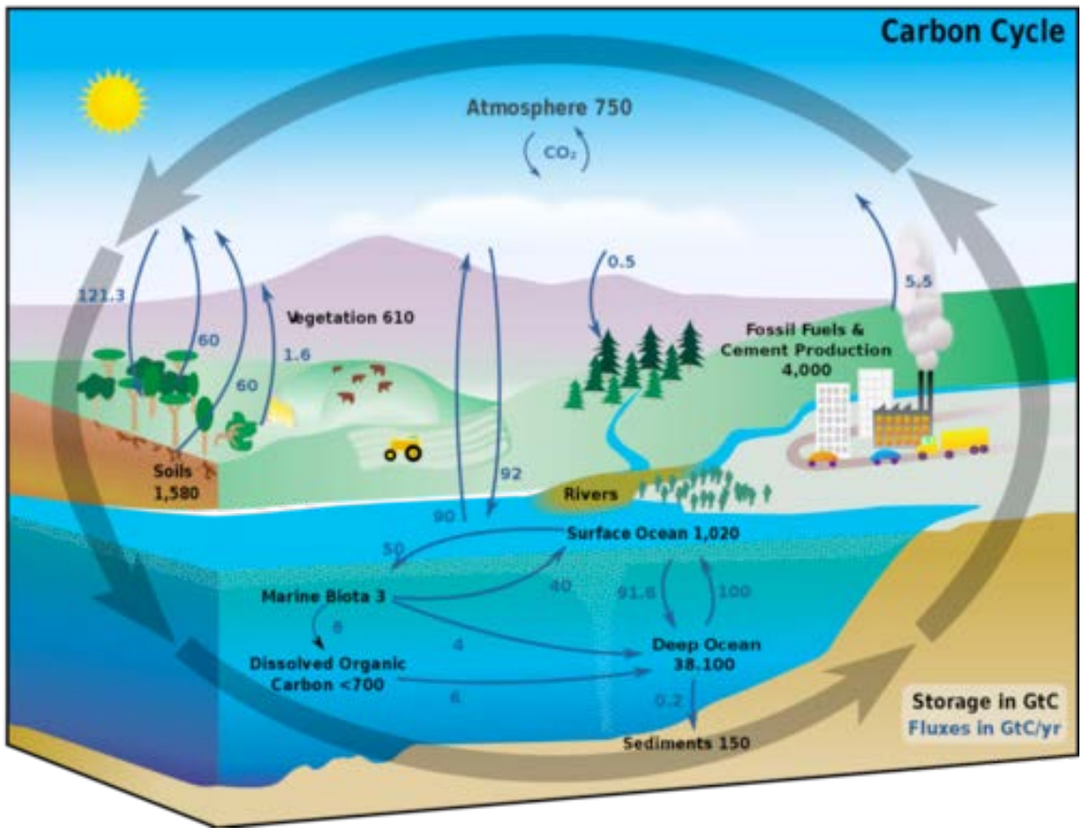


Figure 24.16

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.

Carbon Can Also Cycle in the Long Term

The carbon cycle has been discussed in other chapters. Using what you know, try to answer the following questions.

•How can a carbon atom cycle very quickly? One way would be if a plant takes in CO_2 to make food and then is eaten by an animal, which in turn breathes out CO_2.
•How can carbon be stored for a short period of time? Carbon that is stored as chemical energy in the cells of a plant or animal may remain until the organism dies. At that time, when the organism decomposes its carbon is released back into the environment.
•How can carbon be stored for a long period of time? If the organism is rapidly buried it may be transformed over millions of years into coal, oil, or natural gas. The carbon may be stored for millions of years.
•How can carbon be stored for long periods of time in the oceans? Many ocean creatures use calcium carbonate ($CaCO_3$) to make their shells. When these organisms die, their organic material becomes part of the ocean sediments, which may stay at the bottom of the ocean for thousands or millions of years. Eventually, these sediments may be subducted into the mantle. The carbon could cycle back up into the atmosphere: The ocean sediments melt and form magma, and the CO_2 is released when volcanoes erupt.

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** . 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?

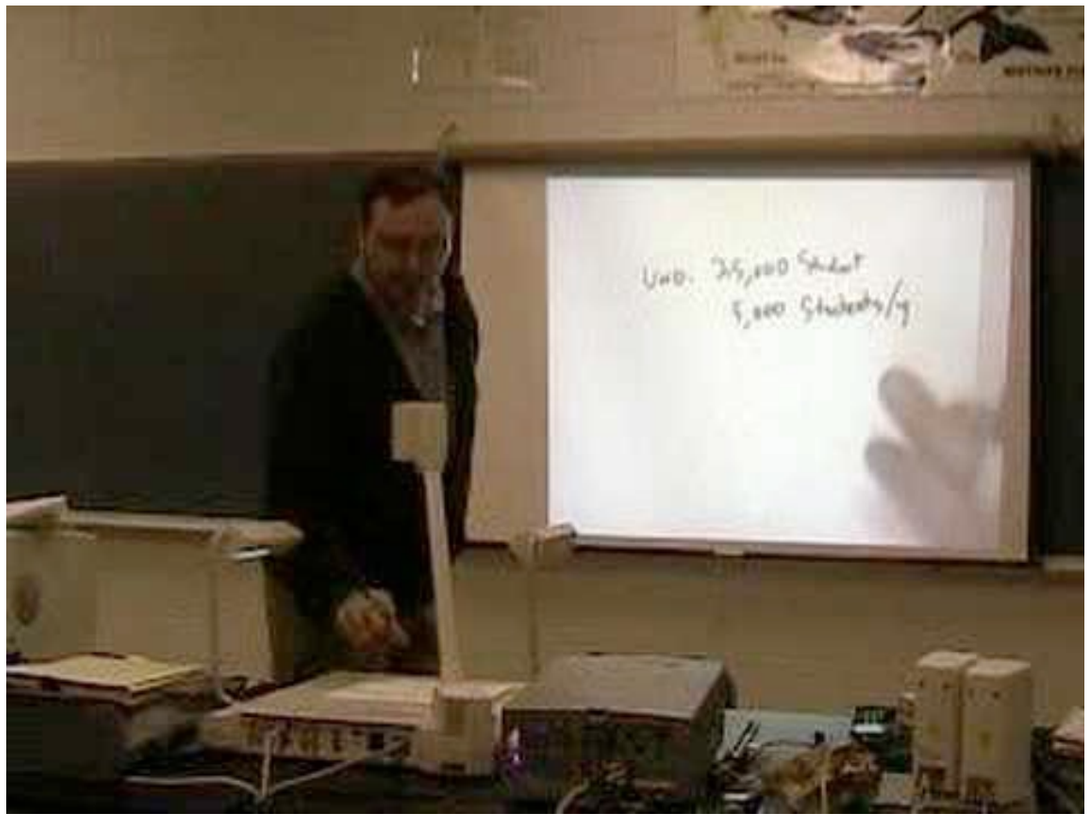
•Carbon sinks are reservoirs where carbon is stored. Healthy living forests and the oceans act as carbon sinks.

•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 **(7d)** : http://www.youtube.com/watch?v=cIuaedcVvQg (2:44).



Click on the image above for more content

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.

Scientists have a number of ways to see what atmospheric CO_2 levels were in the past. One is to measure the composition of air bubbles trapped in glacial ice. The amount of CO_2 in gas bubbles that date from before the Industrial Revolution, when society began to use fossil fuels, 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** below). In 2009, the atmospheric CO_2 content had risen to 387 ppm.

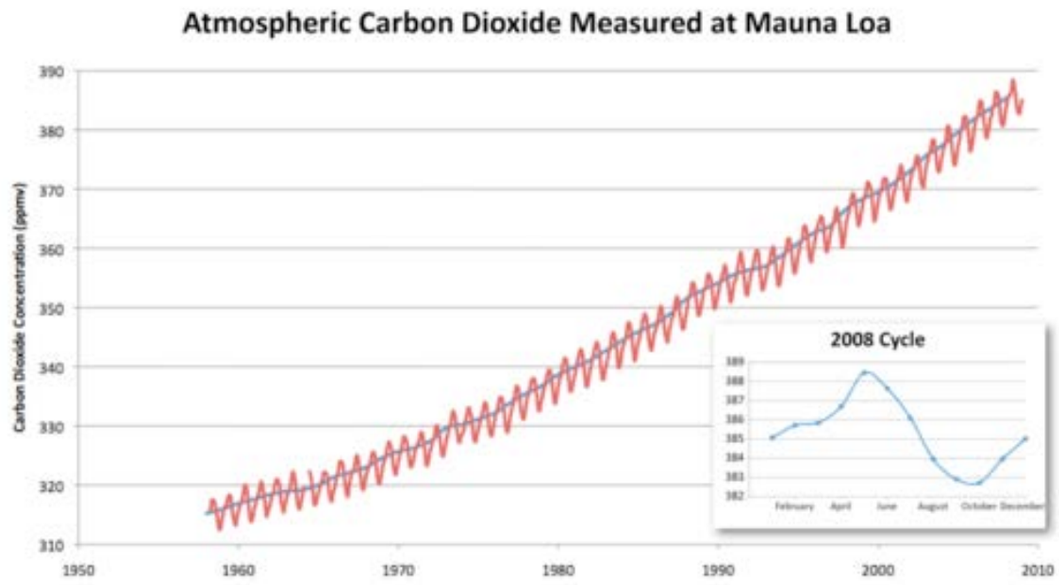


Figure 24.17

The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 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:

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\ O_2} \rightarrow \underset{\text{carbon dioxide}}{3\ CO_2} + \underset{\text{water}}{4\ H_2O}$$

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 **Figure** above .

The second largest source of atmospheric CO_2 is **deforestation** (**Figure** below). 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.



Figure 24.18

This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Coal, oil, and natural gas as well as calcium carbonate rocks and ocean sediments are long term carbon sinks for the natural cycling of carbon. When humans extract and use these resources, combustion makes them into carbon sources.

KQED: Acidic Seas

For years, our oceans have absorbed some of the carbon dioxide that humans create through burning fossil fuels. But all that extra CO2 is making our oceans more acidic with potentially dire consequences. Learn more at: http://science.kqed.org/quest/video/acidic-seas/ .



Click on the image above for more content

Why the Carbon Cycle is Important

Why is such a small amounts of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas (**Figure** below) so it absorbs infrared energy, the longer wavelengths of the Sun's reflected rays. Greenhouse gases trap heat energy that would otherwise radiate out into space and warms Earth. This is like what happens in a greenhouse. The glass that makes up the greenhouse holds in heat that would otherwise radiate out.

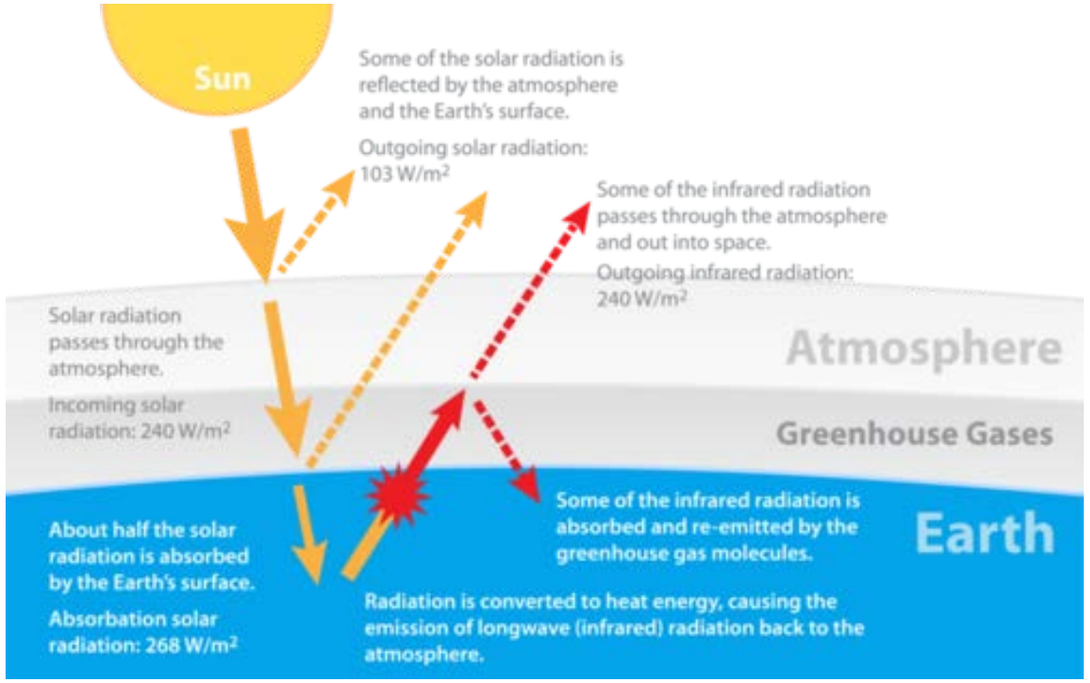
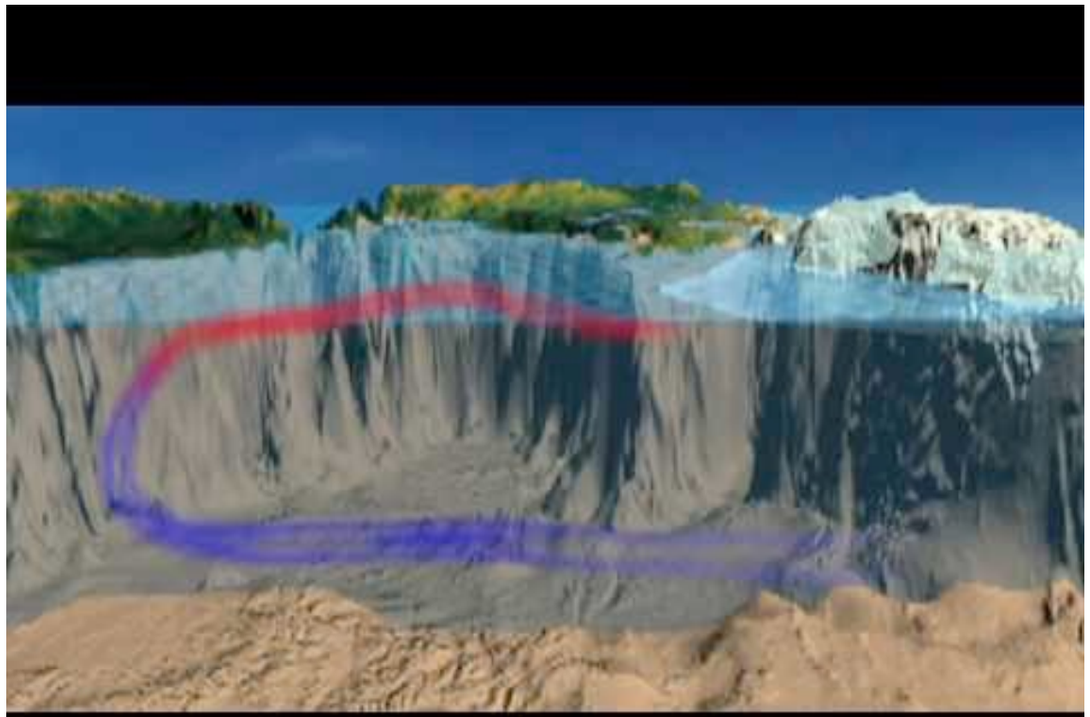


Figure 24.19

This diagram explains the role of greenhouse gases in our atmosphere.

When greenhouse gas levels in the atmosphere increase, the atmosphere holds onto more heat than it normally would. This increase in global temperatures is called global warming. Global warming and the effects of rising temperatures were described in the Climate chapter.

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 **(7a)** : http://www.youtube.com/watch?v=HrIr3xDhQ0E (5:39).



Click on the image above for more content

A very thorough but basic summary of the carbon cycle, including the effect of carbon dioxide in the atmosphere, is found in this video **(7b)** : http://www.youtube.com/watch?v=U3SZKJVKRxQ (4:37).



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The Nitrogen Cycle

Nitrogen (N_2) is also vital for life on Earth as an essential component of organic materials, such as amino acids, nucleic acids, and chlorophyll (**Figure** below).

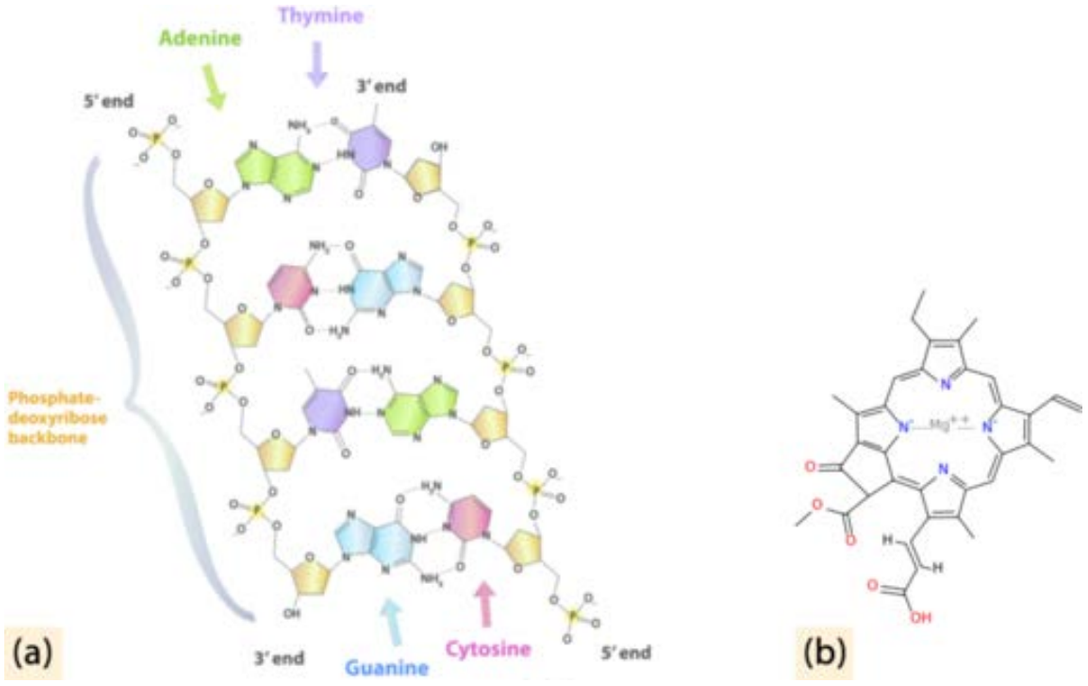


Figure 24.20

(a) Nitrogen is found in all amino acids, proteins, and nucleic acids such as DNA and RNA. (b) Chlorophyll molecules, essential for photosynthesis, contain nitrogen.

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** below).

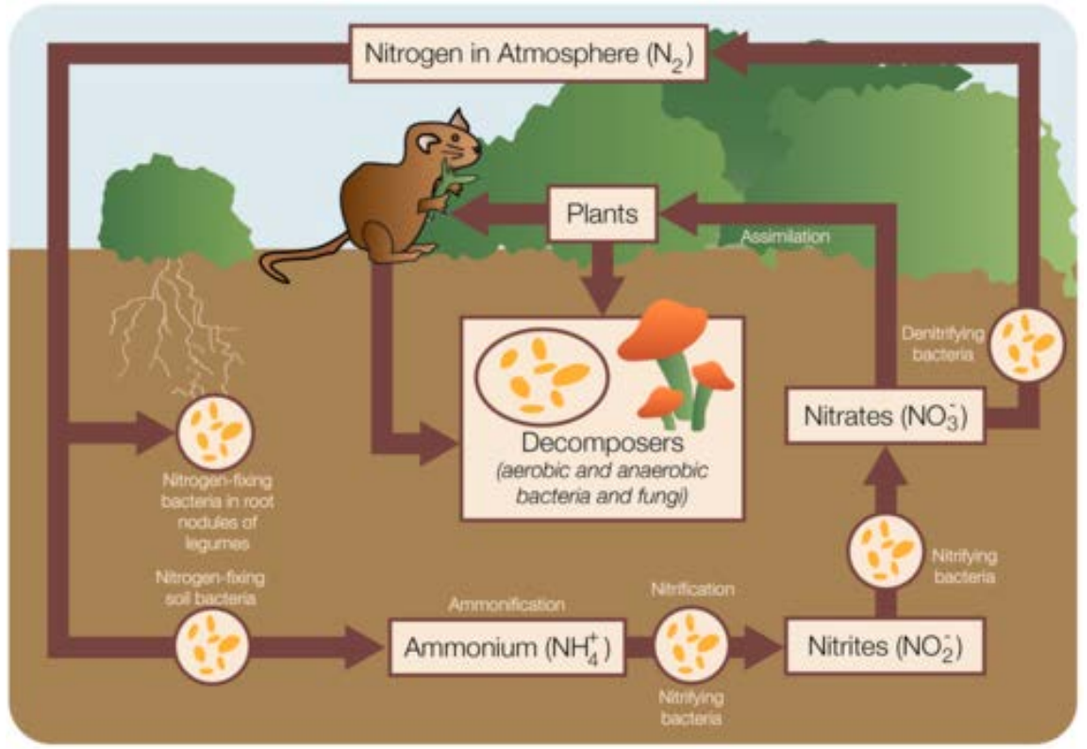


Figure 24.21

The nitrogen cycle.

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 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.

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, other bacteria oxide 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.

Usable nitrogen is sometimes the factor that limits how many organisms can grow in an ecosystem. Modern agricultural practices increase plant productivity by adding nitrogen fertilizers to the soil. This can have unintended consequences:

- Nitrogen from fertilizers may return to the atmosphere as nitrous oxide or ammonia, both of which have deleterious effects. Nitrous oxide contributes to the breakdown of the ozone layer, and ammonia contributes to smog and acid rain.
- Excess fertilizers run off the land, end up in water, and then cause nitrification of ponds, lakes, and nearshore oceanic areas. The nitrogen "fertilizes" the pond, causing bacteria to grow. When these enormous amounts of bacteria die, their decomposition uses up all the available oxygen (**Figure** below). Without oxygen, fish and other larger organisms die. This is called a dead zone when it happens on a large scale.



Figure 24.22

(a) Nitrogen runoff into Lake Atitlán, Guatemala, caused an algae bloom in the normally clear blue mountain lake. (b) Fish killed by a lack of oxygen in the water.

This very thorough video on the nitrogen cycle with an aquatic perspective was created by high school students **(7a)** : http://www.youtube.com/watch?v=pdY4I-EaqJA (5:08).



Click on the image above for more content

Lesson Summary

- Photosynthesis, which transforms inorganic carbon into organic carbon, is an extremely important part of the carbon cycle.
- Forests and oceans are carbon sinks. When carbon is trapped in ocean sediments or fossil fuels, it is stored for millions of years.
- Humans have changed the natural carbon cycle by burning fossil fuels, which releases carbon dioxide into the atmosphere. Fossil fuels burning and deforestation are carbon sources.
- Global warming is a consequence of increased carbon dioxide and other greenhouse gases in the atmosphere.
- The nitrogen cycle begins with nitrogen gas in the atmosphere then goes through nitrogen-fixing

microorganisms to plants, animals, decomposers, and into the soil.

Review Questions

1. Describe the role of carbon in the process of photosynthesis.

2. How can carbon cycle very quickly from the atmosphere and then back into the atmosphere?

3. Describe one way that carbon can be stored for a short time in the natural cycle.

4. Describe two ways that carbon can be stored for a very long time in the natural cycle.

5. Describe what makes a carbon sink and what makes a carbon source; give an example of each.

6. Describe two ways that humans interfere with the natural carbon cycle.

7. Describe two important functions for carbon dioxide in the atmosphere.

8. The impacts of global warming are being felt and will be felt increasingly in your lifetime. What impacts are likely to be seen in the next few decades?

9. Nitrogen is the most abundant gas in the atmosphere. What needs to happen to nitrogen gas before it can be used by living creatures?

10. What is the role of nitrogen in the creation of a dead zone?

Section 3

Human Populations

Human Populations

Lesson Objectives

•Describe how changes in a limiting factor can alter the carrying capacity of a habitat.
•Discuss how humans have increased the carrying capacity of Earth for our species and how we may have exceeded it.
•Discuss how human activities such as agriculture and urbanization have impacted the planet.
•Describe sustainable development.

Vocabulary

•carrying capacity
•Green Revolution
•Industrial Revolution
•invasive species
•limiting factor
•over-consumption
•overpopulation
•pesticide
•sustainable development

Introduction

Improvements in agriculture, sanitation, and medical care have enabled the human population to grow enormously in the last few hundred years. As the population grows, consumption, waste, and the overuse of resources also grows. People are beginning to discuss and carry out sustainable development that decreases the impact humans have on the planet.

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** below). The size of a population is tied to its limiting factor.



Figure 24.23

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, and enough other ingredients 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** below). 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.



Figure 24.24

A frog in frog spawn. An animal produces many more offspring than will survive.

Human Population Growth

Human Population Numbers

Human population growth over the past 10,000 years has been tremendous (**Figure** below). 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.

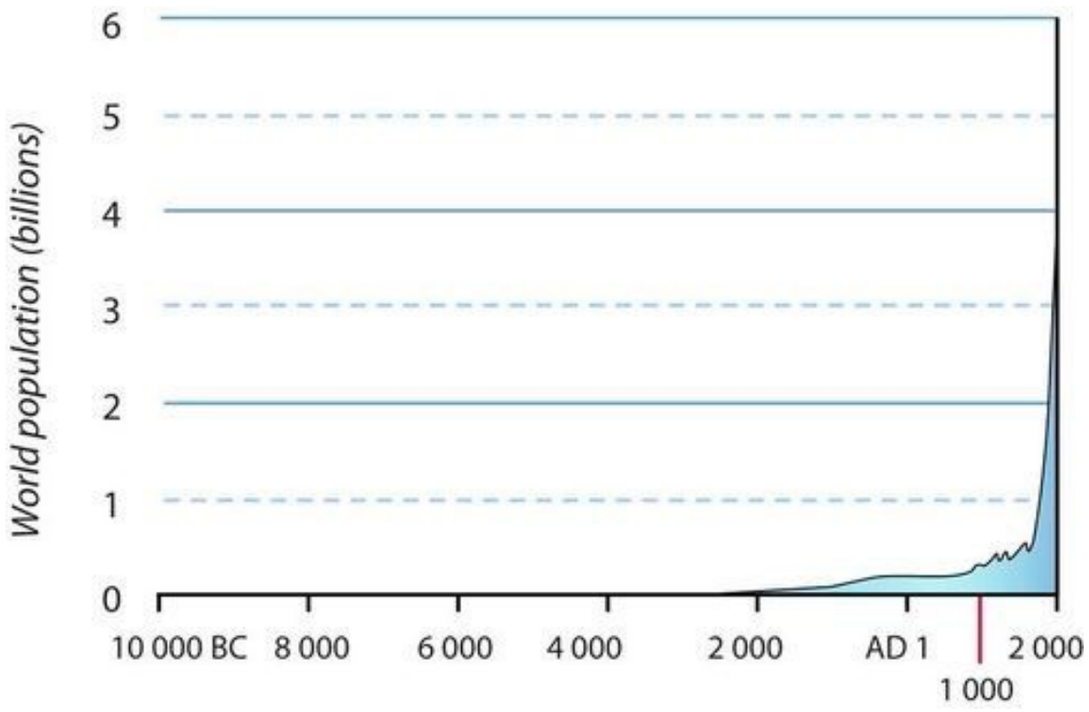


Figure 24.25

Human population from 10,000 BC through 2000 AD showing the exponential increase in human population that has occurred in the last few centuries.

An interactive map of where human population growth has been over time: http://www.pbs.org/wgbh/nova/worldbalance/numbers.html .

Not only has the population increased, but the rate of population growth has increased (**Figure** below). Estimates are that the

population will reach 7 billion in 2012, 13 years after reaching 6 billion.

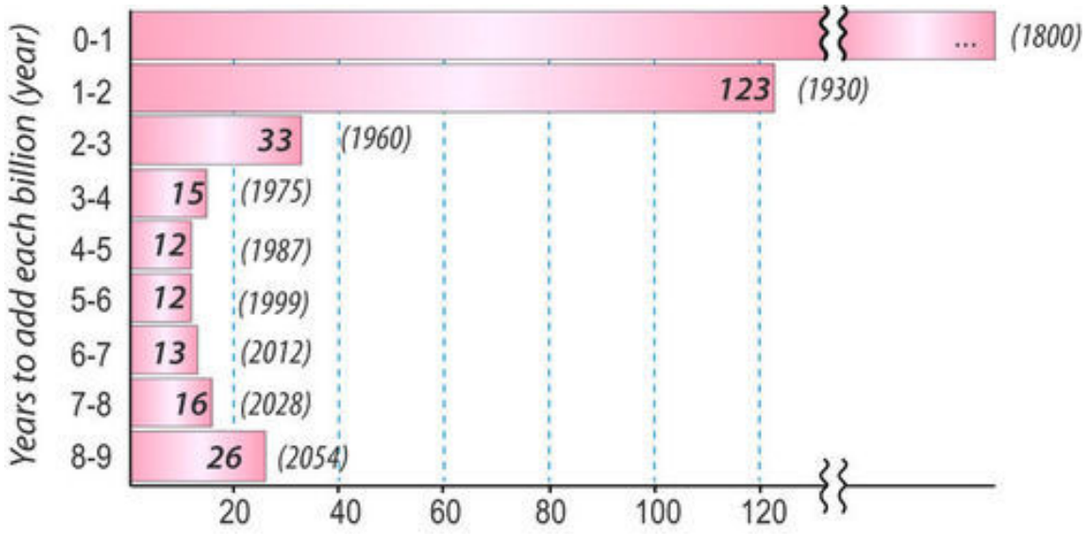


Figure 24.26

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.

Earth's Carrying Capacity for Humans

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** below).

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.



Figure 24.27

In a hunter-gatherer society, people relied on the resources they could find where they lived.

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?

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** below). 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.



Figure 24.28

More advanced farming practices allowed a single farmer to grow food for many more people.

When advanced farming practices allowed farmers to grow more food than they needed for their families (**Figure** below), some people were then able to do other types of work, such as crafts or shop keeping.



Figure 24.29

Farming increasingly depended on machines. Rows of a single crop and heavy machinery are normal sights on modern-day farms.

The next major stage in the growth of the human population was the **Industrial Revolution** , which started in the late 1700s (**Figure** below). This major historical event marks when products were first mass produced and when fossil fuels were first widely used for power.

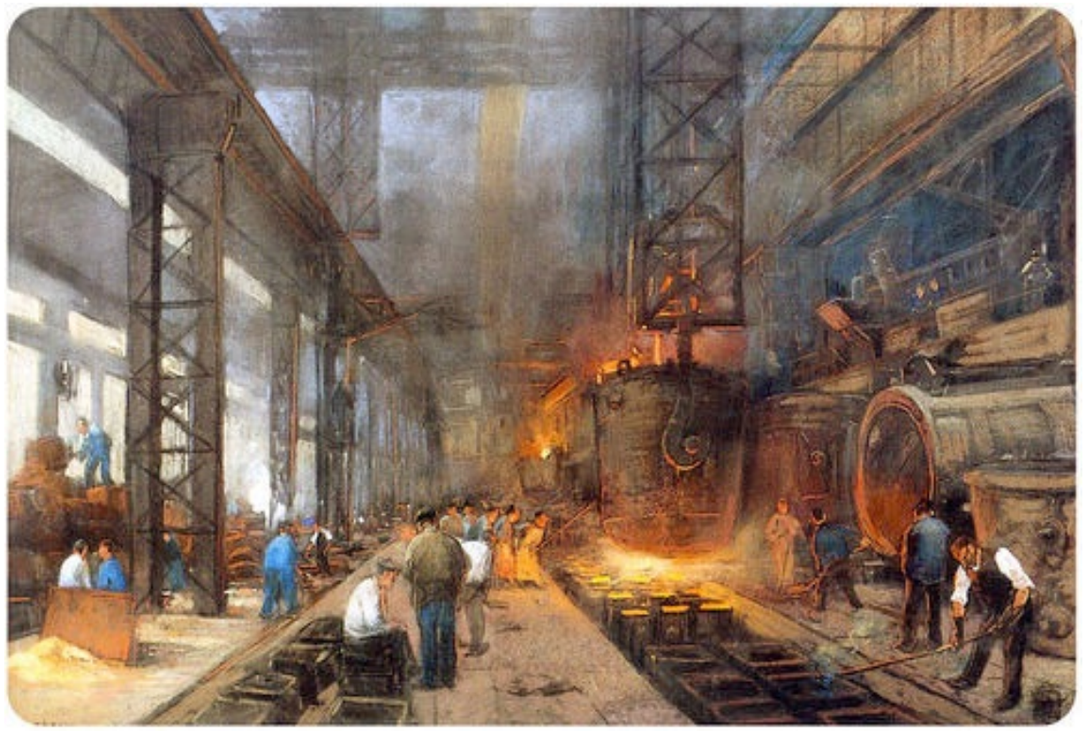


Figure 24.30

Early in the Industrial Revolution, large numbers of people who had been freed from food production were available to work in factories.

Every major advance in agriculture has allowed global population to increase. 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.

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** below).
•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.
•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.



Figure 24.31

Rows of a single crop and heavy machinery are normal sights for modern day farms.

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.

What is the flip side of this? The flip side 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.

The question is, even though we have increased the carrying capacity of the planet, have we now exceeded it (**Figure** below)? Are humans on Earth experiencing **overpopulation** ?



Figure 24.32

Manhattan is one of the most heavily populated regions in the world.

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 almost 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?

Humans and the Environment

The Green Revolution has brought enormous impacts to the planet. Natural landscapes have been altered to create farmland and cities. Already, half of the ice-free lands have been converted to human uses (**Figure** below). 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.

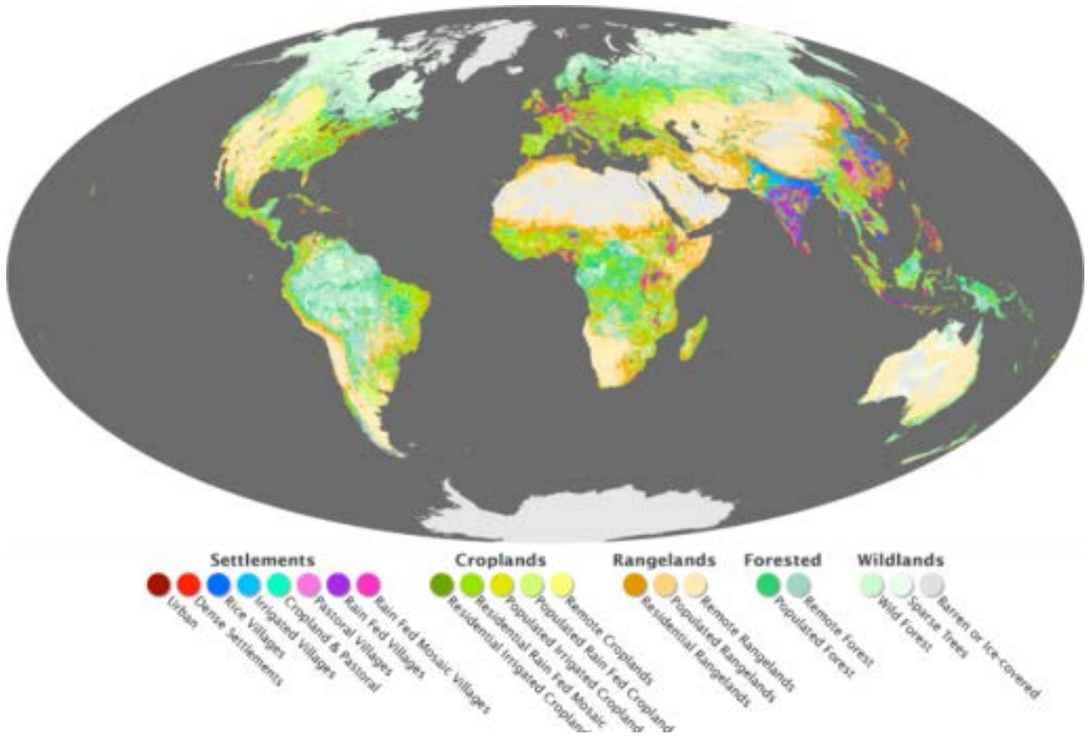


Figure 24.33

Similar to the biomes map in the Climate chapter, this map shows human ecosystems. Much of the planet's surface is populated and used by humans.

Modern agricultural practices produce a lot of pollution (**Figure** below). 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 24.34

Pesticides are hazardous in large quantities and some are toxic in small quantities.

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** below).

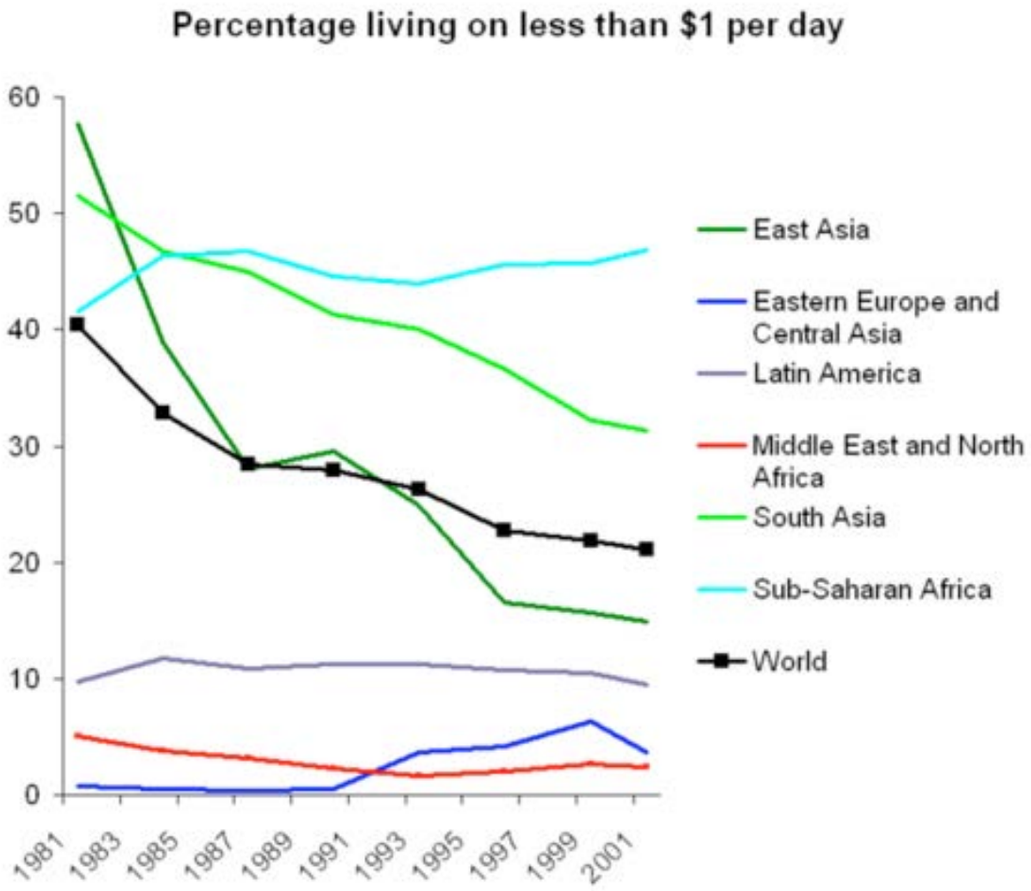


Figure 24.35

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.

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 decades ago. All of these need resources to produce, and fossil fuels to power (**Figure** below). 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.

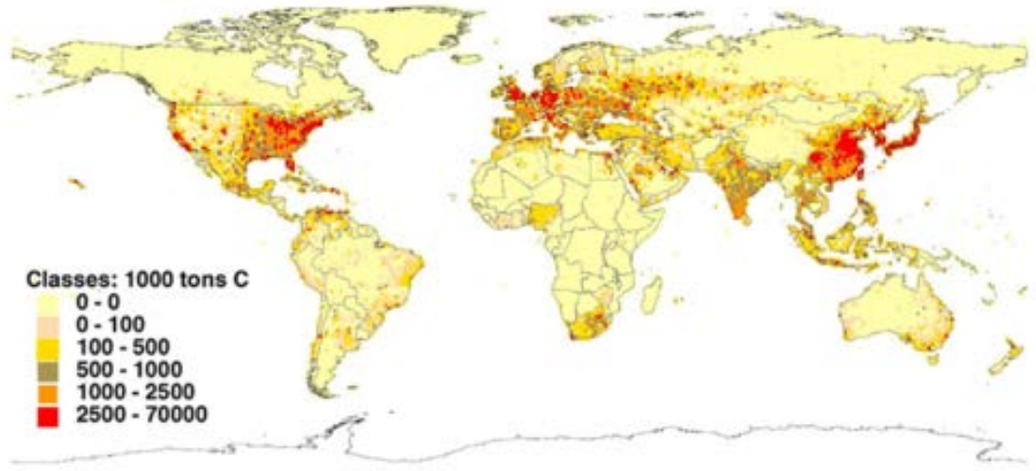


Figure 24.36

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.

Many problems worldwide result from overpopulation and over-consumption. One such problem is the advance of farms and cities into wild lands, which diminishes the habitat of many organisms. In addition, water also must be transported for irrigation and domestic uses. This means building dams on rivers or drilling wells to pump groundwater. Large numbers of people living together need effective sanitation systems. Many developing

countries do not have the resources to provide all of their citizens with clean water. It is not uncommon for some of these children to die of diseases related to poor sanitation. Improving sanitation in many different areas — sewers, landfills, and safe food handling — are important to prevent disease from spreading.

Wildlife is threatened by fishing, hunting, and trading as population increases. Besides losing their habitat as land is transformed, organisms are threatened by hunting and fishing as human population grows. Hunting is highly regulated in developed nations, but many developing nations are losing many native animals because of hunting. Wild fish are being caught at too high a rate and many ocean-fish stocks are in peril.

Humans also cause problems with ecosystems when they introduce species that do not belong in a habitat. **Invasive species** are sometimes introduced purposefully, but often they arrive by accident, like rats on a ship. Invasive species often have major impacts in their new environments. A sad example is the Australian Brown Tree Snake that has wiped out 9 of the 13 native bird species on the island of Guam (**Figure** below).



Figure 24.37

An Australian Brown Tree Snake

A dynamic map of the spread of invasive zebra mussels is found here: http://www.nationalatlas.gov/dynamic/dyn_zm.html# .

Pollution is a by-product of agriculture, urbanization, and the production and consumption of goods. Global warming is the result of fossil fuel burning.

Back to the question: Have humans have exceeded Earth's carrying capacity for our species? Carrying capacity is exceeded if:

•resources are being used faster than they are being replenished.
•the environment is being damaged.

Seen this way: The answer appears to be yes.

•Many resources are being used far in excess of the rate at which they are being replaced.
•The best farmland is already in use and more marginal lands are being developed.
•Many rivers are already dammed as much as they can be.
•Groundwater is being used far more rapidly than it is being replaced.
•Fossil fuels and mineral resources are being used faster than they are being replaced.
•Forests are being chopped down in developed and developing nations.
•Wild fish are being overharvested.
•The environment is certainly being damaged
•Pollution is discussed in the coming chapters.
•Temperatures are rising and the effects are being seen worldwide.
•Humans have caused the rate of extinction of wild species to increase to about at least 100 times the normal extinction rate.

Although many more people are alive in the world than ever before, many of these people do not have secure lives. Many people in the world live in poverty, with barely enough to eat. They often do not have safe water for drinking and bathing (**Figure** below). Diseases kill many of the world's children before they reach five years of age.



Figure 24.38

Nearly half of the people living in Africa do not have access to clean water.

What if humans suddenly disappeared? Here is a very interesting view of Earth recovering from our presence: http://news.nationalgeographic.com/news/2008/11/081103-ozone-video-vin.html .

Sustainable Development

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** below)? Will warming temperatures cause problems for human populations? The only answer to all of these questions is, time will tell.



Figure 24.39

As China industrializes, its cities have become among the most polluted in the world.

Lesson Summary

- Populations of organisms are kept to a habitat's carrying capacity by factors that limit their growth.
- By developing agriculture and other technologies, the human population has grown well past any natural population limits.
- Many people on Earth live in poverty, without enough food, clean water, or shelter.
- Overpopulation and over-consumption are causing resources to be overused and much pollution to be generated.
- Society must choose development that is more sustainable to secure a long-term future for our species and the other species we share the planet with.

Review Questions

1. If phosphorous is limiting to a species in an ecosystem and the amount of phosphorous is increased, what will happen to the population of that species? What will happen to the carrying capacity?

2. Name some factors that could cause a population to increase. Try to include as many types of factors as possible.

3. In terms of numbers of births and deaths, explain in detail why you think human population is growing so tremendously.

4. If all people on Earth were allowed only to replace themselves (that is, each person could only have one child or each couple two children), what would happen to the planet's population in the next decade? Would it decrease, increase, or remain exactly the same as it is now? Why do you say that?

5. What role has agriculture played in human population and why?

6. Discuss the good and bad points about the Green Revolution.

7. In the United States, 17% of energy is used for agriculture. How is this possible, if plants photosynthesize with sunlight?

8. What is more threatening to the future of the planet: overpopulation or over-consumption? How does an increase in the standard of living for people living in poverty affect the planet?

9. What evidence is there that humans are exceeding Earth's carrying capacity for our species?

10. What is sustainable development?

Further Reading / Supplemental Links

A good explanation of exponential growth and how small differences in growth rate can bring big differences in numbers: http://zebu.uoregon.edu/2003/es202/lec06.html .

Points to Consider

- How much impact on the planet does an infant born in the United States have during its lifetime, compared with one born in Senegal?
- How does consuming less impact global warming?
- Can ordinary people really make a difference in changing society toward more sustainable living?

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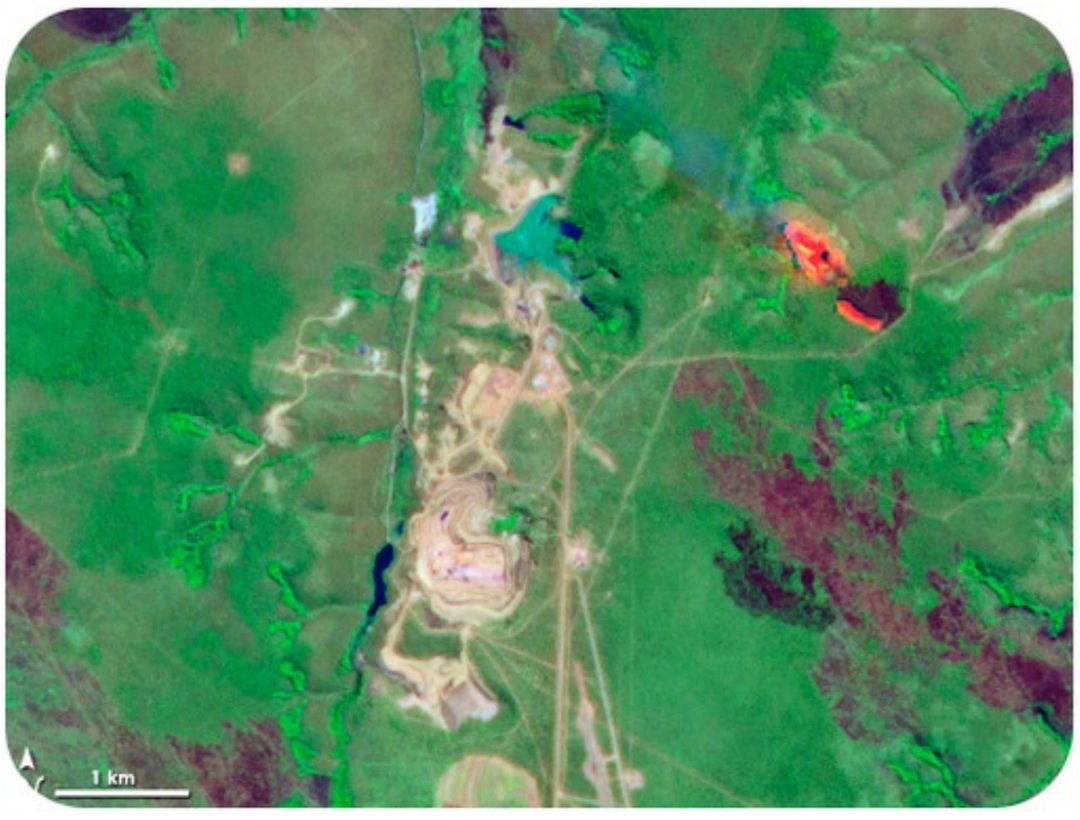
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Ch. 22: Human Actions and the Land



This site in Angola is a diamond mine. Diamonds form at great depths, about 150 km (95 miles) below the surface, and jet up to the surface in kimberlitic pipes. Because they are from so deep and need such a specialized way to get to the surface, they are very rare. In this image, vegetation is in green. Where the vegetation has been cleared at the mine, the land appears brown or pinkish because rock and soil are exposed. For every carat of diamond mined, a metric ton of rock must be removed. Considerable amounts of toxic wastes are also produced in a mine this size.

The bright red spot is a fire, which is likely the result of slash-and-burn agriculture. The purple areas are the scars from prior burns. In all, many of the impacts humans have on a landscape are seen.

Courtesy of Jesse Allen and NASA. earthobservatory.nasa.gov/IOTD/view.php?id=8928. Public Domain.

Loss of Soils

Loss of Soils

Lesson Objectives

- Explain how human actions accelerate soil erosion.
- Describe ways that we can prevent soil erosion.

Vocabulary

- leaf litter

Introduction

Soil is an extremely important natural resource, one that is not always recognized or appreciated. Soil loss can lead to tragedy, as it did during the Dust Bowl of the 1930s, and can degrade farmland permanently. There are many ways to prevent soil erosion and, at least in the developed nations, those practices are increasingly followed.

The Dust Bowl

The 1930s were a terrible time in U.S. history. That was the time of the Great Depression and the Dust Bowl. The Dust Bowl was a portion of the prairie where farmers were forced from their lands as the soil was blown away in storms that came to be known as black blizzards.

The Dust Bowl was caused by bad farming practices in a region that was not naturally suited for farming (see **Figure** below). The problem began during World War I, when grain was needed to feed the troops and farmers were paid a good wage for growing it. The Great Plains is naturally grassland and soil erosion is minimal. Why do you think the soil did not erode very much while the region was grassland?

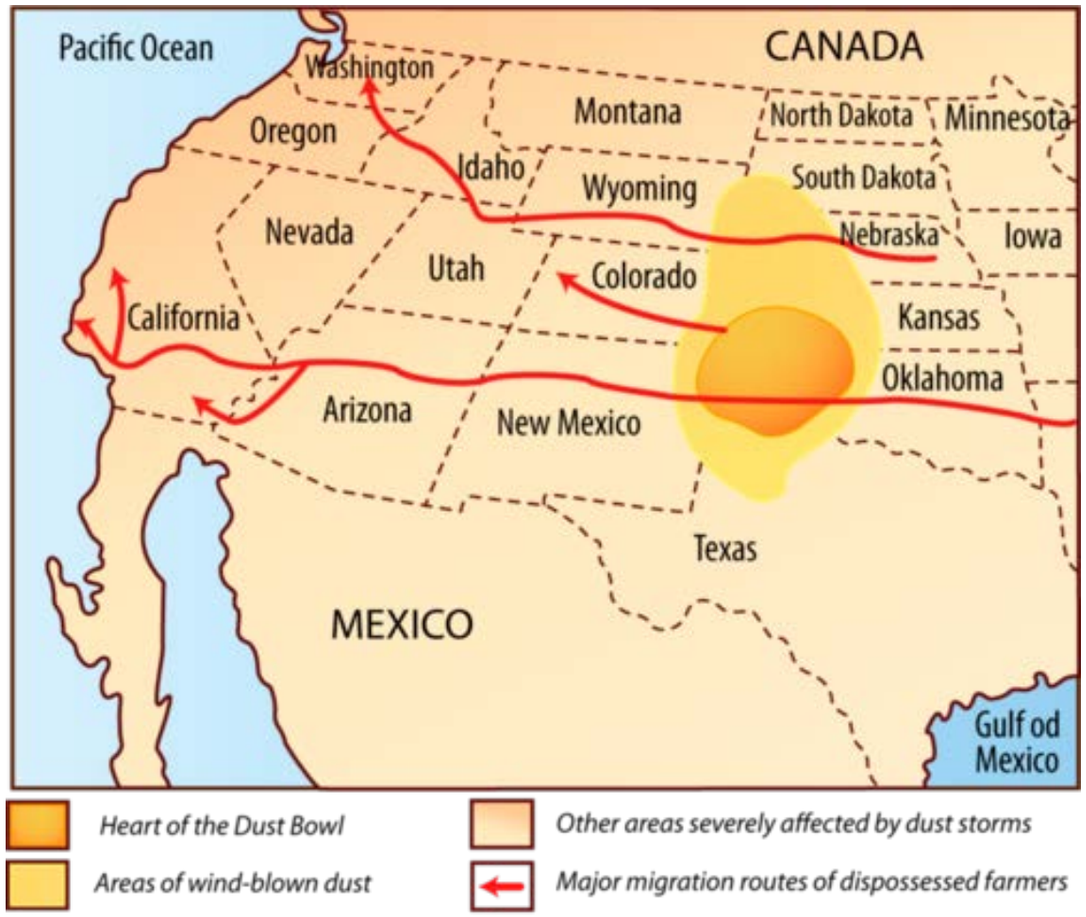


Figure 25.1

The region of the Dust Bowl and the places displaced farmers migrated to after they had been forced off their land.

Initially, rains fell and the land was productive. But in 1931, the rains stopped. Without grasses to hold the soil in place, wind picked up the dirt and blew it across the region. Muddy rain even fell out of the atmosphere as far away as the eastern United States (**Figure** below). Farmers that were forced off their land migrated to southern California and other places along the west coast where they met with poverty of a different sort. John Steinbeck's *The Grapes of Wrath* deals with this difficult time in American history.



Figure 25.2

This wind storm blew huge amounts of soil into the air in Texas on April 14, 1935.

We learned many lessons from the Dust Bowl storms. Modern practices encourage farmers to keep the soil covered so that it is not exposed and vulnerable to erosion. Massive irrigation projects, with water coming from groundwater sources, including the Ogallala Aquifer, keep crops healthy and soil in place. Still, some of the region's topsoil erodes away each year.

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** below). 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 25.3

(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** below) wander over large areas of pasture or natural grasslands eating grasses and shrubs. Grazers expose soil by removing the plant cover for an area and 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 25.4

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** below).



Figure 25.5

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** below). Soils eroded from logged forests clog rivers and lakes, fill estuaries, and bury coral reefs.

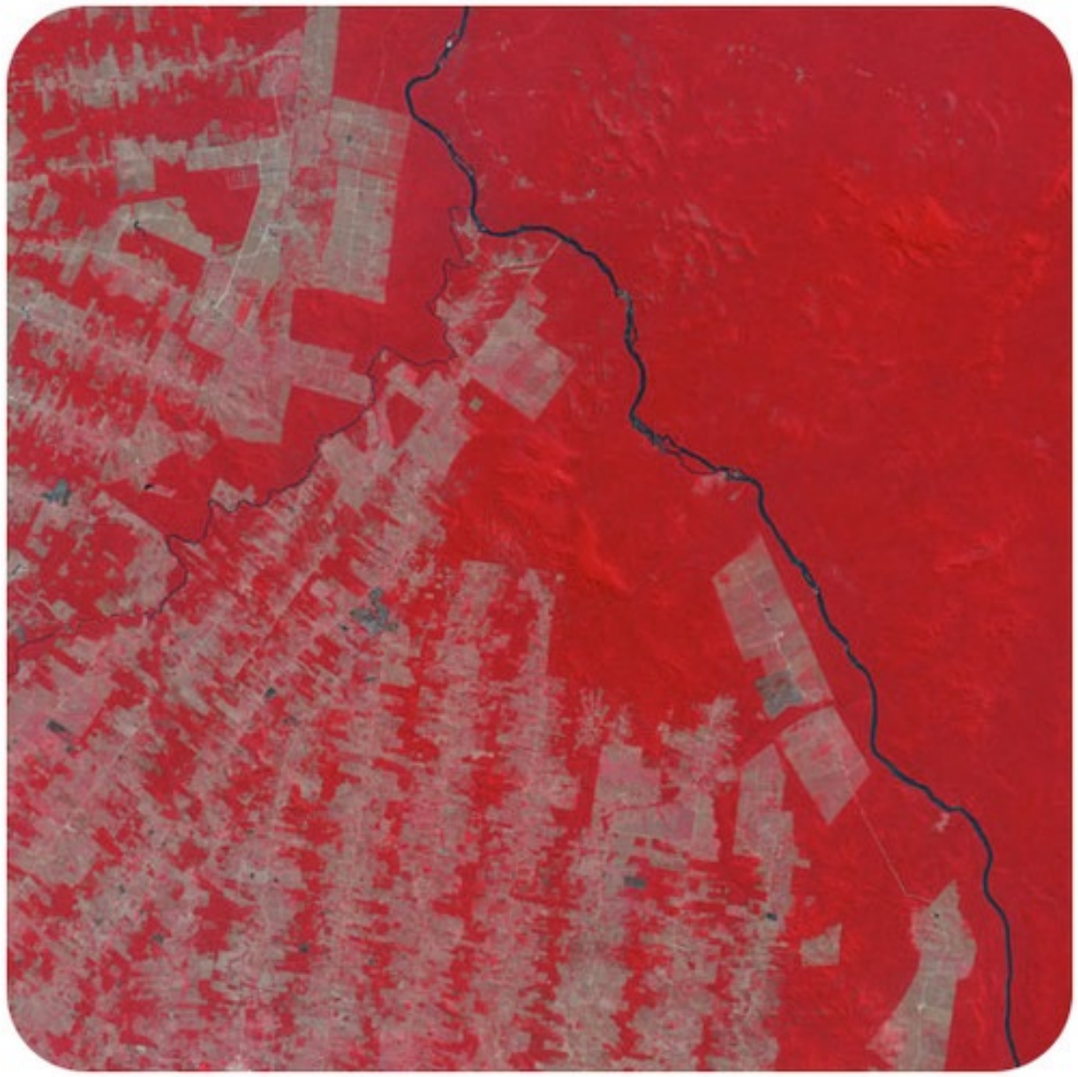


Figure 25.6

Deforested swatches in Brazil show up as gray amid the bright red tropical rainforest.

Surface mining disturbs the land (**Figure** below) and leaves the soil vulnerable to erosion.



Figure 25.7

(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.

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** below).



Figure 25.8

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.

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** below).



Figure 25.9

(a) ATV'S churn up the soil, accelerating erosion. (b) Arid landscapes, hiking trails may become eroded during hard times.

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 have arrived in the United States, about one-third of the nation's topsoil has eroded away.

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. 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 below 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.

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.

Lesson Summary

•Soil erosion is a natural process that has been greatly accelerated by human activities.
•Activities that accelerate erosion include agriculture, grazing, logging, mining, development, and recreation.
•Soil is an important natural resource and should be protected as any natural resource.
•Many practices can be adopted to slow down or prevent soil erosion.

Review Questions

1. Many farmers harvest their crops in the fall and then let the leftover plant material stay on the ground over winter. How does this help prevent erosion?

2. Discuss five ways human activity has accelerated soil erosion.

3. How do urban areas contribute to soil erosion?

4. What is the connection between poverty and soil erosion in developing countries?

5. What is one way you can prevent soil erosion when you are hiking?

6. You often see stone barriers or cage-like materials set up along coastal shores and river banks. How do you think these serve to prevent erosion? Why are areas like this prone to erosion?

7. What can people in developed nations do to reduce the likelihood of bad environmental practices being used in developing countries, particularly activities that increase soil erosion?

Further Reading / Supplemental Links

People who lived during the Dust Bowl talk about their experiences, the Ganzel Group http://www.livinghistoryfarm.org/farminginthe30s/water_02.html

Video of the Dust Bowl http://www.weru.ksu.edu/vids/dust002.mpg

Points to Consider

•Why should soil be considered a renewable resource? Why should it be considered a non-renewable resource?
•Could humans live without soil?
•What can you do to help to conserve soil?

Pollution of the Land

Pollution of the Land

Lesson Objectives

•Define hazardous waste and describe its sources.
•Describe some of the impacts of hazardous waste on human health and on the environment.
•Detail some ways that people can control hazardous wastes.

Vocabulary

•Superfund Act
•Superfund site

Introduction

Sometimes human activities degrade the land with pollutants. In the United States, lands that are extremely polluted become one of the Superfund sites destined for cleanup.

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** below). 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 25.10

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 (**Figure** below). 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.



Figure 25.11

A resident of Love Canal protests the hazardous waste contamination in her neighborhood.

A video of Lois Gibbs describing the origin of the Love Canal problem: http://www.youtube.com/watch?v=PrzqFPego4A .

In 1978, people were relocated to safe areas. The problem 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.

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, 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 (**Figure** below). 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** below .



Figure 25.12

This farm worker wears special clothes for protection from the hazardous pesticide in the container.

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.

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.

Sometimes the chemicals are not so easily seen as they were at Love Canal and the impacts are 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).

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** below). In the 1970s and 1980s, the United States government passed laws completely banning lead in gasoline and paint.



Figure 25.13

(a) Leaded gas sold in the US for decades. (b) 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.

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 in the Human Actions and the Atmosphere chapter.

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 waste 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 above, the Superfund Act requires companies to clean up contaminated sites that are designated as Superfund sites (**Figure** below). 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.

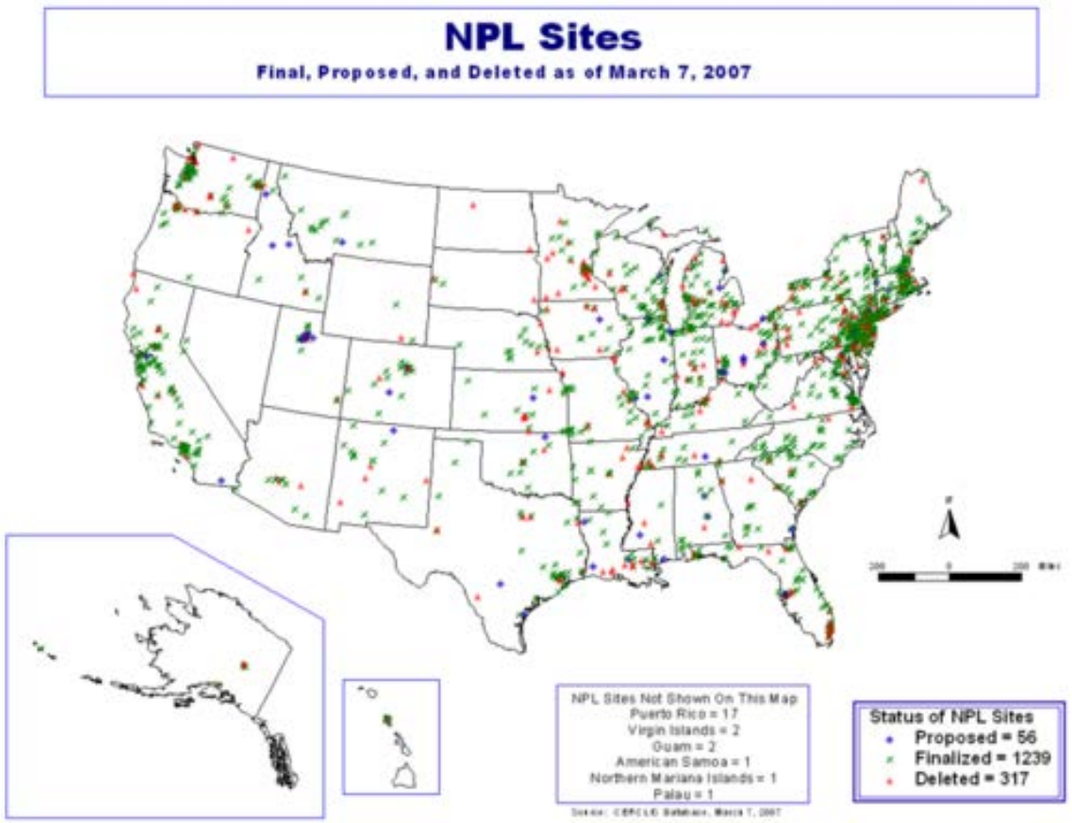


Figure 25.14

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.

Lesson Summary

•Hazardous wastes are dangerous to human health and the environment. The many sources of hazardous waste include household chemicals, gasoline, paints, old batteries, discarded appliances, and industry.
•Once toxic chemicals are released into the environment they can cause health problems or even death, and they can degrade the environment for other organisms.
•Developed countries such as the United States produce most of the world's hazardous waste but have the most advanced laws to deal with them.

Review Questions

1. Who was responsible for the tragedy at Love Canal? What was the role of private individuals in fixing the problem? What was the role of government?

2. How does the United States Superfund Act help control hazardous wastes?

3. What is the difference between corrosive and flammable?

4. What is often the first indicator that a region has a problem with toxic waste?

5. Organic farming is a method of growing food crops with natural alternatives to chemical pesticides. How does organic farming help control hazardous wastes?

6. Why is storing hazardous wastes in barrels and burying them deep in the ground a bad idea? How might that approach be made safer?

7. What hazardous wastes are common in ordinary households? What can you do to reduce the impact you make on the environment from the use of hazardous wastes?

8. Which do you think is easiest and hardest to keep track of: hazardous waste that is present as a gas, liquid, or solid? Why?

Further Information / Supplemental Links

•Love Canal Pathfinder, Nathan Tallman http://www.nathantallman.org/pathfinders/lovecanal.html
•Superfund Sites Where You Live http://www.epa.gov/superfund/sites/index.htm

Points to Consider

•What are the best ways to either prevent or safely dispose of hazardous materials?
•What is the effect of hazardous wastes on other living things?
•Is it important for each generation to leave the world a safe place? If one generation doesn't do this, who pays the price?

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Ch. 23: Human Actions and Earth's Resources



This landscape in west Texas and southeastern New Mexico is pock-marked with oil wells and drilling structures connected by roads. The Yates Oil Field exploits petroleum from the Permian Basin, one of the highest producing oil provinces in North America. In the image it's possible to see the basin's folded sedimentary rocks. At the base of the basin is ancient continental crust that filled with sediments as the region was covered by shallow seas and then exposed several times during the Paleozoic Era. The thick Permian sediments were organic-rich carbonates and salts that were buried and later folded. Oil was produced and later trapped by the rock layer.

Oil was first discovered on the Yates land in 1926, and by 1995 the land had produced more than 2 billion barrels of oil. The oil field is still productive, but at a diminished rate. While nearly 1 billion barrels is estimated to be still in the ground, it is more difficult to extract than the oil that was produced earlier.

Courtesy of the Johnson Space Center/NASA's Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=6776. Public Domain.

Section 1

Use and Conservation of Re-

Use and Conservation of Resources

Lesson Objectives

- Discuss some natural resources used to make common objects.
- Describe some ways to conserve natural resources.

Vocabulary

- conserve
- export
- import
- timber

Introduction

Natural resources may be living or non-living. Their value may be tangible, such as the price of an ounce of gold, or intangible, like the psychological value of being able to visit pristine natural areas. Some natural resources must be used and used wisely, but some must be preserved to maintain their value.

Mystery in the Forest

Like all forests, the Monongahela National Forest of West Virginia is an important natural resource. A forest is a resource in ways that are obvious and ways that are not so obvious. This forest is used for many things including:

- Recreation, such as hiking, camping, and picnicking.
- Habitat for many organisms, including nine endangered species and 50 species of rare plants.
- Streams [207 kilometers (129 miles)] for fishing, particularly trout fishing.
- Wildlife management areas for hunting deer, squirrels, turkeys, rabbits, mink, and foxes.
- Mineral and energy resources such as coal, gas, limestone, and gravel.
- Hardwood trees used for **timber** , which brings in over $7 million a year.

But Monongahela National Forest has a problem; for several years, trees in the forest have not grown well. What are some reasons that trees might not grow well (**Figure** below)?



Figure 26.1

The Monongahela National Forest in West Virginia contains many natural resources. Notice the air pollution that obscures the view.

Scientists have been working for several years to solve the mystery. The scientists suspected that the soil is missing nutrients that the trees and other plants need to grow. Can you design an experiment that scientists could do to test this hypothesis? (There is a clue in the caption for **Figure** above .)

The scientists sampled the soil and tested it for important nutrients. They discovered that the soil has very low levels of plant nutrients, such as magnesium and calcium. Can you develop a hypothesis for why these nutrients might be missing from the soil? The scientists thought that air pollution from nearby factories had released chemicals into the environment that removed the nutrients from the soil and carried them away. How would the scientists test that hypothesis?

Scientists in the Monongahela National Forest are still researching the missing plant nutrients. They are trying to learn what they can do to help keep the nutrients in the soil so the trees will grow better.

Like the Monongahela National Forest, people use parts of the Earth for many reasons, such as food, water, building materials, timber, recreation, and energy (**Figure** below). As you've already learned, human activities can degrade natural resources, just like air pollution from factories is speeding up the loss of soil nutrients in West Virginia.



Figure 26.2

We use Earth’s resources for many purposes, including recreation and natural beauty.

For natural resources to continue to be available, they need to be protected. We also need to **conserve** natural resources so they will last longer. When we practice conservation, we make sure resources will be available in the future, both for ourselves and for other organisms.

Renewable versus Non-Renewable Resources

In the Earth's Energy chapter, energy resources were classified as renewable or non-renewable. How do you think other natural resources, such as minerals and forests, are classified? Like energy resources, all natural resources are divided into renewable and non-renewable. Can you define these terms?

Renewable resources can be regenerated or grown so rapidly that they reappear at the same rate or even faster as they are being used (**Figure** below). Are forests a renewable resource? Why are they a renewable resource? Why aren’t they a renewable resource? Although new trees can grow to replace logged trees, their growth is often too slow for the trees to be of use for a long time. Loggers just move to a new area rather than wait for the forest to regenerate.



Figure 26.3

An old growth forest, like this tropical rainforest in Malaysia, is a complex ecosystem with many types of plants and animals. When a forest is destroyed by logging, it takes hundreds or thousands of years for the forest to regenerate.

Other examples of resources that are renewable but not entirely renewable include soil, wildlife, and water. How do these resources fit in both categories? Soil has a very slow renewal rate, so they are often non-renewable. Fish and other wildlife can reproduce and so are a renewable resource, yet it is possible to take so many of these creatures that the populations are not able to rebound, making them a non-renewable resource (**Figure** below). Organisms can be over-hunted, over-fished or have populations decline because of habitat loss so that their numbers go so low they are no longer a renewable resource.



Figure 26.4

Chimpanzees are eaten and taken as pets so their numbers in the wild are declining.

Non-renewable resources are resources that cannot be regenerated on a useful timescale. Fossil fuels and most minerals are non-renewable resources. We can (and eventually will) run out of these resources.

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** below shows some common objects, the materials they are made from and whether they are renewable or non-renewable.

Common Object	Natural Resources Used	Are These Resources Renewable or Non-renewable?
Cars	15 different metals, such as iron, lead, and chromium to make the body.	Non-renewable
Jewelry	Precious metals like gold, silver, and platinum. Gems like diamonds, rubies, emeralds, turquoise.	Non-renewable
Electronic Appliances (TV's, computers, DVD players, cell phones, etc.)	Many different metals, like copper, mercury, gold.	Non-renewable

Resource Availability

From the table above you can see that many of the resources we depend on are non-renewable. Non-renewable resources vary in their availability; some are very abundant and others are rare. Materials, such as gravel or sand are technically non-renewable but 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.

Besides abundance, resource 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** below). As the cost of desalination plants comes down, more will likely be built.



Figure 26.5

Tampa Bay, Florida, has one of the few desalination plants in the United States.

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. Only 12 countries have approximately 80% of all of the world's oil (**Figure** below). 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.



Figure 26.6

The nations in blue are the 12 biggest producers of oil; they are Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela.

The topic of overconsumption was touched on in the Ecosystems and Human Populations chapter. 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** below).



Figure 26.7

Pollution from discarded materials degrades the environment and reduces the availability of natural resources.

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.

Besides obtaining resources, we also dump waste on these nations. Many of our electronic wastes, which we think are being recycled, end up in developing countries where they pose a problem for human health and the environment (**Figure** below).



Figure 26.8

Electronic wastes are sent to developing nations where people pick through them for valuable materials. These wastes contain many toxic compounds and are hazardous.

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** below). People are researching ways to find renewable alternatives to non-renewable resources. Here is a checklist of ways to conserve resources:



Figure 26.9

Recycling can help conserve natural 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.
- 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).

National Geographic videos found on this site in Environment Videos, Environmental Threats, Deforestation: http://video.nationalgeographic.com/video/player/environment/

- "Sustainable Logging"

Or Environment Videos, Habitats, Rainforest: http://video.nationalgeographic.com/video/player/environment/

- "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 videos, Environment Videos, Going Green, http://video.nationalgeographic.com/video/player/environment/

- The problem with plastic bags is discussed in this Conservation in action, "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"

Lesson Summary

- We use natural resources for many things. Natural resources give us food, water, recreation, energy, building materials, and luxury items.
- Many resources vary in their availability throughout the world. Some are rare, difficult to get, or in short supply.
- Natural resources must be preserved and protected from pollution and overuse.
- Buying fewer new products and recycling will help to conserve resources.

Review Questions

1. List five general things we get from natural resources.

2. Are forests a renewable resource? Are they ordinarily used in a renewable way? How can forests be used more sustainably?

3. Of what value are forests besides for wood? Is there a value to forests that is not a monetary value? How much is that value considered when forests are being used for their resources?

4. How are fish and other wildlife renewable resources? How are they nonrenewable resources?

5. What is overconsumption? How does overconsumption mirror overpopulation?

6. If a product is recycled, is anything lost in terms of material or energy?

7. Resource X is scarce except in Nation A. Many nations want to use Resource X. How does politics play into the ability of other nations to get access to the resource?

Further Reading / Supplemental Links

- Maps of Renewable Resources in the United States http://www.nrel.gov/gis/maps.html

Points to Consider

•Could a renewable resource ever become non-renewable?
•What are some of the intangible values that a natural resource might have?
•Do you think about the material and energy resources you use as you use them?
•Which is more sustainable: using renewable resources or non-renewable resources? Why?

Section 2

Energy Conservation

Energy Conservation

Lesson Objectives

- Discuss why it takes energy to get energy and why some forms of energy are more useful than others.
- Describe some ways to conserve energy or to use energy more efficiently.

Vocabulary

- energy efficiency
- net energy
- net-energy ratio

Introduction

The Earth's Energy chapter deals with many aspects of energy and energy use. It would be good to review it before embarking on this lesson on energy conservation. Getting and using natural energy sources is a lot like spending money to get money. To get energy, we must use a lot of energy. Finding an energy source, extracting it, refining it, and transporting it to where it will be used all require energy. One way to keep the energy costs of energy down is to use energy more efficiently: to conserve energy.

Obtaining 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** below). If the energy cost of obtaining energy increases, the resource will be used even faster.



Figure 26.10

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.

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 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 below shows the net-energy ratios for some 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** below).



Figure 26.11

Obtaining coal for energy takes a lot of energy. The coal must be located, extracted, refined, and transported.

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 subtracts 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. Compact fluorescent light bulbs are more efficient than incandescent light bulbs (**Figure** below).

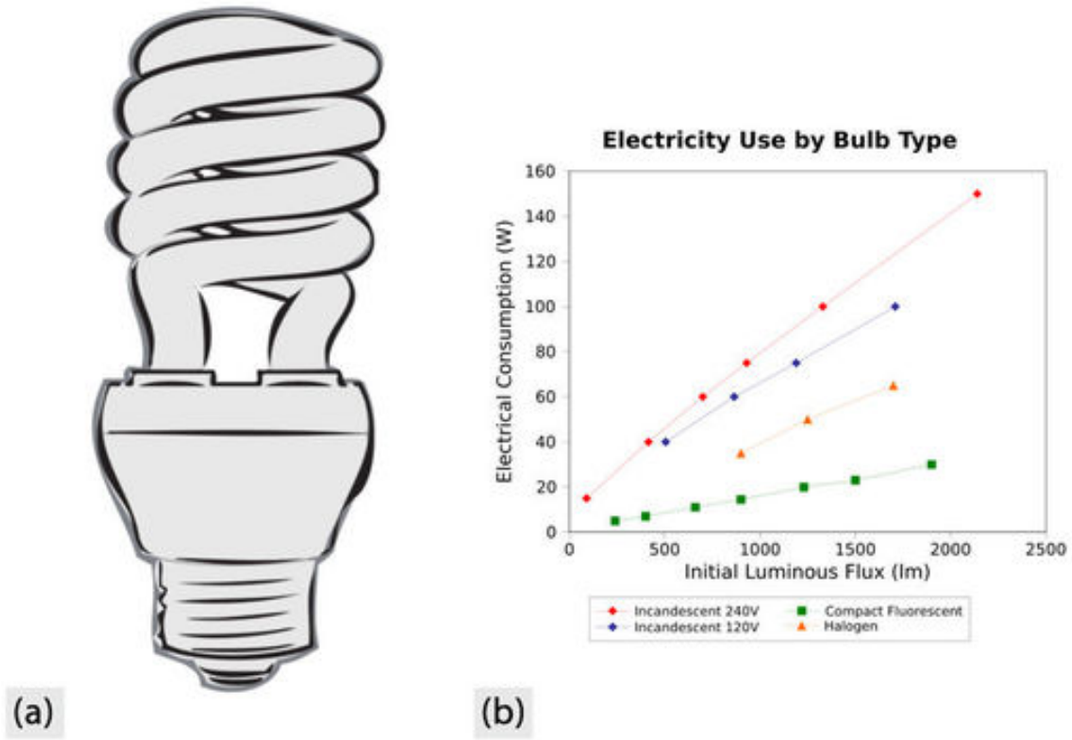


Figure 26.12

(a) A compact fluorescent light bulb. (b) Compact fluorescent bulbs use less electricity to produce light than incandescent or halogen bulbs.

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** below) shows how energy is used in the United States.

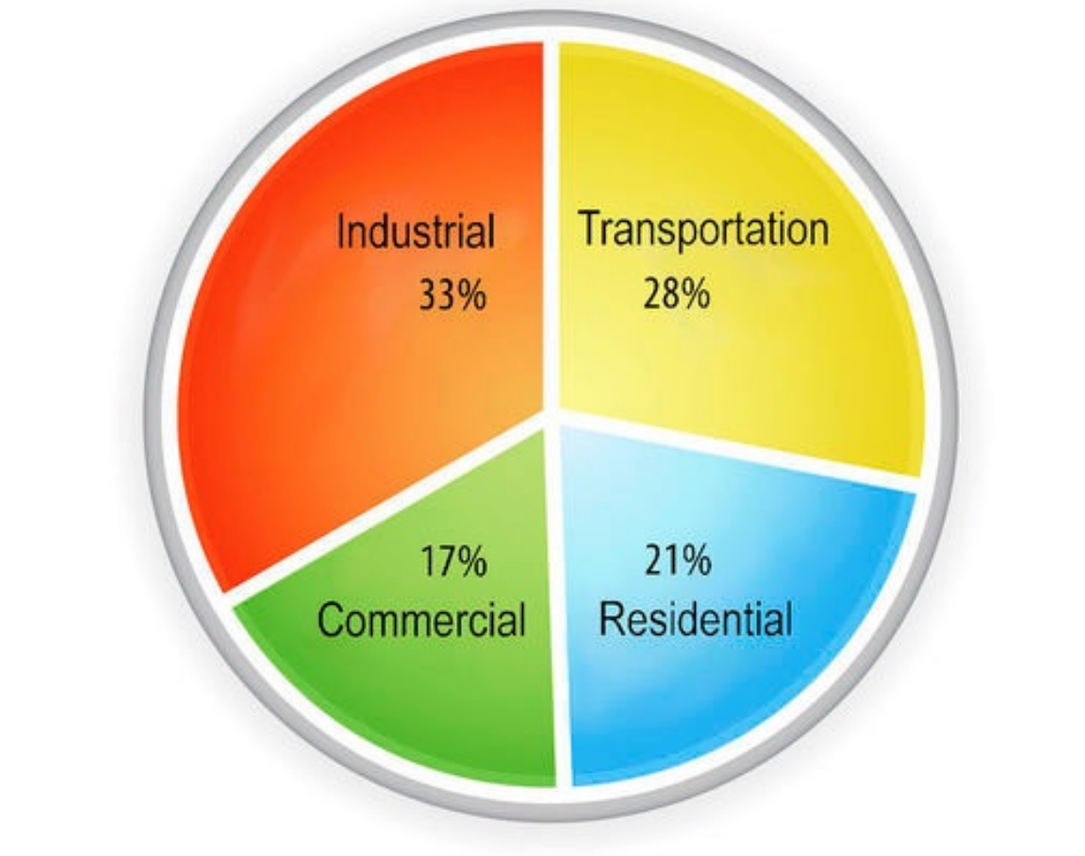


Figure 26.13

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.

Table below shows some ways that people can decrease energy use and use energy more efficiently in transportation, residences, industries, and office settings.

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. Reduce the number of trips you make. Use public transportation.	Increase fuel efficiency in cars. Buy and drive smaller cars. Build cars from lighter and stronger materials. Drive at speeds at or below 90 kilometers per hour (55 miles per hour).

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

Lesson Summary

- It takes energy to get energy. Net energy refers to the amount of energy left for use after we expend energy to get, transport, and refine other forms of energy.
- Energy resources can be conserved by reducing energy use.
- Energy can be used more efficiently by getting more work out of each unit of energy.
- There are many ways for an individual to conserve energy.

Review Questions

1. Define net energy.

2. Why does solar power have a higher net-energy ratio than coal-fired electricity?

3. Some coal-fired electricity has a net-energy ratio of 2.5. Explain what this means. When is coal a good choice for generating electricity? When is coal not a good choice for generating electricity?

4. What are two ways you can use less energy in your home?

5. What are two ways that energy can be conserved?

6. Why is it especially important to not waste energy from fossil fuels?

7. Why are trains much more efficient than trucks for transporting items? Why are boats more efficient than airplanes or cars for travel?

8. If you were to replace a 240V incandescent bulb with a compact fluorescent bulb with an initial luminous flux of about 1500 lm, how much would you decrease electrical consumption?

Points to Consider

- If it takes energy to get energy, then what are the best choices for types of energy?
- Put each of these actions in order from most important to least: choosing a sustainable form of energy, increasing energy efficiency, conserving energy use. Explain the order you chose.
- Could everyone in the world use as much energy as a person in the United States does each day? Why or why not?

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Ch: 27: Human Actions and Earth's Waters



The Colorado River originates in the mountains of northern Colorado and then travels through the desert before reaching its delta at the Gulf of California. Where the river once roared into the Gulf, there is now nothing left after five states and a bit of northern Mexico use its water for irrigation and to provide water for the overgrown desert cities of the Southwest.

The river is seen in dark blue at the top left of the image. After traveling through farmlands, it fans out at the base of the mountains on the left side. The bluish purple running from left to right across the image is water from the Gulf that has traveled up the inlet since no river water fills the inlet. The river's mouth is the bright blue horseshoe on the bottom right. The little bit of water that reaches Mexico is used by farmers near the international border. The gray mudflats were built with sediments deposited in the delta before two massive dams stopped the downstream flow of sediments. The large yellow region is the Gran Desierto, an arid, sand-covered landscape.

The distribution of water resources in the Western United States will be a topic of much discussion in the coming decades.

Courtesy of NASA?GSFC/MITI/ERSDAC/JAROS and US/Japan ASTER Science Team. earthobservatory.nasa.gov/IOTD/view.php?id=1288. Public Domain.

Section 1

Humans and the Water Sup-

Humans and the Water Supply

Learning Objectives

- Discuss how much water is taken up by each water use.
- Explain the difference between consumptive and non-consumptive water uses.
- What is the origin of California's fresh water supply?

Vocabulary

- aquaculture
- consumptive water use
- drip irrigation
- non-consumptive water use

Introduction

What is the most important thing for all life on Earth? Arguably, it is water (arguably, because a lot of other things are needed for life, too). From the smallest bacteria to the largest trees, all forms of life on Earth depend on water for survival. Although you could likely go a few weeks without eating, people cannot survive for more than a few days without drinking water.

Human Uses of Water

Besides drinking and washing, people need water for agriculture, industry, household uses, and recreation (**Figure** below). Recreational use and environmental use average 1% each.

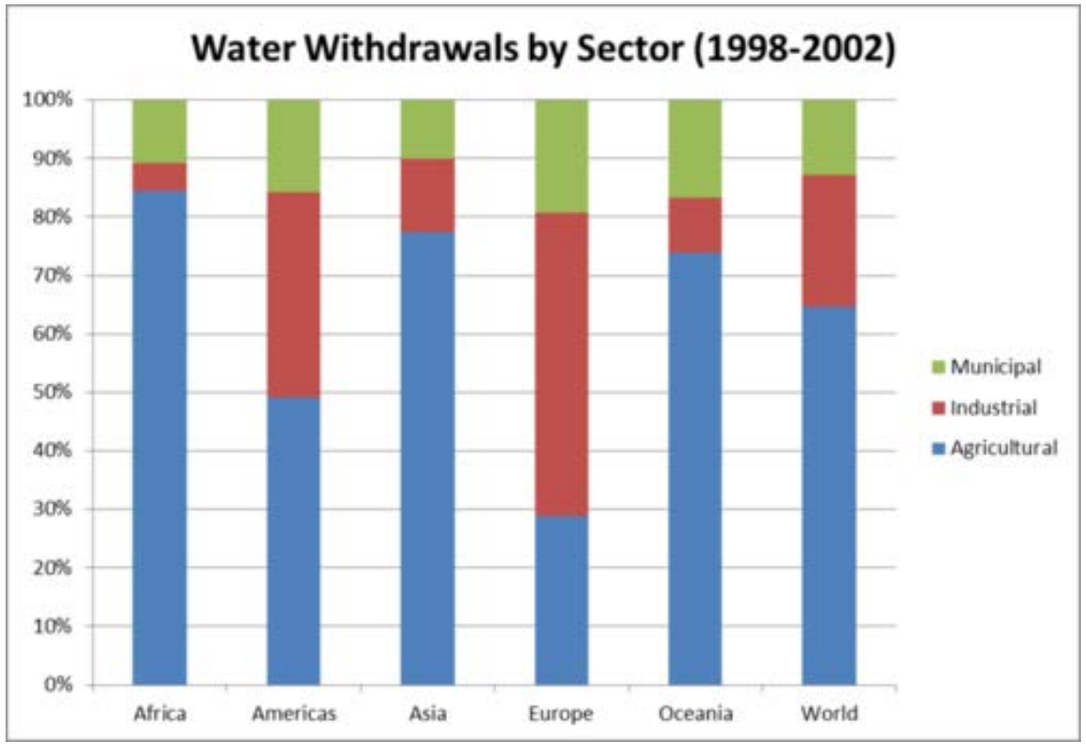


Figure 27.1

Water used for home, industrial, and agricultural purposes in different regions. Globally more than two-thirds of water is for agriculture.

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 (**Figure** below). 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.



Figure 27.2

Non-consumptive water use also includes water that is used for recreation, such as whitewater rafting on these rapids.

- **Consumptive** water use takes the water out of the ecosystem (**Figure** below). Can you name some examples of consumptive water use?



Figure 27.3

A large amount of the water that comes out of these sprinklers is consumptive because it is lost to evaporation and runoff.

Agricultural Water Use

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 no food, many of the world's crops are produced using irrigation.

Two popular irrigation methods are:

- Overhead sprinklers (pictured in the **Figure** above).
- Trench irrigation: canals carry water from a water source to the fields.

Both 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 (**Figure** below). Water that runs off a field often takes valuable soil with it. So why do people use these methods?



Figure 27.4

Flood irrigation is similarly wasteful of water. This farm is in the Arizona desert where evaporation greatly exceeds precipitation.

A much more efficient way to water crops is **drip irrigation** (**Figure** below). 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.



Figure 27.5

Drip irrigation delivers water to the base of each plant so little is lost to evaporation and runoff.

So back to the question, 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?

Aquaculture

Aquaculture is a different type of agriculture. Aquaculture is farming to raise fish, shellfish, algae, or aquatic plants (**Figure** below). 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.



Figure 27.6

Workers at a fish farm harvest fish they will sell to stores. The next time you pass the fish display in the grocery store, look for labels for “farm raised” fish.

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 (**Figure** below). Wastes must be flushed out to keep animals healthy. Raising shellfish at farms can also be successful.

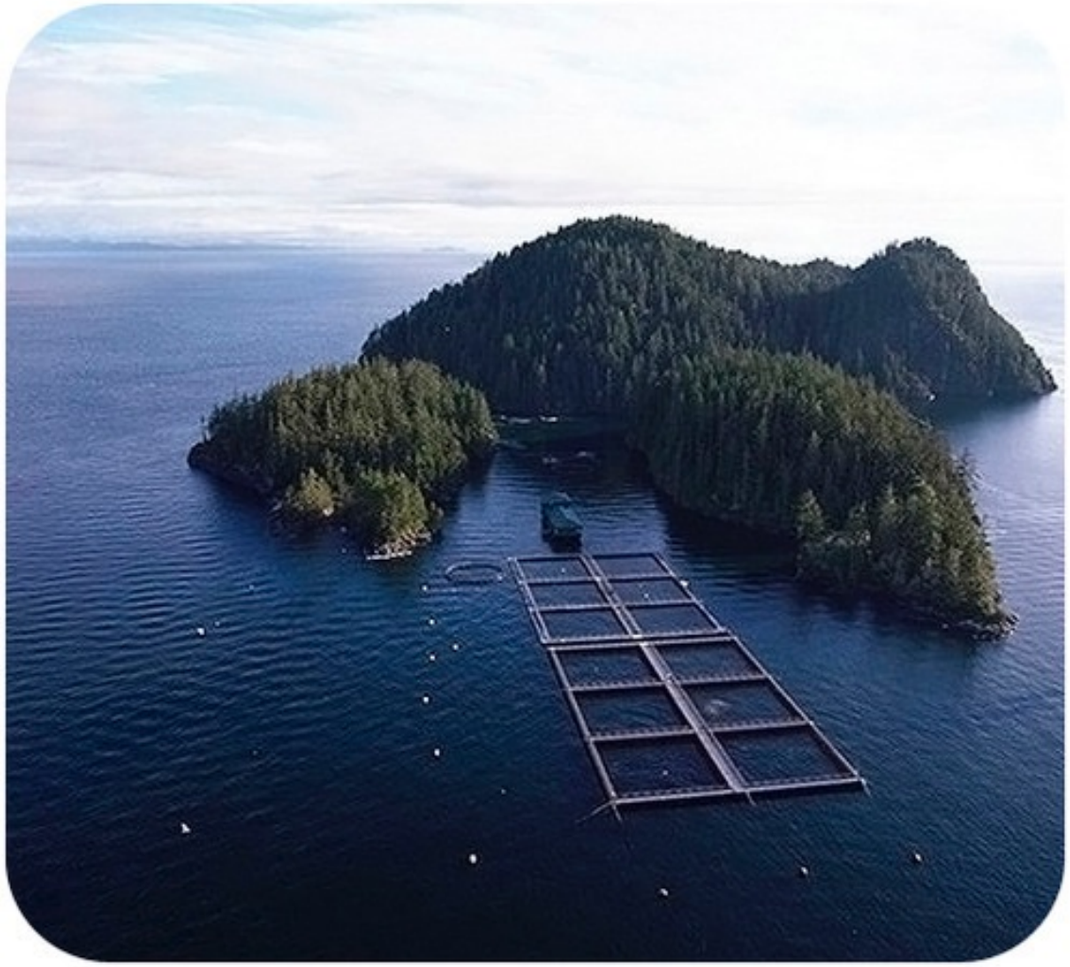
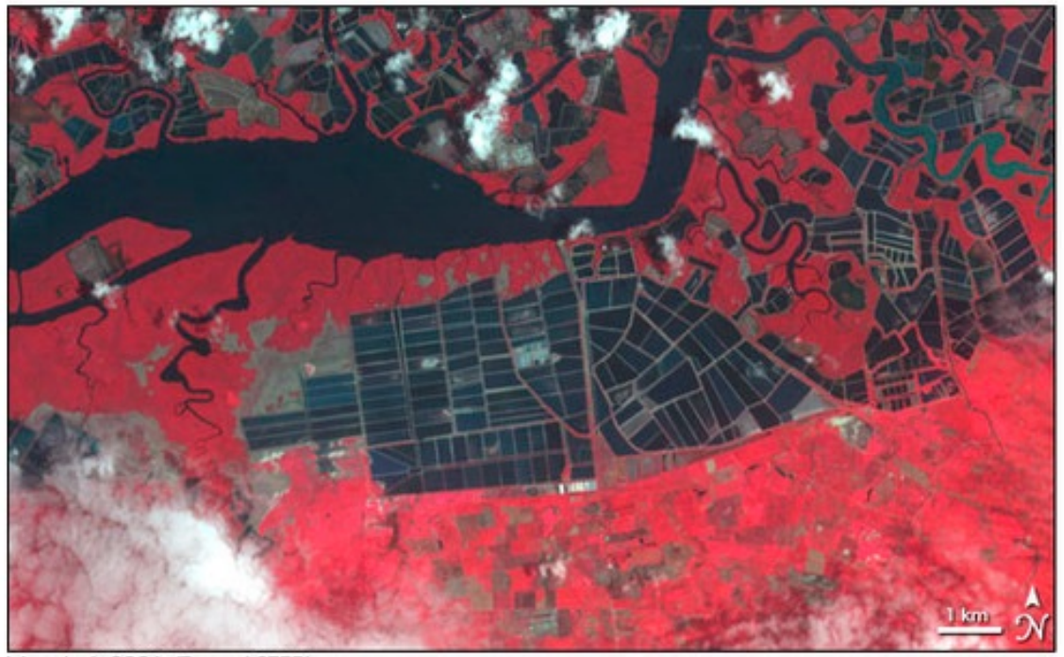


Figure 27.7

This salmon farm in British Columbia keeps young fish for up to two years.

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** below). 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.



March 6, 2006 (Terra ASTER)

Figure 27.8

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.

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 (**Figure** below).



Figure 27.9

A power plant in Poland sits on the edge of a lake with easy access to water for cooling and other purposes.

Household Use

Think about all the ways you use water in a day (**Figure** below). 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 developed countries people use much less. Globally, household or personal water use is estimated to account for 15% of world-wide water use.



Figure 27.10

Domestic 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 activities (**Figure** below). 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.



Figure 27.11

Swimming is a non-consumptive water activity.

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.

Environmental Use

Environmental use of water includes creating wildlife habitat. Lakes are built to create places for fish and water birds (**Figure** below). Most environmental uses are non-consumptive and account for even a smaller percentage of water use than recreational uses.



Figure 27.12

Environmental Water Use: Wetlands and other environments depend on clean water to survive. Water shortages are a leading cause of global biodiversity loss.

California Water Resources

California has many sources of water (**Figure** below). The winter snow pack in the Sierra Nevada and other mountain ranges feeds rivers that crisscross the state. Virtually all of these rivers are dammed, some more than once, to supply power and water to the cities and farmlands of the state.

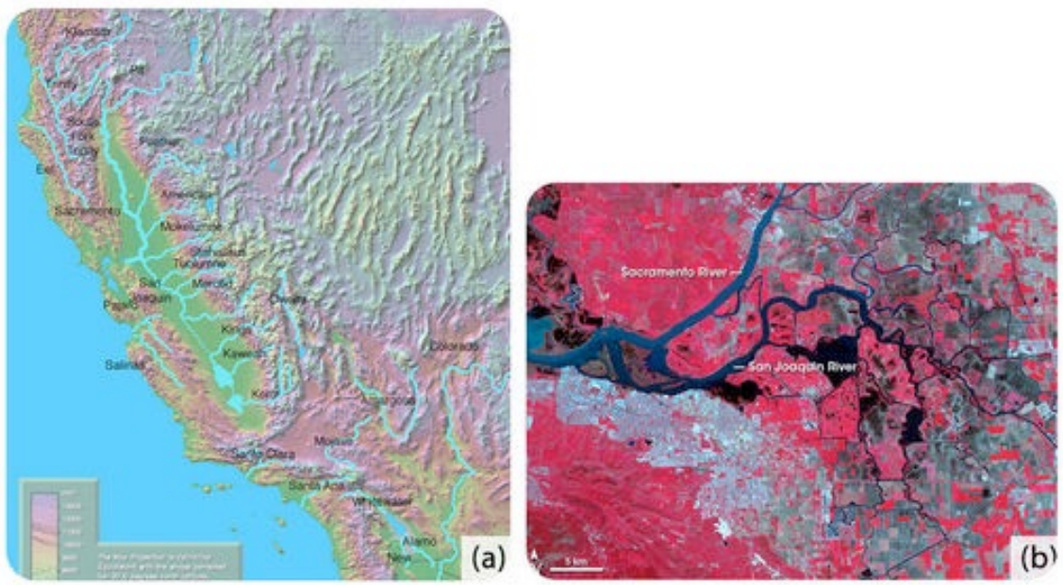


Figure 27.13

(a) California’s surface water resources include streams with headwaters in and outside the state. (b) Many of California’s rivers feed into the Sacramento River in the northern part of the Central Valley, and the San Joaquin River in the southern portion. Red is vegetation and blue-gray areas are buildings.

Groundwater is also an important source of water in California. In a normal year about 40% of the state’s water supply comes from groundwater. In a drought year, the number can rise to 60% or more. The largest groundwater reservoirs are found in the Central Valley where thousands of years of snow melt has fed the aquifers. In many locations, much more groundwater is used each year than is available to recharge the aquifer. Subsidence of the land is common in these regions.

Despite these vast water sources, the state’s large population and enormous agricultural landscape put a strain on the water supply. Water rights in California are complex and controversial. Although about 75% of the water resources are in the northern one-third of the state, the largest usage, about 80%, is in the southern two-thirds. Besides projects that exist to distribute water within the state, a large source of water is the Colorado River.

KQED: State of Thirst: California's Water Future

California's population is growing by hundreds of thousands of people a year, but much of the state receives as 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. Learn more at: http://www.kqed.org/quest/television/state-of-thirst-californias-water-future



Click on the image above for more content

Lesson Summary

•Human water use is dominantly in five categories: agriculture, industry, domestic, recreation, and environmental.
•Water use can be consumptive or non-consumptive.
•Despite California's abundant water supply from surface streams and groundwater, the state has a number of water rights issues that will be important long into the future.

Review Questions

1. List the three water uses that consume the most fresh water.

2. How do farmers grow crops when there is no irrigation?

3. Describe why some water uses are called consumptive.

4. Describe drip irrigation and why it wastes less water than irrigating with sprinklers.

5. Explain why water use by humans has increased dramatically in the past century or so.

6. Why do farmers sometimes use more wasteful methods of irrigation than are available?

7. What are some of the positives of aquaculture? Some of the negatives?

8. Describe four consequences of water shortages to people.

9. What is the origin of California's fresh water sources?

10. Describe why droughts are more serious in the arid regions of the world than in wetter regions.

Points to Consider

•Is fresh water ever more valuable than gold or diamonds?
•How can farmers and other people be encouraged to use more efficient irrigation methods?
•With such abundant water resources, why do California's planners worry about the state's future water resources?

Problems with Water Distri-

Problems with Water Distribution

Learning Objectives

- Explain why water shortages are increasingly frequent throughout the world.
- Discuss why 1.1 billion people (one-fifth of the people on Earth) do not have access to safe drinking water.

Vocabulary

- drought
- pathogen

Introduction

Humans are facing a worldwide water crisis, according to the United Nations. Many people do not have access to clean water to drink or to wash with. Sometimes there just is not enough water and sometimes the available water is unclean and unhealthy.

World Water Distribution and Supply

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. 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.

Water Distribution

Water is unevenly distributed around the world. Large portions of the world receive very little water from rainfall or rivers relative to their population. This includes much of northern Africa and central Asia. 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. Over time, many nations, even developed nations, are projected to have less water per person than now.

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 snow melt 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 Shortages

In 1995, about 40% of the world's population faced water scarcity. 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.

As water supplies become scarce, conflicts will arise between the individuals or nations that have enough clean water and those that do not (**Figure** below). Just as with energy resources today, wars may erupt over water.

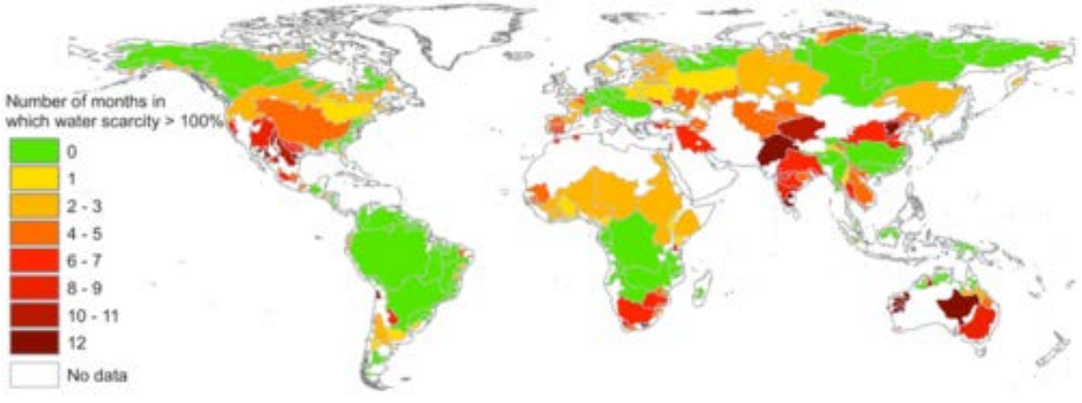


Figure 27.14

Many regions already experience water scarcity. This map shows the number of months in which the amount of water that is used exceeds the availability of water that can be used sustainably. This is projected to get worse as demand increases.

Droughts occur when a region experiences unusually low precipitation for months or years (**Figure** below). 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.



Figure 27.15

Extended periods with lower than normal rainfall cause droughts.

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.

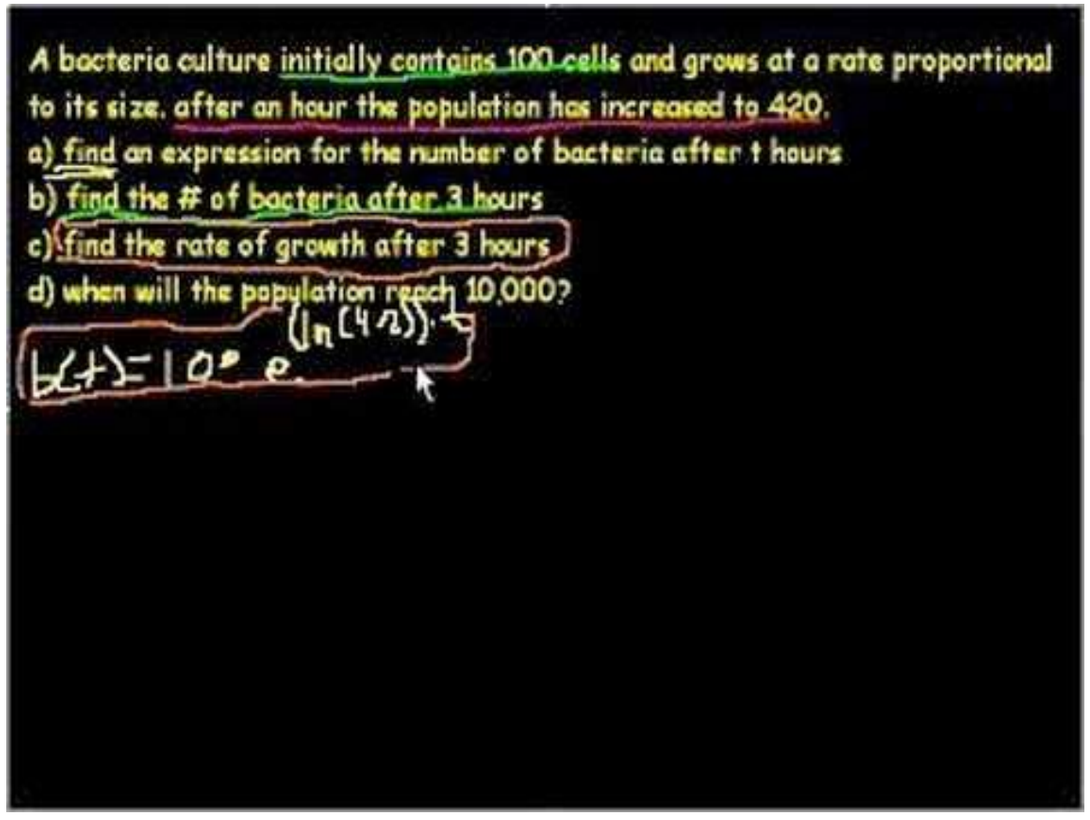
Polluted Water

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 (**Figure** below). Unsafe drinking water carries many **pathogens** , or infectious organisms, such as bacteria or

fungi. Toxic chemicals, radiological hazards, and parasites are also disease-causing agents found in water.

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. http://www.youtube.com/watch?v=JWfTckls59k

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 (16:00).



Click on the image above for more content



Figure 27.16

The Ganges River is a source of water for drinking and bathing for millions of people.

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** below). 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 27.17

Dracunculiasis commonly known as Guinea Worm, is contracted when a person drinks the guinea worm larvae.

Guinea worm is a serious problem in parts of Africa that is being eradicated. Learn what is being done to decrease the number of people suffering from this parasite in the video below.

http://www.youtube.com/watch?v=u4kQWvUv_Ns



Click on the image above for more content

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. Industrial, 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.

In many cases, water disputes add to tensions between countries where differing national interests and withdrawal rights have been in conflict. Some of today's greatest tensions are happening in

places where water is scarce. 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.

Lesson Summary

•Water is a renewable resource, but it is not unlimited. Water is not evenly distributed across the globe.
•Water is so valuable that countries have fought each other over water rights throughout history.
•Many people live with water scarcity and many more will do so in the future.
•Underdeveloped countries are rarely able to afford water treatment and purification facilities, although international aid is sometimes available.

Review Questions

1. If most of the Earth is covered with water, how can there be water shortages?

2. Where in the world is there the least amount of water available relative to the human population? Where in North America is there the least amount of water relative to the population?

3. In 2025, where are the water shortages likely to be?

4. Why will there be more regions prone to water shortages in 2025 than there are today?

5. How do human activities contribute to the frequency or duration of droughts?

6. Why are waterborne diseases more common in less developed countries than developed countries?

7. Why does the United Nations describe the current water status today as a crisis?

8. How do droughts affect water supplies?

9. What are the possible consequences of water shortages?

10. Give two reasons why water shortages are happening around the world today.

Points to Consider

•What can we do to help the one-fifth of the people on Earth who do not have access to safe drinking water?
•How can we reduce water shortages because of overuse, overpopulation, and drought?
•Water is so valuable that wars have been fought over it throughout history. Could conserving freshwater now help avoid future wars?

Water Pollution

Water Pollution

Learning Objectives

- Discuss the risks that water pollution poses to human and environmental health.
- Explain where fresh and saltwater pollution come from.
- Discuss how pathogen born diseases are caused by water pollution.
- Describe why conserving water and protecting water quality is important to human health and the environment.
- Describe how water pollution reduces the amount of safe drinking water available.
- Discuss who is responsible for preventing and cleaning up water pollution.

Vocabulary

- thermal pollution

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 undeveloped 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.

KQED: Mercury in San Francisco Bay

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. Learn more at: http://science.kqed.org/quest/video/mercury-in-san-francisco-bay/ .



Click on the image above for more content

Municipal Pollution

Wastewater from cities and towns contains many different contaminants from many different homes, businesses, and industries (**Figure** below). 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 27.18

Municipal and agricultural pollution.

Industrial Pollution

Factories and hospitals spew pollutants into the air and waterways (**Figure** below). Some of the most hazardous industrial pollutants include:

- Radioactive substances from nuclear power plants, 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 27.19

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** below). Soil and silt also runs off farms. Animal wastes may carry harmful diseases, particularly in the developing world.



Figure 27.20

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.

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 (**Figure** below).



Figure 27.21

The Gulf of Mexico dead zone is created by the Mississippi River, which carries fertilizer from farms and yards covering an enormous land area. In 2009 the dead zone was more than 22,000 square kilometers (8,500 mi^2).

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** below).

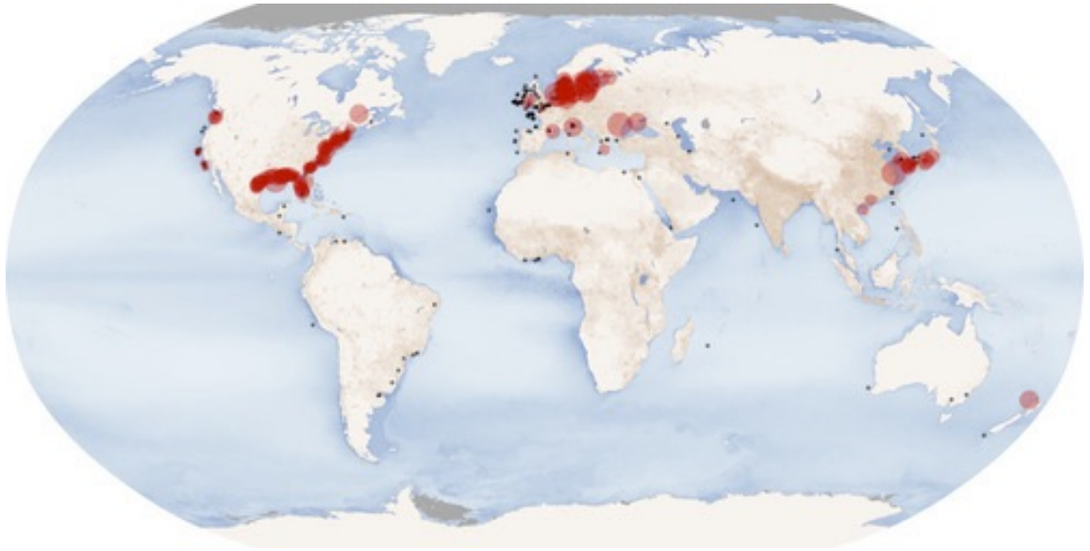


Figure 27.22

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.

Ocean Pollution

Most ocean pollution comes as runoff from land and originates as agricultural, industrial, and municipal wastes (**Figure** below). 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.



Figure 27.23

In some areas of the world, ocean pollution is all too obvious.

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 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/player/environment/ .

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 possible but with great technological difficulty. The risks from deepwater drilling and the consequences when something goes wrong are greater.

Working on oil platforms is dangerous and 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** below). 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 27.24

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.

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** below). 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.

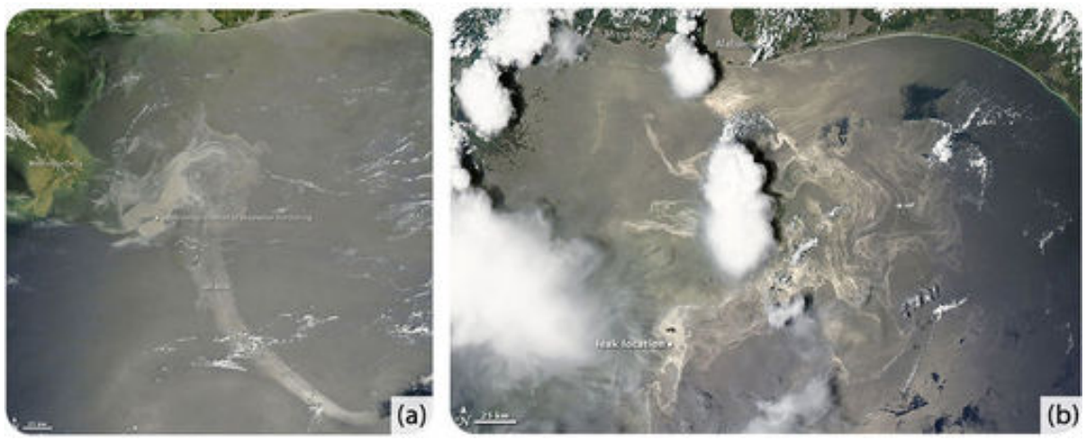


Figure 27.25

(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.

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** below). 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.



Figure 27.26

Burning the oil can reduce the amount in the water.

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** below). Sand berms have been constructed off of the Louisiana coast to keep the oil from reaching shore.



Figure 27.27

A containment boom holds back oil, but it is only effective in calm water.

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 become ill from exposure to the chemicals.

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 original well was declared effectively dead on September 19, 2010.

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** below). 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.

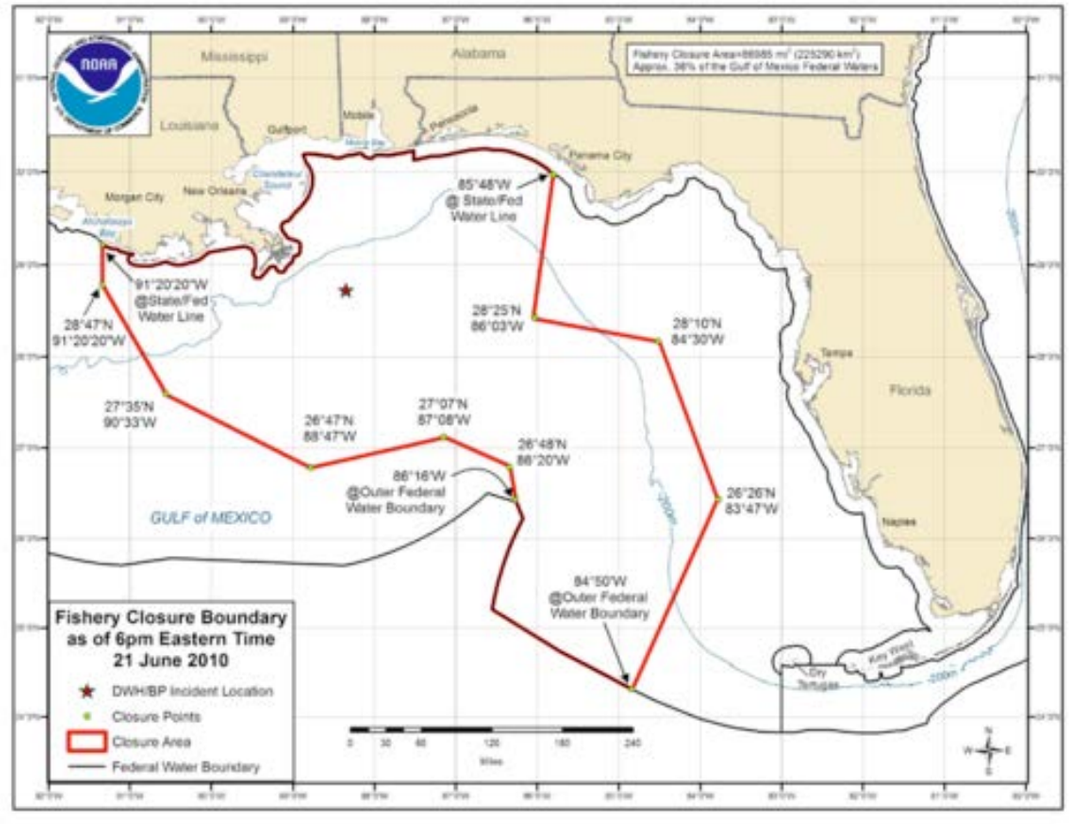


Figure 27.28

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 (**Figure** below). With such low numbers, rebuilding their populations after the spill will be difficult.



Figure 27.29

The endangered Kemp's Ridley turtle breeds only around the Gulf of Mexico.

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 (**Figure** below).



Figure 27.30

Seabirds dive into a slick because the surface looks like calmer water. Oil coated birds cannot regulate their body temperatures. These pelicans are waiting for cleanup.

Eight national parks and seashores are found along the Gulf shores. Other locations may be ecologically sensitive habitats such as mangroves or marshlands (**Figure** below).



Figure 27.31

The Chandeleur Islands are a popular location for migrating birds to rest. Oil was already found off the islands in early May.

This story is a long way from being over.

Thermal Water Pollution

Thermal pollution is any rise or fall in water temperatures that is not weather related. Power plants cool heated equipment with local streams, lakes, or ocean water and then return that heated water back into the environment. Cold water pollution is observed when very cold water is released from reservoirs. Aquatic organisms are often sensitive to even small temperature changes. The Macquarie perch is now extinct in most of its upland river habitats partially because of thermal pollution by dams.

Lesson Summary

- Industrial, agricultural, and municipal sources produce harmful water pollutants such as toxic chemicals, radiological agents, and animal wastes.
- Deep water oil drilling presents an enormous threat to the economic and ecological health of the oceans as seen in the Gulf Oil Spill of 2010.

Review Questions

1. How does water pollution contribute to water shortages?

2. How are the major sources of water pollution different between developing and developed countries?

3. Where are most of the dead zones located?

4. Explain what a dead zone is.

5. Why are coastal wetlands important and what are the sources of pollution that affects them?

6. What is the leading cause of death for children around the world?

7. What are the risks of deepwater drilling for petroleum?

8. Months after the oil spill the amount of oil that is located at the top of the Gulf water and on the shorelines is much less than the amount that was predicted to be in those locations. What happened to the oil? Did id just disappear? Does this mean that the dire predictions being made just after the spill were wrong?

Points to Consider

•How does water pollution reduce the amount of drinking water available for people to use?
•About 50% of all infectious diseases are caused by water pollution. What can be done to reduce the number of pathogens that reach our fresh water supplies?
•Ocean pollution harms some of the most productive sources of marine life. How can we change our behaviors to protect marine life?

Protecting the Water Supply

Learning Objectives

- Describe several ways water can be conserved.
- Discuss how water is treated to eliminate harmful particles.
- State what governments and international organizations can do to reduce water pollution.

Vocabulary

- sewage treatment
- water purification

Water Treatment

The goal of water treatment is to make water suitable for such uses as drinking water, 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 (**Figure** below). Many underdeveloped nations have few or no water treatment facilities.



Figure 27.32

A wastewater treatment facility uses settling containers, filters, chemicals, and biological agents to remove impurities.

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.

KQED: Wastewater Woes: Sewage Spill in SF Bay

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. Learn more at: http://science.kqed.org/quest/video/wastewater-woes-sewage-spills-in-sf-bay/ .



Click on the image above for more content

Reducing Water Pollution

Water pollution can be reduced in two ways:

- Keep the water from becoming polluted.
- Clean water that is already polluted.

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 sets 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** below).



Figure 27.33

Scientists control water pollution by sampling the water and studying the pollutants that are in the water.

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.

Controlling Ocean Pollution

Because so much of the pollution that ends up in the oceans starts out on land, one way to reduce ocean pollution is to reduce pollutants in rivers and other effluent that ends up in the sea. Although it is extremely difficult to do because the ocean is so vast, pollution that is put directly into the ocean can be better regulated and monitored (**Figure** below).



Figure 27.34

Marine pollution can be controlled by regulation, such as preventing pumping of ballast water from ships.

Government and international agencies can pass laws, provide funding, and enforce laws to prevent and clean up ocean pollution. Several national and international agencies monitor and control ocean pollution, including the National Oceanic and Atmospheric Administration (NOAA) and the EPA.

The long-term effects of oil spills are not well understood. Although the waters contaminated by the Exxon Valdez spill have been free of contaminants for years, the rocks and sand beneath the surface on many beaches are still coated with oil. The best way to avoid these problems is to keep oil spills from happening. This

requires better monitoring of the companies that are permitted to engage in drilling for oil and transporting oil. The recent spill into the Gulf of Mexico suggests that this type of monitoring is so far insufficient.

Conserving Water



Figure 27.35

Low-flow showerheads reduce the amount water used during showers.

As human population growth continues, water conservation will become increasingly important globally (**Figure** above), 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: water lawns less, sweep rather than hose down sidewalks, and others.

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.

Lesson Summary

- Many technologies are available to conserve water as well as to prevent and treat water pollution.
- Many underdeveloped countries cannot afford the technology to provide their citizens with clean water.
- The best way to have clean water is to keep water from being polluted.
- Conserving water is necessary to be sure that water will be available for as many uses as possible.

Review Questions

1. What is the purpose of water treatment and purification?

2. How can governments and international organizations help to reduce water pollution?

3. How can ocean pollution be controlled?

4. Name three things that a person could do to reduce pollution.

5. Name three ways that you could reduce your personal water use.

Further Reading / Supplemental Links

- The American Association for the Advancement of Science, AAAS Atlas of Population and Environment. University of California Press, 2000.
- http://www.globalchange.umich.edu/globalchange2/current/lectures/freshwater_supply/freshwater.html
- The World Resources Institute website discusses environmental issues http://www.wri.org/#
- Water issues are some of the problems dealt with by the World Health Organization http://www.who.int/en/
- The World Bank website also discusses issues of poverty: http://www.worldbank.org/

Points to Consider

- Who is responsible for controlling water pollution?
- What can governments and international organizations do to control pollution?
- It is usually cheaper to dump polluted water without spending money to treat and purify the water. What incentives would convince industry to control water pollution?

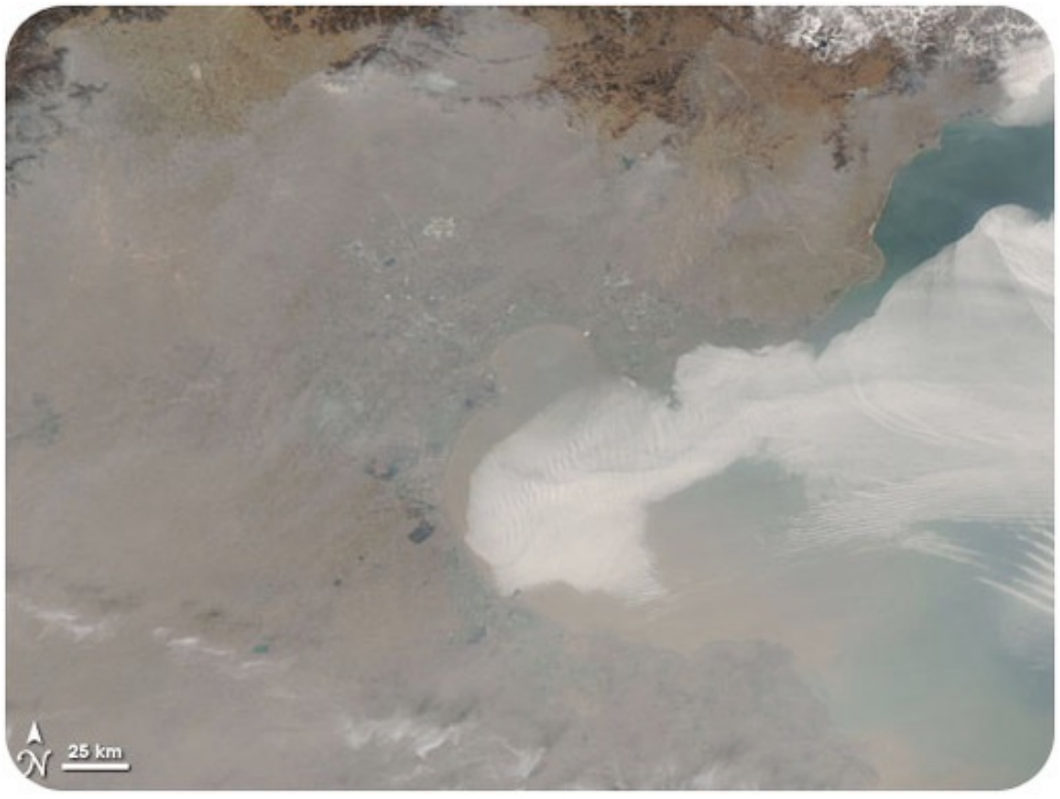
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Ch. 28: Human Actions and the Atmosphere



Air pollution goes hand-in-hand with industrialization as can be seen in this satellite image taken over Beijing, China. The air is a uniform brownish gray, showing that the region is thick with smog. Although legislation protects the people who live in developed nations from at least some of the problems caused by air pollution, people in many developing nations have no such protection. In China, an ongoing battle to improve the standard of living of its people has resulted in unrestrained growth and little protection from environmental damage. At least 75% of the people who live in China's cities live with air quality that is below the national standard. Beijing is an enormous city of more than 10 million people, where many of the bicycles that have transported people for decades are being traded in for cars. Along with the increase in electricity generation from coal, and many other factors, the result is unhealthy living conditions.

There is, unfortunately, still plenty of smog in developed nations as can be seen in this chapter.

Courtesy of MODIS Land Rapid Response Team and NASA. earthobservatory.nasa.gov/IOTD/view.php?id=6344. Public Domain.

Air Pollution

Lesson Objectives

- Describe the different types of air pollutants.
- Discuss what conditions lead some cities to become more polluted than others.
- Describe the sources of air pollutants.

Vocabulary

- photochemical smog
- slash-and-burn agriculture

Introduction

Earth's atmosphere provides living creatures on the planet with the gases they need for photosynthesis and respiration. In addition, the ozone layer protects organisms from the Sun's ultraviolet radiation. The importance of the atmosphere for Earth's life cannot be overestimated yet people also use the atmosphere as a dump for waste gases and particles.

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 (**Figure** below).



Figure 28.1

The 2012 Olympic Games in London opening ceremony contained a reenactment of the Industrial Revolution - complete with pollution streaming from smokestacks.

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. In Donora, Pennsylvania, in October 1948, 20 people died and 4,000 became ill when coal smoke was trapped by an inversion. 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 , 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** below). Photochemical smog consists of more than 100 compounds, most importantly ozone.

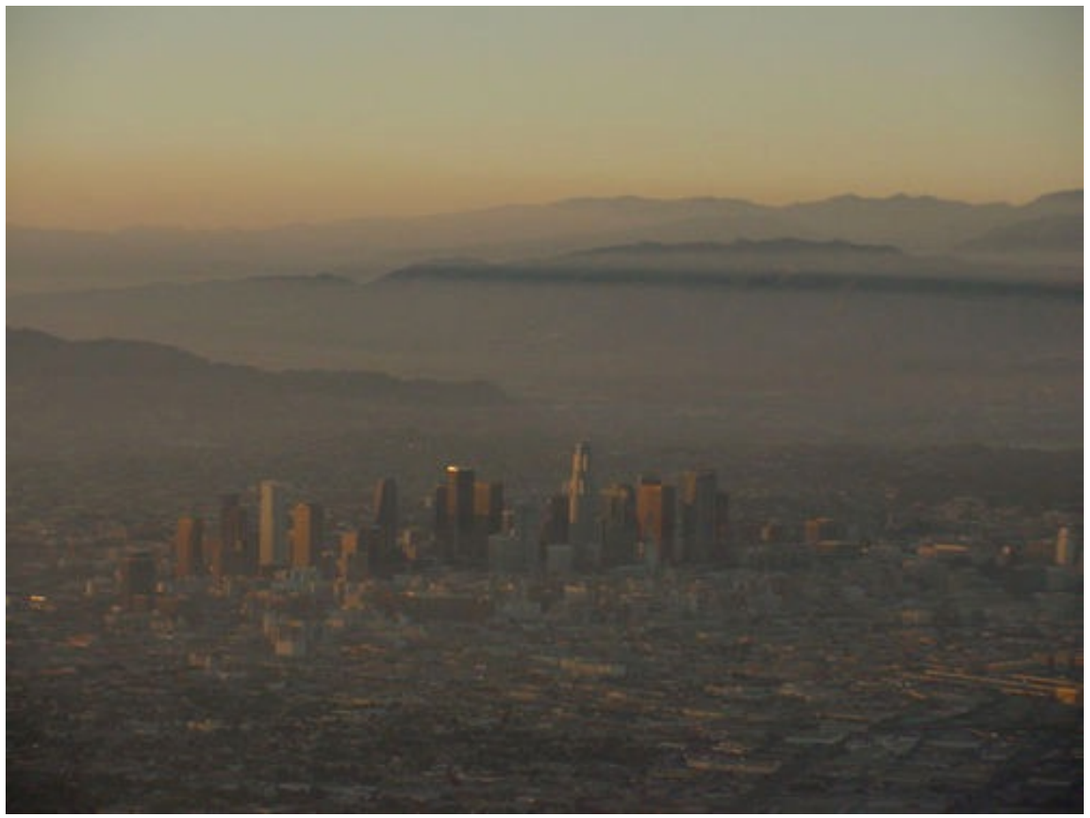


Figure 28.2

Much of the air pollution seen over Los Angeles is photochemical smog.

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.

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 below lists the smoggiest cities in 2012: nine 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.

Rank	City, State
1	Los Angeles, California
2	Visalia-Porterville, California
3	Bakersfield, California
4	Fresno, California
5	Hanford, California
6	Sacramento, California
7	San Diego, California
8	Houston, Texas
9	San Luis Obispo, California
10	Merced, California

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** below). Both are colorless,

odorless gases. CO is toxic to both plants and animals. CO and CO_2 are both greenhouse gases.

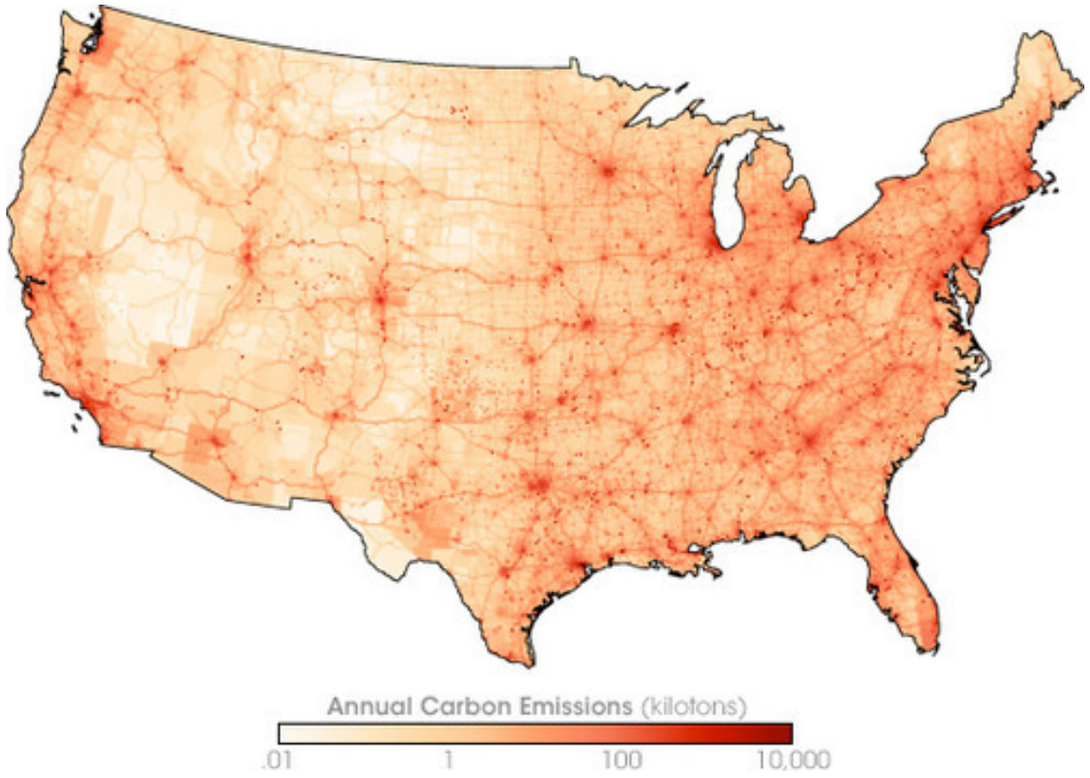


Figure 28.3

High CO_2 levels are found in major metropolitan areas and along the major interstate highways.

- 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.
- 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** below). 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.



Figure 28.4

Particulates from a brush fire give the sky a strange glow in Arizona.

- 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 compounds are some of the components of this type of air pollution.

Photochemical smog forms when car exhaust is exposed to sunlight. Nitrogen oxides is created by gas combustion in cars and then into the air (**Figure** below). 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 nitrous oxide levels are high, ozone will not be created.



Figure 28.5

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 (**Figure** below). Photochemical smog peaks at midday on the hottest days of summer. Ozone is also a greenhouse gas.

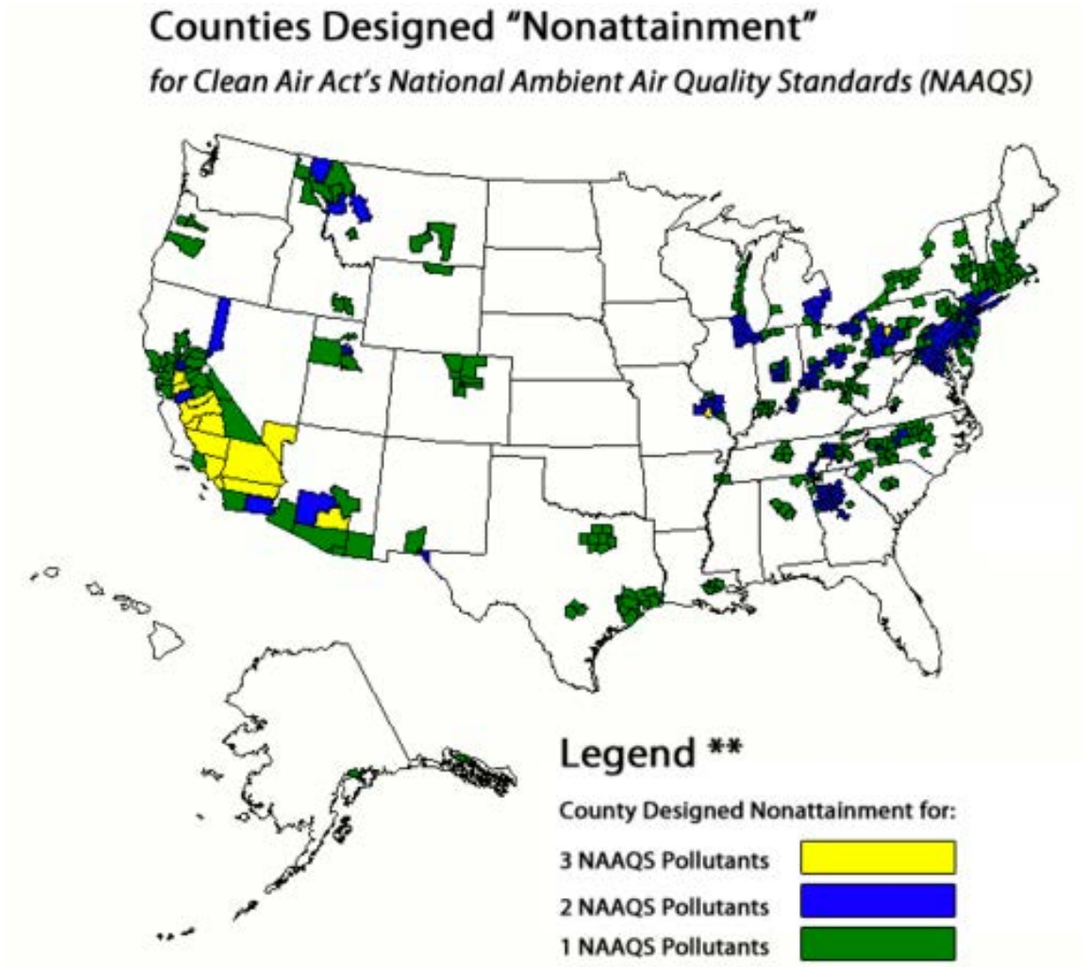


Figure 28.6

Counties with such high ozone levels that they do not attain federal air quality standards.

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** below). 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 28.7

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 (**Figure** below). 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.



Figure 28.8

A power plant and its emissions before emission control equipment was added.

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** below). 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.



Figure 28.9

A forest that has been slash-and-burned to make new farmland.

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.

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** below). Methane occurs naturally, but human agriculture is increasing the amount of methane in the atmosphere.

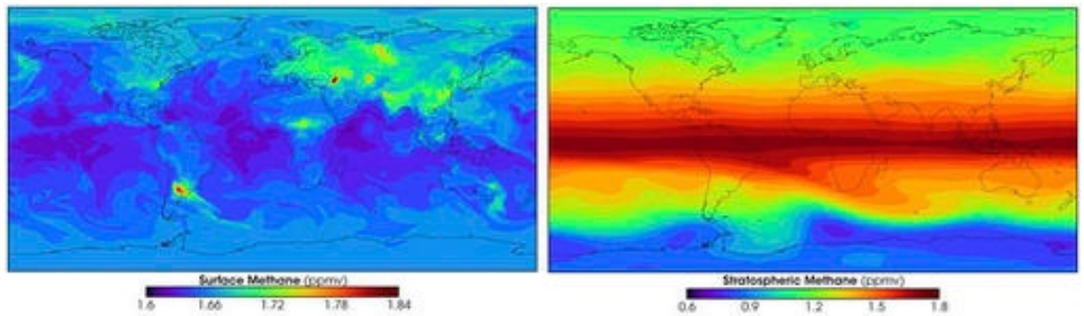


Figure 28.10

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.

Lesson Summary

•Industrial pollution causes health problems, though the Clean Air Act has decreased these health problems in the United States by forcing industry to clean their emissions.
•The increase in motor vehicles in arid cities has increased ozone and other secondary pollutants.
•Burning fossil fuels is the greatest source of air pollution.
•Biomass burning is also a large source of air pollution, especially in places where slash-and-burn agriculture is practiced.

Review Questions

1. What is the difference between the type of smog experienced by cities in the eastern United States and that found in Southern California?

2. London has suffered from terrible air pollution for at least seven centuries. Why is the city so prone to its famous "London fog?" What did London do to get rid of its air pollution?

3. Imagine two cities of the same size with the same amount of industrialization and the same number of motor vehicles. City A is incredibly smoggy most of the time and City B usually has very little air pollution. What factors might go into creating these two different situations?

4. What might be a reason why the city of San Francisco and its metropolitan area is not on the list of smoggiest cities for 2012?

5. Why are naturally occurring substances, such as particulates or carbon dioxide, sometimes considered pollutants?

6. How does ozone form from vehicle exhaust?

7. What are the necessary ingredients for ozone creation, excluding those that are readily available in the atmosphere? Why could there be a city with a lot of cars but relatively little ozone pollution?

8. Some people say that we need to phase out fossil fuel use and replace it with clean energy. Why is fossil fuel use becoming undesirable?

9. Mercury is not particularly toxic as a metal but it is very dangerous in its organic form. How does mercury convert from the metal to the organic form?

10. In what two ways does deforestation contribute to air pollution?

Points to Consider

•Despite the Clean Air Act, the air over many regions in the United States is still not clean. Why?
•How do pollutants damage human health?
•In what ways does air pollution harm the environment?

Effects of Air Pollution

Effects of Air Pollution

Lesson Objectives

- Describe the damage that is being done by smog.
- Discuss how acid rain is formed and the damage it does.
- Discuss how chlorofluorocarbons destroy the ozone layer.

Vocabulary

- acid rain
- alkaline
- bioaccumulation
- ozone hole
- pH scale
- polar stratospheric clouds (PSC)

Introduction

People in developing countries often do not have laws to protect the air that they breathe. The World Health Organization estimates that 22 million people die each year from complications caused by air pollution. Even in the United States, more than 120 million Americans live in areas where the air is considered unhealthy.

This lesson looks at the human health and environmental problems caused by different types of air pollution.

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** below).



Figure 28.11

Smog in New York City.

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.

By reducing sunshine, particulates can also alter air temperature. 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 (**Figure** below) . Imagine how much all of the sources of particulates combine to reduce temperatures. What might this effect be on global warming?



Figure 28.12

Jet contrails block sunlight.

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** below). 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 28.13

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.

KQED: Lichen Point to Pollution

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. Learn more at: http://science.kqed.org/quest/audio/lichen-point-to-pollution/ .



Click on the image above for more content

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** below). 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.

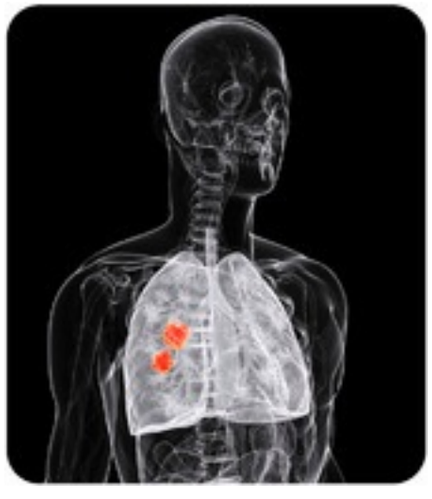


Figure 28.14

A lung tumor is highlighted in this illustration.

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 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.

Do you know why you are only 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.

Mercury is released into the atmosphere when coal is burned (**Figure** below). But breathing the mercury is not harmful. In the atmosphere, the mercury forms small droplets that are deposited in water or sediments.

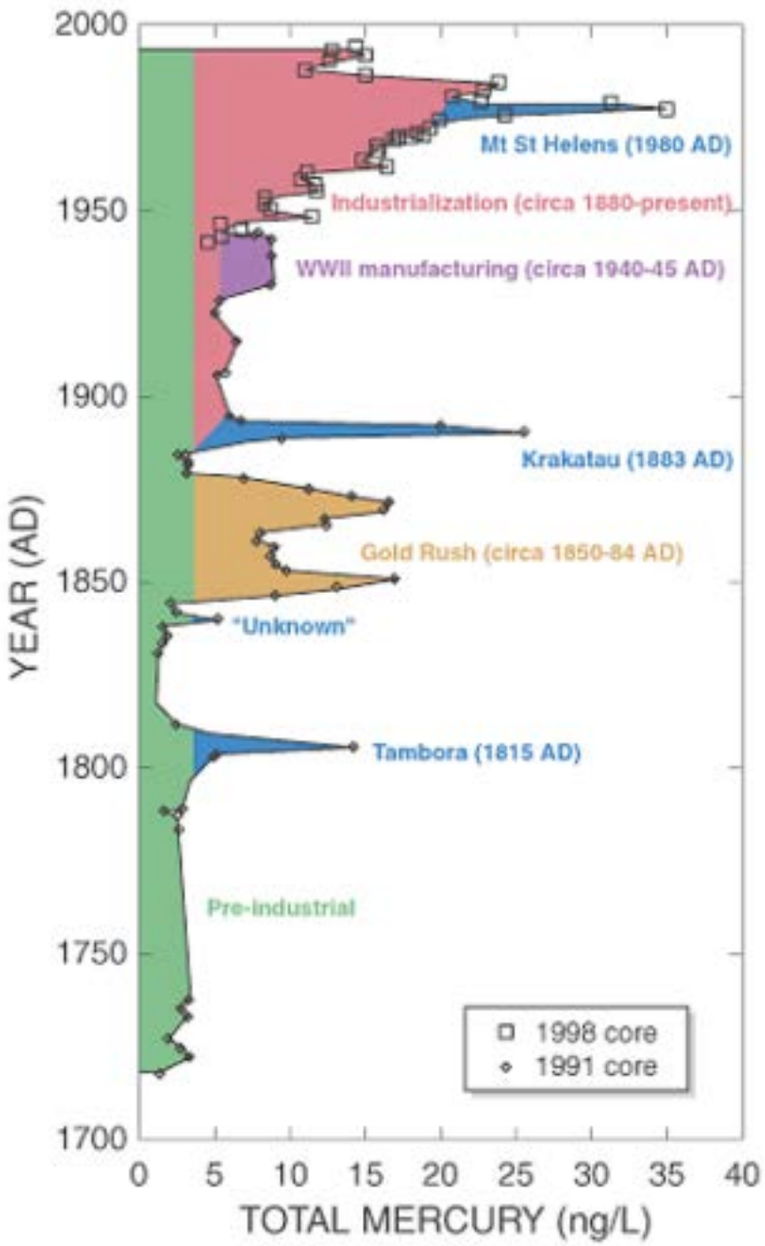


Figure 28.15

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.

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** below). 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.

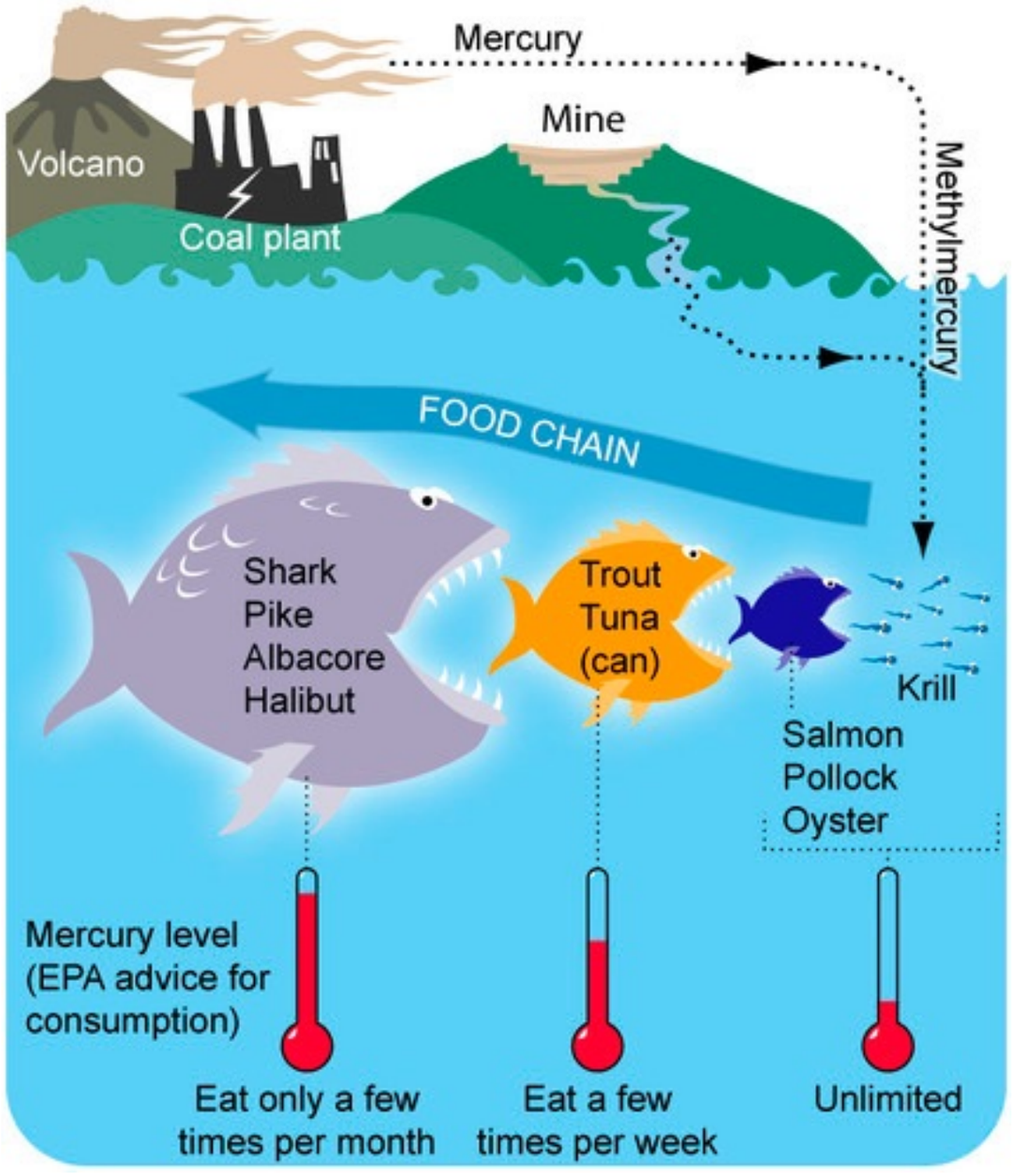


Figure 28.16

Methyl mercury bioaccumulates up the food chain.

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.

Methyl mercury poisoning can cause nervous system or brain damage, especially in infants and children. Children may experience brain damage or developmental delays (**Figure** below). Like mercury, other metals and VOCS can bioaccumulate, causing harm to animals and people high on the food chain.



Figure 28.17

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.

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** below).



Figure 28.18

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** below).

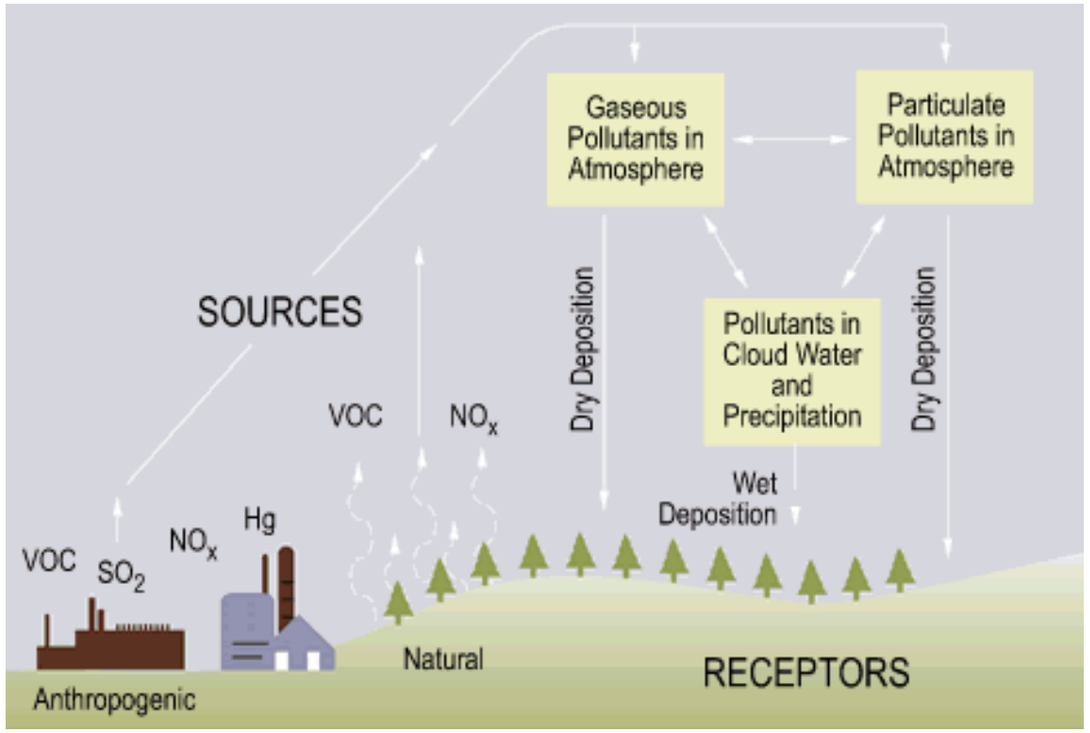


Figure 28.19

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** below). 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.

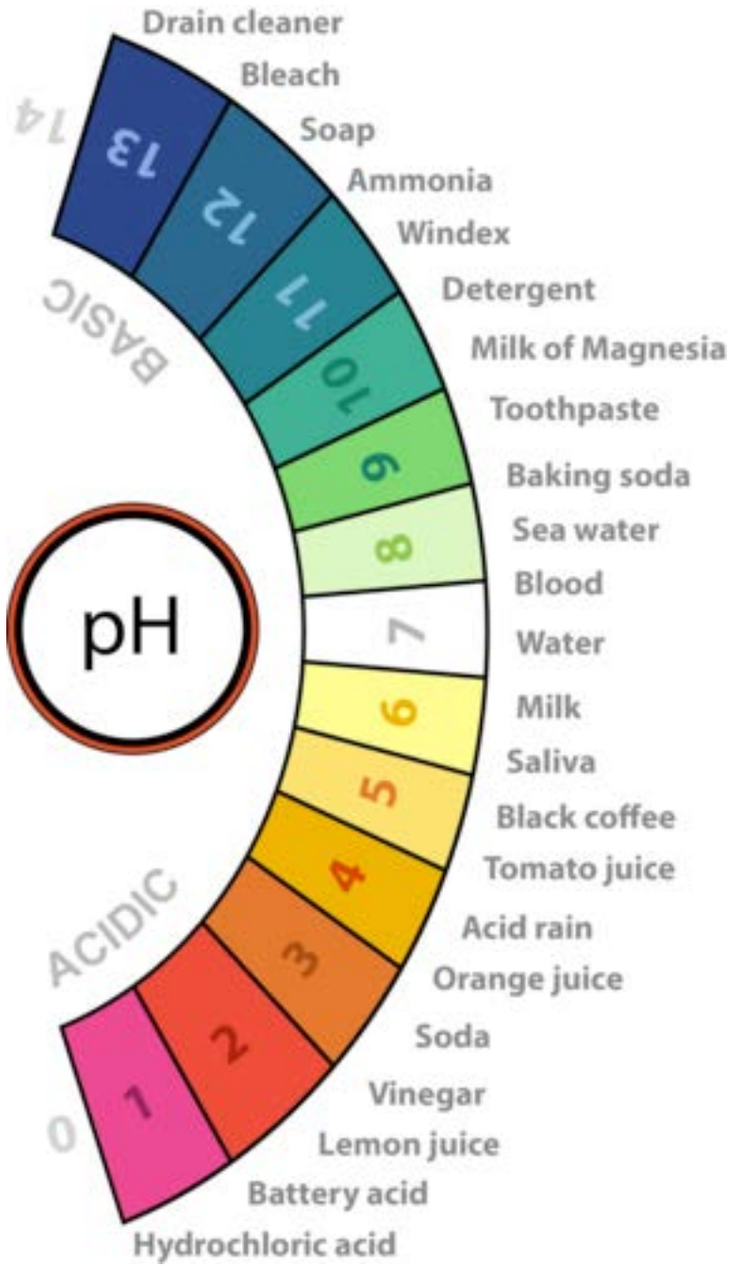


Figure 28.20

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** below). 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.



Figure 28.21

Acid rain has killed trees in this forest in the Czech Republic.

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. Capital and many buildings in Europe, such as Westminster Abbey (**Figure** below).



Figure 28.22

A statue damaged by acid rain.

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 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.

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** below).

- 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.

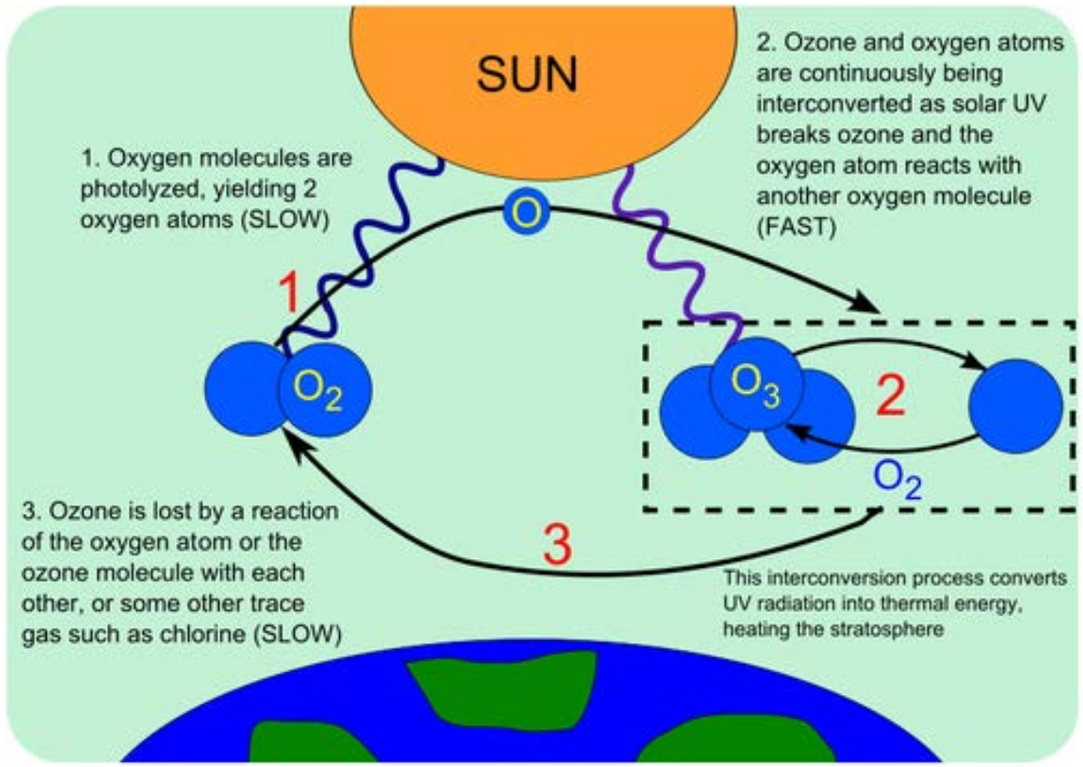


Figure 28.23

(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 Ozone Hole

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** below). In the spring, 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.

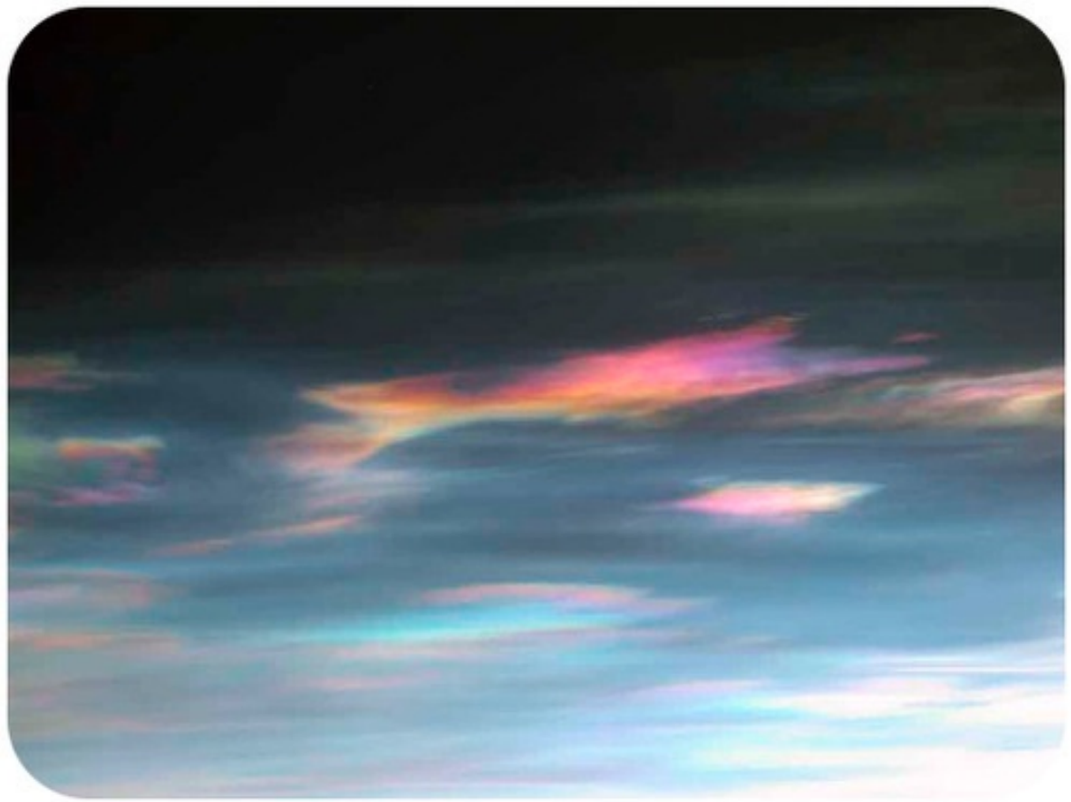


Figure 28.24

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.

Ozone destruction creates the **ozone hole** where the layer is dangerously thin (**Figure** below). 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.

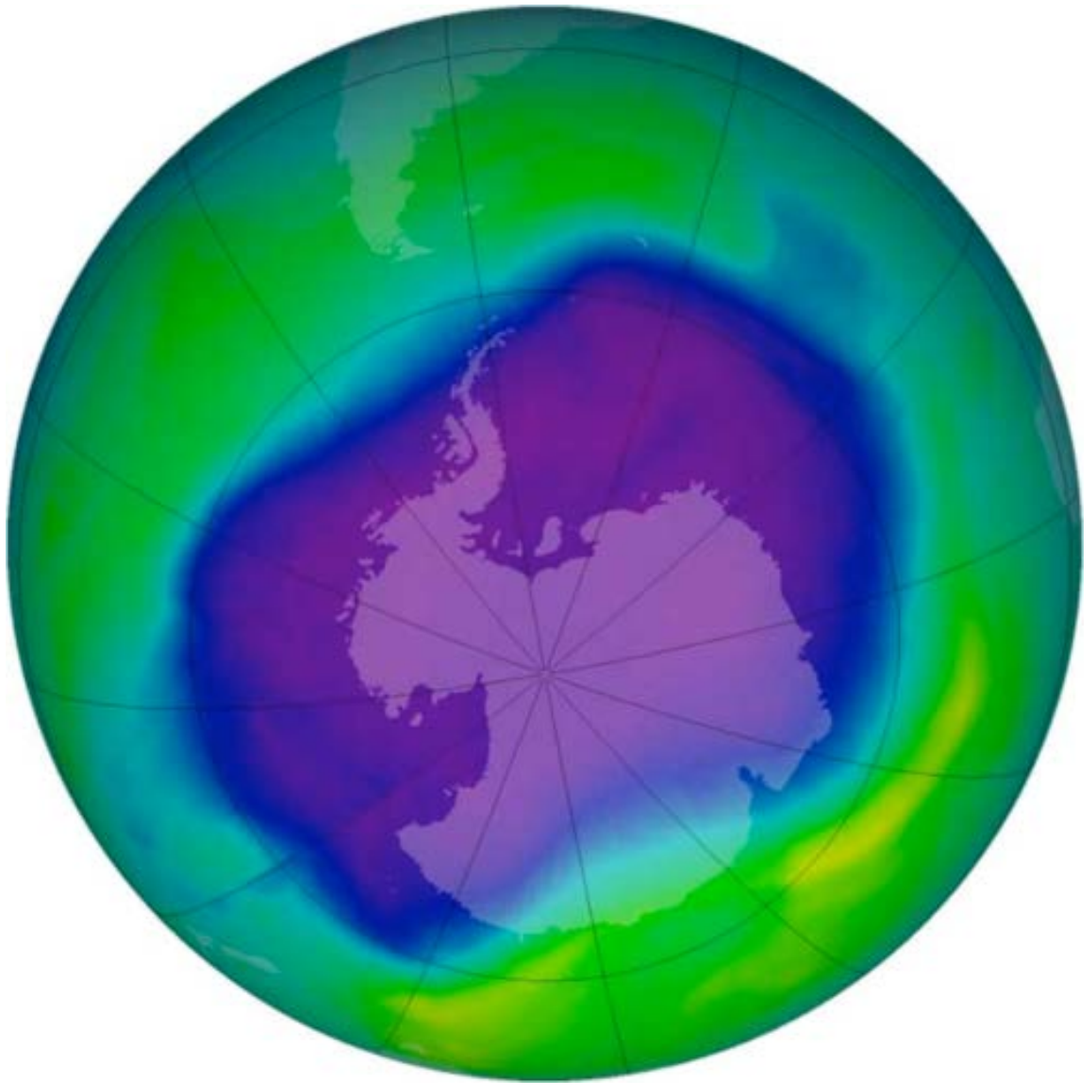


Figure 28.25

The September 2006 ozone hole, the largest observed (through 2009). 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 .

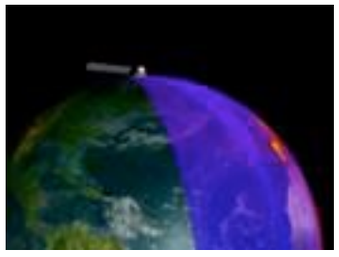
Ozone loss also occurs over the North Polar Region, but it is not enough for scientists to call it a hole. Why do you think there is less ozone loss over the North Pole area? The region of low ozone levels is small because the atmosphere is not as cold and PSCs do not form as readily. Still, springtime 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°N, the latitude of New York City, UV-B has increased about 4% per decade since 1978. At 55°N, 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 (1:52).



Click on the image above for more content

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 (2:20).



Click on the image above for more content

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 sunburn 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.

Lesson Summary

•Air pollutants damage human health and the environment. Particulates reduce visibility, alter the weather, and cause lung problems such as asthma attacks.
•Ozone damages plants and can also cause lung disease. Acid rain damages forests, crops, buildings, and statues.
•The ozone hole, caused by ozone-destroying chemicals, allows more UV radiation to strike the Earth.
•UV radiation can cause plankton populations to decline and skin cancers in humans to increase, along with other effects.

Review Questions

1. Why is visibility so reduced in the United States?

2. Why do health recommendations suggest that people limit the amount of tuna they eat?

3. Why might ozone pollution or acid rain change an entire ecosystem?

4. Why does air pollution cause problems in developing nations more than in developed ones?

5. Why are children more vulnerable to the effects of air pollutants than adults?

6. Describe bioaccumulation.

7. How does pollution indirectly kill or harm plants?

8. What do you think the effect is of jet airplanes on global warming?

9. Why is air pollution a local, regional, and global problem?

10. How do CFCs deplete the ozone layer?

Points to Consider

•Since mercury bioaccumulates and coal-fired power plants continue to emit mercury into the atmosphere, what will be the consequence for people who like to eat tuna and other large predatory fish?
•What are the possible causes of rising asthma rates in children?
•A ban has been imposed on CFCs and some other ozone-depleting substances. How will the ozone hole change in response to this ban?

Section 3

Reducing Air Pollution

Reducing Air Pollution

Lesson Objectives

- Describe the major ways that energy use can be reduced.
- Discuss new technologies that are being developed to reduce air pollutants, including greenhouse gases.
- Describe the difference between placing caps on emissions and reducing emissions.

Vocabulary

- biofuel
- cap-and-trade
- carbon sequestration
- carbon tax
- catalyst
- catalytic converter
- fuel cell
- gasification
- hybrid vehicle

Introduction

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.

Ways to 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. Think back to the chapter, Earth's Energy. 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/player/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 . A very simple thing you can do to conserve energy is discussed in "This Bulb," http://www.youtube.com/watch?v=FvOBHMb6Cqc .

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** below). 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 28.26

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 are beginning 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** below). 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.



Figure 28.27

A hydrogen fuel-cell car looks like a gasoline-powered car.

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** below). Gases, such as nitrogen oxides, can be broken down at very high temperatures.

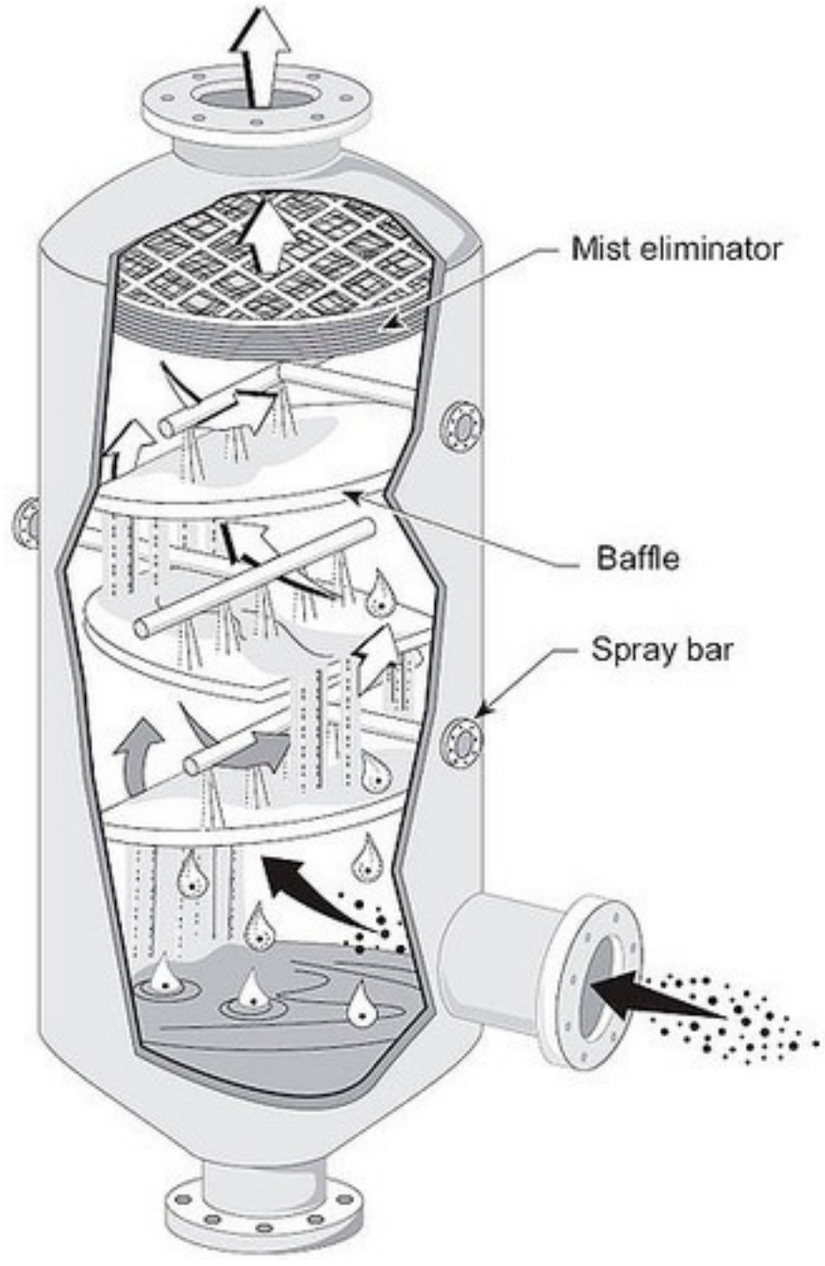


Figure 28.28

Scrubbers remove particles and waste gases from exhaust.

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 and 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.

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. Two years later, 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** below). 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.

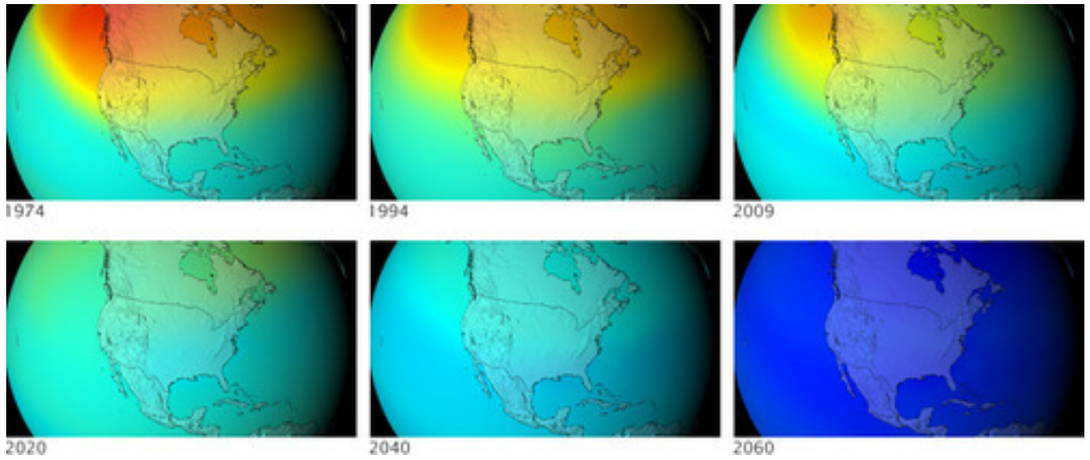


Figure 28.29

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.

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.

Since CFCs take many years to reach the stratosphere and they 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.

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.

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°: http://www.youtube.com/watch?v=2_ZQRIsn2pA
- 2°: http://www.youtube.com/watch?v=P-0_gDXqYeQ

- 3°: http://www.youtube.com/watch?v=6rdLu7wiZOE
- 4°: http://www.youtube.com/watch?v=skFrR3g4BRQ
- 5°: http://www.youtube.com/watch?v=7nRf2RTqANg
- 6°: http://www.youtube.com/watch?v=O8qmaAMK4cM

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 the chapter,Earth's Energy. **Biofuels** can replace gasoline in vehicles, but they must be developed sensibly (**Figure** below). 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 28.30

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.

Lesson Summary

- Air pollutants can be reduced in many ways. The best method is to not use energy that produces the pollutants through conservation or increasing energy efficiency.
- Alternative energy sources are another good way to reduce pollution. Most of these alternate energy technologies are still being refined (solar, wind) and some have other problems associated with them (nuclear, biofuels).
- Pollutants can be removed from an exhaust stream by being filtered out or broken down. Some pollutants, such as CFCs, are best not released at all.

Review Questions

1. Since the Clean Air Act was passed in 1970, why is the air still not clean?

2. What are some ways that you can conserve energy?

3. How does reducing air pollutants, as described in the Clean Air Act of 1970, affect greenhouse gas emissions?

4. What has to be done before alternative energy sources can replace fossil fuels?

5. What are catalytic converters?

6. Why are hybrid vehicles more energy efficient than regular vehicles powered by internal combustion engines?

7. Why aren't fuel-cell vehicles widely available yet?

8. How does a cyclone reduce particulate pollution?

9. How can coal power be made so that it has nearly zero carbon contribution to the atmosphere?

10. Why is it that the ozone hole will not be healed for several decades?

11. Many people think that biofuels are the solution to a lot of the problems of climate change, but others disagree. What requirements would biofuels have to meet if they were to be really effective at replacing gasoline in motor vehicles?

Points to Consider

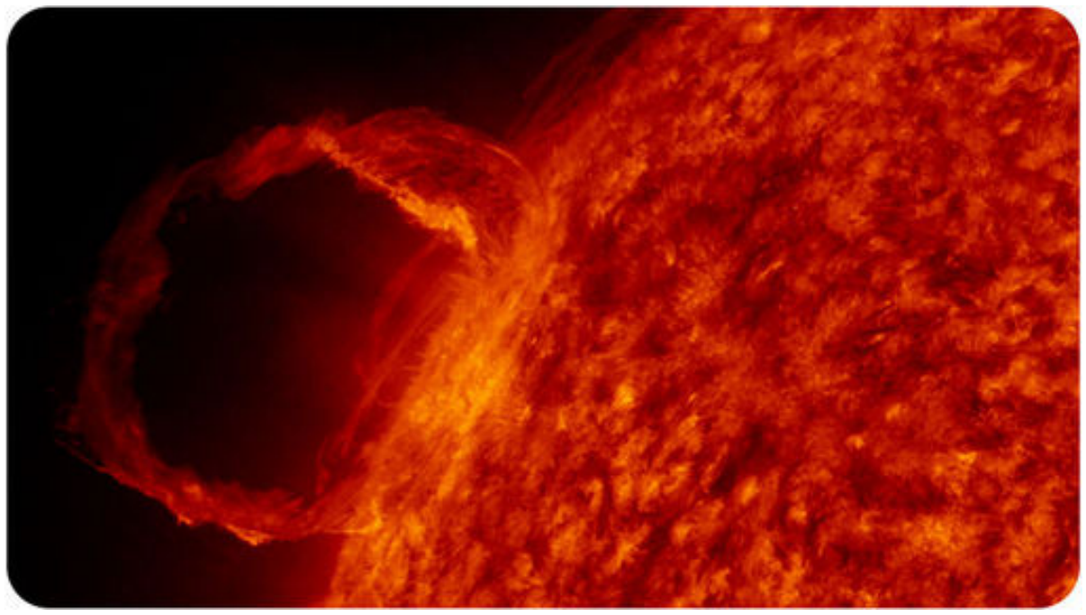
- Why is it important to reduce air pollution?
- What can you do in your own life to reduce your impact on the atmosphere?
- Why is a worldwide effort needed to reduce the threat of global climate change?

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Ch. 29: Earth's Energy



Much of Earth’s energy comes from the Sun. Nearly all life on Earth depends on solar energy since plants use sunlight to make food through the process of photosynthesis. Photosynthesis was the process that fed plants and animals, which in turn, over the course of millions of years, became fossil fuels. The Sun heats some areas of Earth more than other areas, which causes wind. The Sun's energy also drives the water cycle, which moves water over the surface of the Earth. Some of these types of energy can be harnessed for use by people.

The other main source of energy is Earth’s internal heat. This heat has two origins: the breakdown of chemical elements by radioactivity, and the heat that is left over from when the planet came together. These two sources will be described in more detail in later chapters.

Courtesy of NASA. earthobservatory.nasa.gov/IOTD/view.php?id=43717. Public Domain.

Section 1

Energy Resources

Energy Resources

Lesson Objectives

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

Vocabulary

- chemical energy
- energy
- fuel
- heat
- kinetic energy
- law of conservation of energy
- non-renewable resources
- potential energy
- renewable resources

Introduction

Everything requires energy. Even when you are sitting as still as you possibly can, your body is using energy to breathe, circulate blood, digest food, and perform many other functions. Producing light or heat requires energy. Making something requires energy. Plants and animals all require energy to function. To repeat, everything requires energy!

The Need for Energy

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 (**Figure** below). Energy conservation is something everyone can do now to help reduce the strain on energy resources.

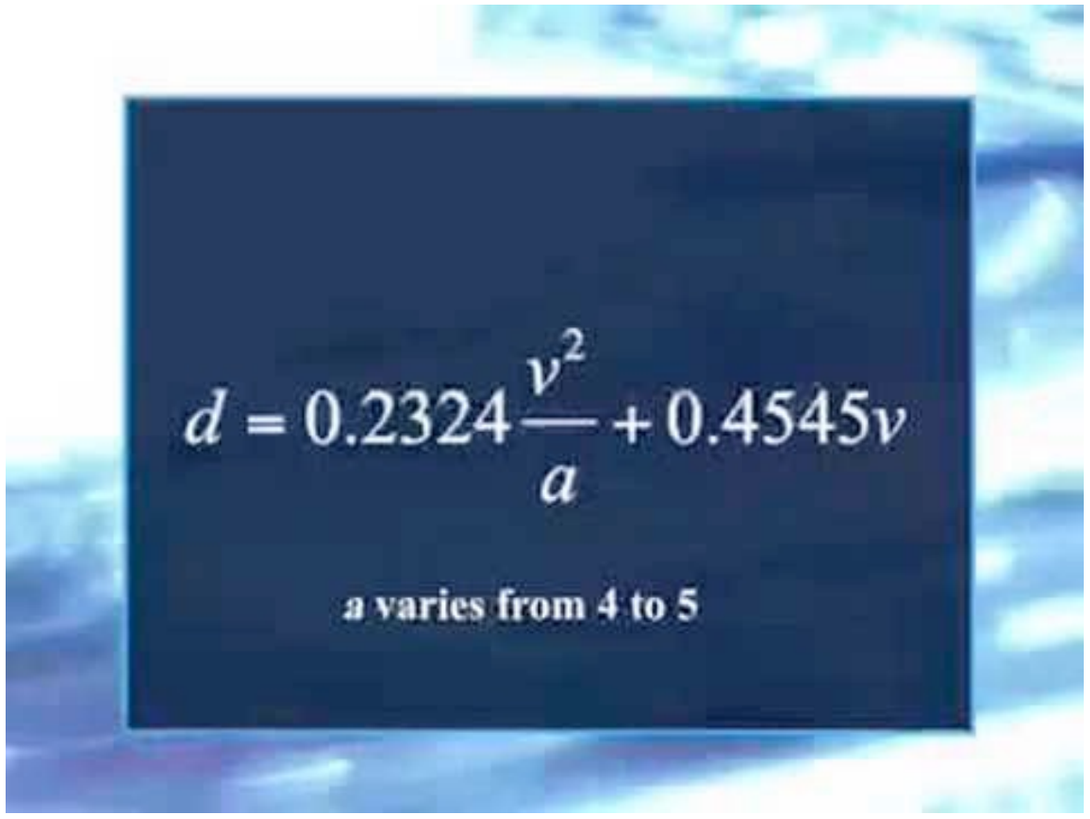


Figure 29.1

Electrical transmission towers like the one shown in this picture help deliver the electricity people use for energy every day.

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** . Chemical energy is stored within chemical bonds. 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 (6:01).



Click on the image above 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

Energy, Fuel, and Heat

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. When fuel is used for its energy, it is usually burned, and most of the energy is released as **heat** (**Figure** below). 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 29.2

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.

Types of Energy Resources

Energy resources are either renewable or non-renewable. **Non-renewable resources** are used faster than they can be replaced,so the supply available to society is limited (see example in **Figure** below). **Renewable resources** will not run out because they are replaced as quickly as they are used. Can you think of some renewable and non-renewable energy sources?



Figure 29.3

Anthracite coal is a non-renewable energy resource.

Non-renewable Resources

Fossil fuels - coal, oil, and natural gas - are the most common example of non-renewable 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. The environmental effects of fossil fuel use are discussed in the “Climate” and “Human Actions and the Atmosphere” chapters.

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, coal, oil, and natural gas, these non-renewable resources will become more expensive. At some point, even if renewable energy costs are high, non-renewable 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 non-renewable 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.

KQED: Climate Watch: Unlocking the Grid

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



Click on the image above for more content

Lesson Summary

•According to the law of conservation of energy, energy is neither created nor destroyed.
•Renewable resources can be replaced at the rate they are being used.
•Non-renewable resources are available in limited amounts or are being used faster than they can be replaced.

Review Questions

1.What is needed by anything that moves or changes in any way?
2.What is the original source of most energy used on Earth?
3.In what form does a living creature store energy from food?
4.When we burn a fuel, what is released that allows work to be done?
5.For biomass, solar, coal, natural gas, oil, and geothermal energy, identify each energy resource as renewable or non-renewable and explain why.
6.What factors are important in judging how helpful an energy resource is to us?
7.Is the energy from a rechargeable battery renewable? (A rechargeable battery can be recharged by being put into a device that is plugged into the wall.) Explain.

Further Reading / Supplemental Links

•Kydes, Andy, "Primary Energy." Encyclopedia of Earth, 2006. Available on the Web at: http://www.eoearth.org/article/Primary_energy .
•Some of the Earth science news on this website is related to energy: http://www.earthportal.org/ .

Points to Consider

•How long do fossil fuels take to form?

•Are all fossil fuels non-renewable resources?
•Do all fossil fuels affect the environment equally?
•How is food energy measured?
•Is a rechargeable battery a renewable source of energy?

Section 2

Non-renewable Energy Re-

Non-renewable Energy Resources

Lesson Objectives

- Describe the natural processes that form the different fossil fuels.
- Describe different fossil fuels, and understand why they are non-renewable resources.
- Explain how fossil fuels are turned into useful forms of energy.
- Understand that when we burn a fossil fuel, its energy is released as heat.
- Describe how a nuclear power plant produces energy.

Vocabulary

- coal
- crude oil
- fossil
- fossil fuel
- hydrocarbon
- natural gas
- nuclear energy
- oil

Introduction

Millions of years ago, plants used energy from the Sun to form sugars, carbohydrates, and other energy-rich carbon compounds that were later transformed into coal, oil, or natural gas. The solar energy stored in these fuels is a rich source of energy. Although fossil fuels provide very high quality energy, they are non-renewable.

In large part, non-renewable energy sources are responsible for the world's lights seen in this animation: http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/LIGHTS_3.MPG .

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 trace from a living creature that becomes a 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. As plants and animals died, their remains settled on the ground on land and in swamps, lakes, and seas (**Figure** below).



Figure 29.4

This wetland may look something like an ancient coal-forming swamp.

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 turned into chemicals called **hydrocarbons** (**Figure** below). An animated view of a hydrocarbon is seen here: http://www.nature.nps.gov/GEOLOGY/usgsnps/oilgas/CH4_3.MPG .

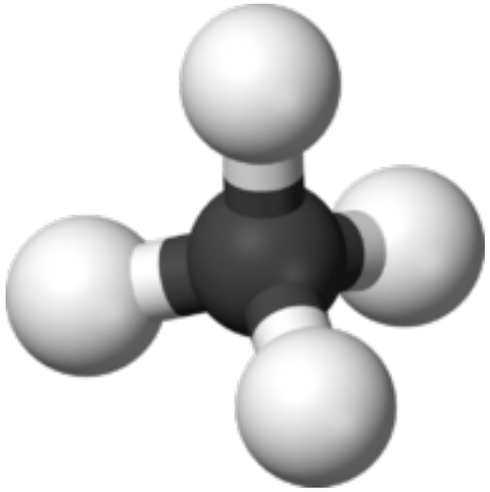


Figure 29.5

Hydrocarbons are made of carbon and hydrogen atoms. This molecule with one carbon and four hydrogen atoms is methane.

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.

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 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** below). The climate was warmer then.

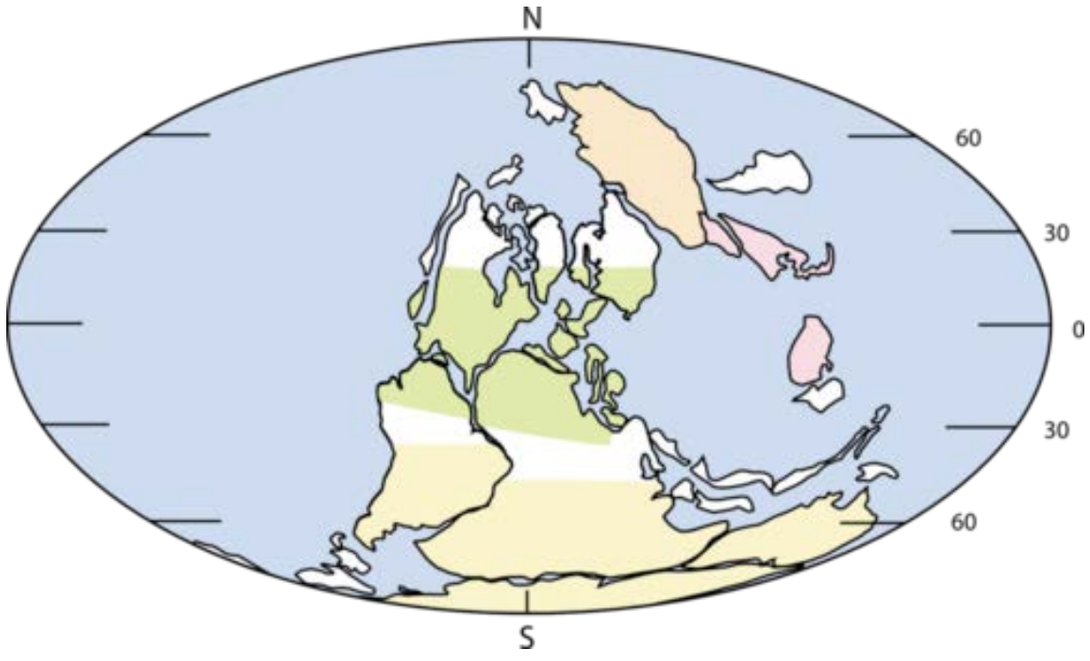


Figure 29.6

The location of the continents during the Carboniferous period. Notice that quite a lot of land area is in the region of the tropics.

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 is black or brownish-black. The most common form of coal is bituminous, a sedimentary rock that contains impurities such as sulfur (**Figure** below). Anthracite coal, seen in **Figure** above , has been metamorphosed and is nearly all carbon. For this reason, anthracite coal burns more cleanly than bituminous coal.



Figure 29.7

Bituminous coal is a sedimentary rock.

Coal Use

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal (**Figure** below). 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.

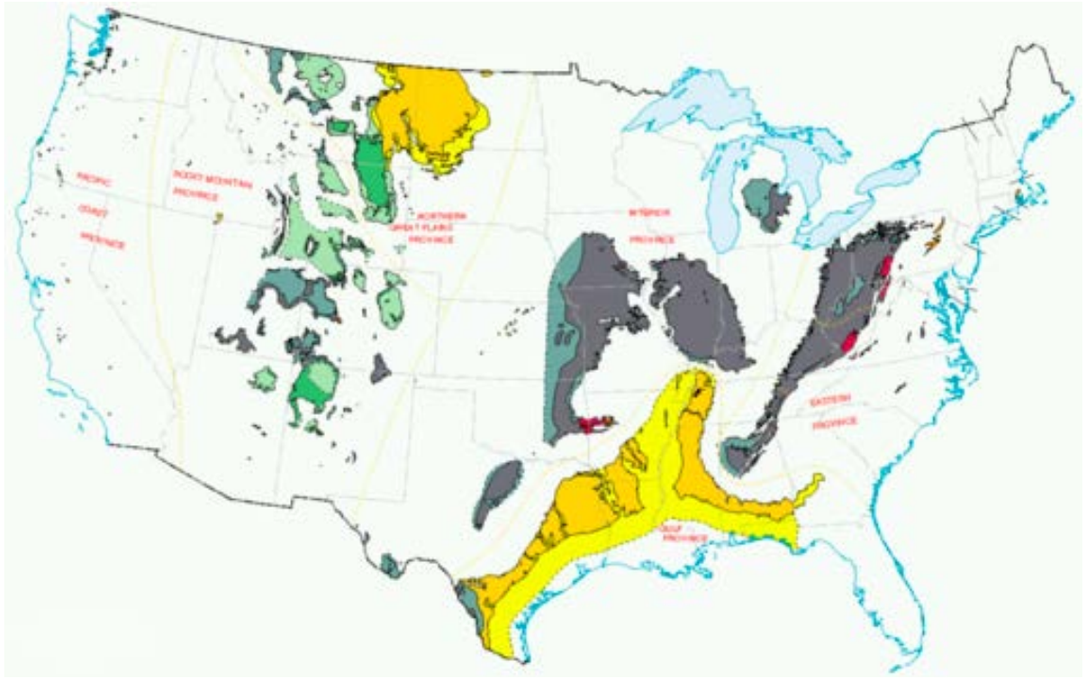


Figure 29.8

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.

Coal that has been located but is not being used is part of our reserves. Reserves are important because if the price of the resource goes up or the cost of extracting it goes down, they may be useful.

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 “Earth's Minerals” chapter (**Figure** below). Mining, especially 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 being mined by mountaintop removal.

A small coal-fired power plant.

Figure 29.9

The coal used in power plants must be mined. One method to mine coal is by mountaintop removal.

Some possible types of environmental damage from mining are discussed in the “Earth's Minerals” chapter. 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.

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** below). 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.

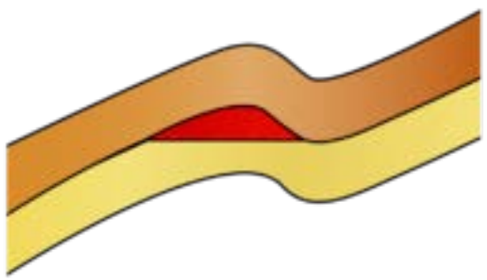


Figure 29.10

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** below . 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 29.11

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, and 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. Most offshore drilling occurs in the Gulf of Mexico, but there are offshore platforms in California as well (**Figure** below). 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 .

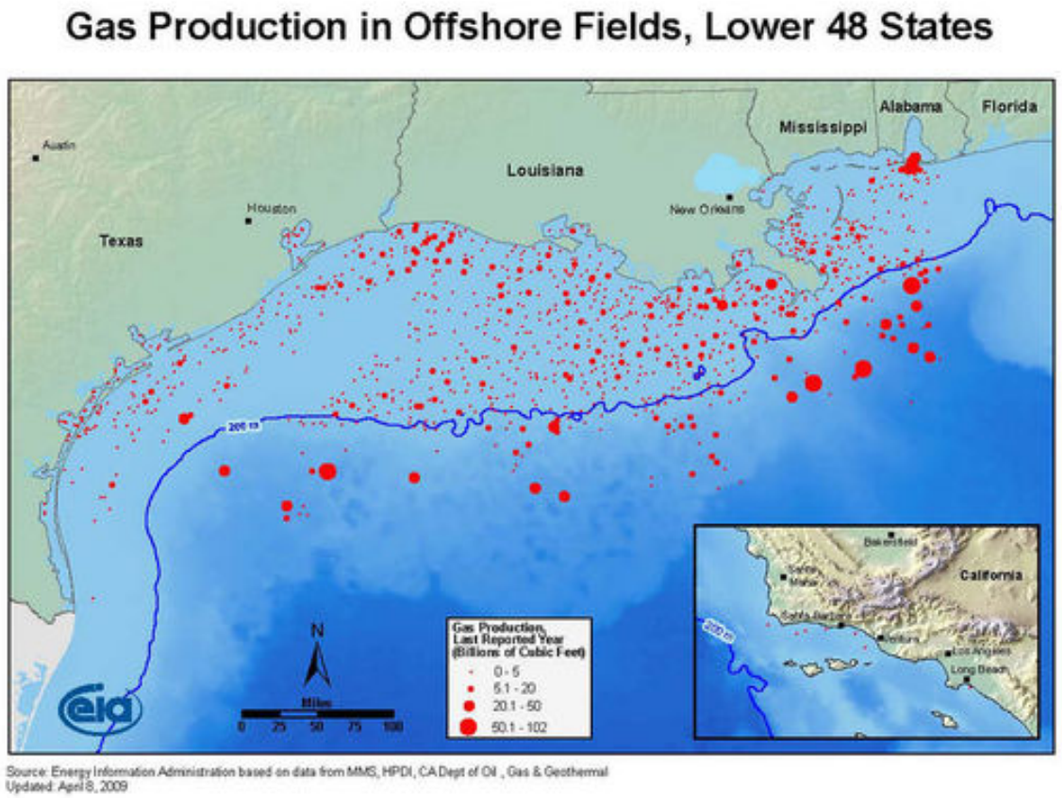


Figure 29.12

Offshore well locations in the Gulf of Mexico. Note that some wells are located in very deep water.

As in every type of mining, mining for oil has environmental consequences. Oil rigs are unsightly (**Figure** below), and spills are too common (**Figure** below).



Figure 29.13

Drill rigs at the San Ardo Oil Field in Monterey, California.

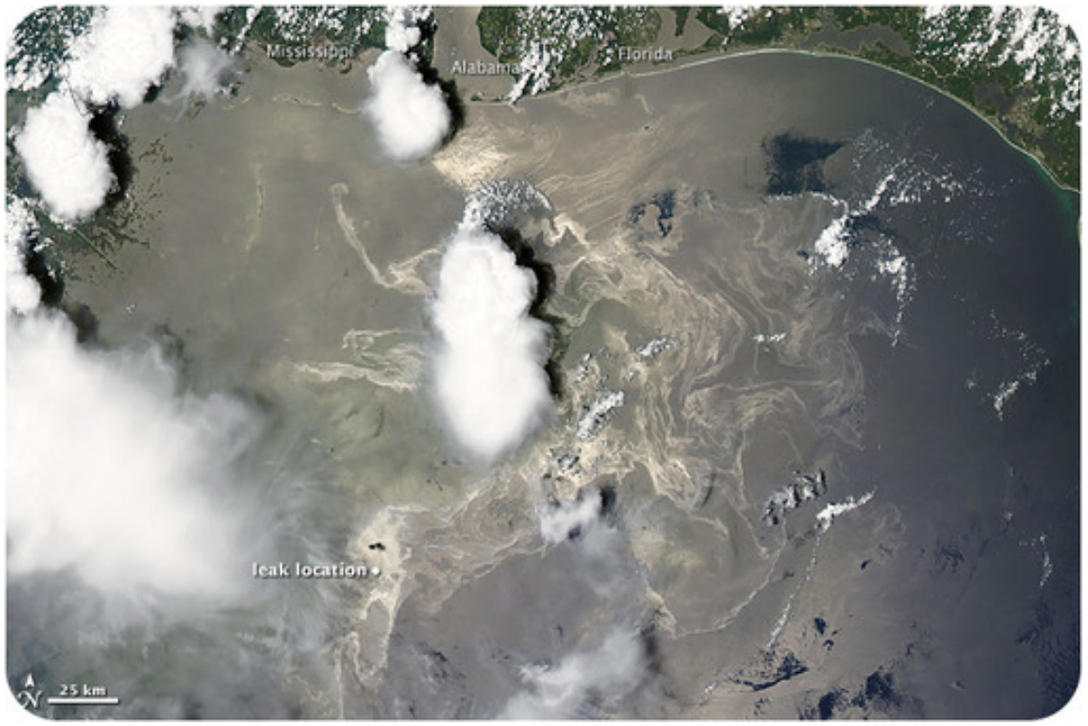


Figure 29.14

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.

Natural Gas

Natural gas , often known simply as gas, is composed mostly of the hydrocarbon methane (refer to **Figure** above for the structure).

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 a minable oil and gas deposit 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** below). 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).

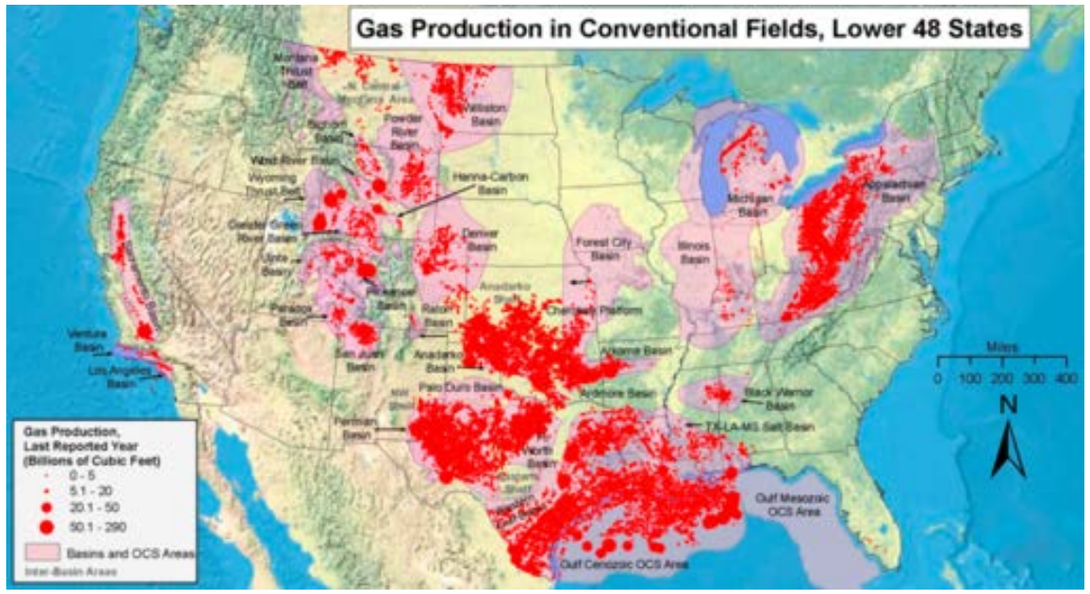


Figure 29.15

Gas production in the Lower l8 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** below).



Figure 29.16

A natural gas drill rig.

•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.

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.

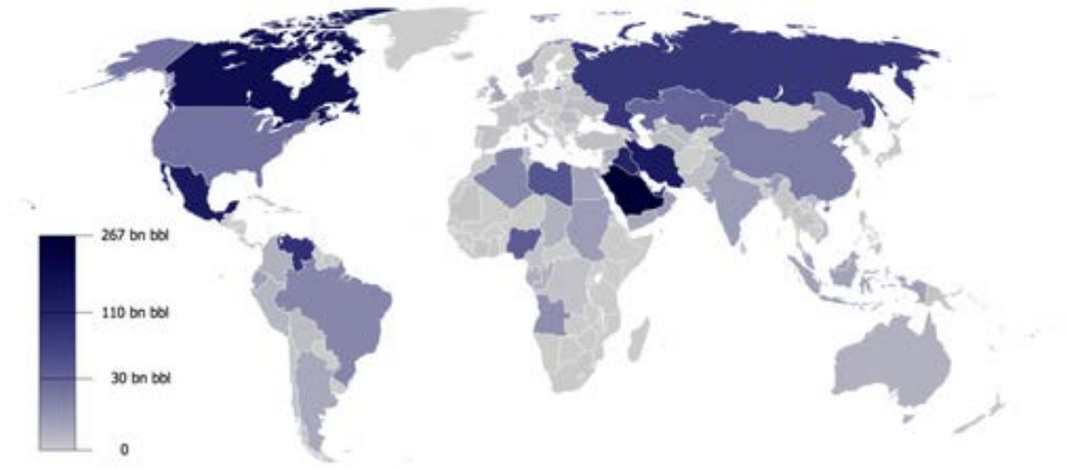


Figure 29.17

Worldwide oil reserves.

- 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** above). Alternative sources of fossil fuels, such as oil shales and tar sands, are increasingly being exploited (**Figure** below).



Figure 29.18

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.

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** below).

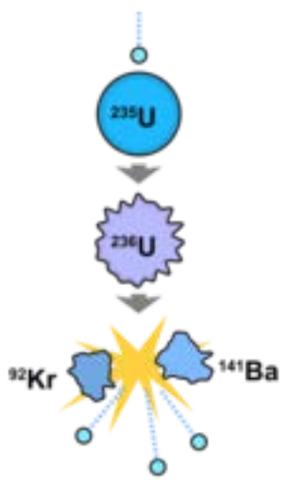


Figure 29.19

When struck by a tiny particle, Uranium-235 breaks apart and releases energy.

Nuclear Energy Use

Nuclear power plants, such as the one seen in **Figure** below , 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.



Figure 29.20

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

Consequences of Nuclear Power

Nuclear power is clean. It does not pollute the air or release carbon dioxide. However, the use of nuclear energy does create other environmental problems. Uranium must be mined (**Figure** below). 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.



Figure 29.21

Uranium mine in Kakadu National Park, Australia.

The development of nuclear power plants has been on hold for three decades. Accidents at Three Mile Island and Chernobyl, Ukraine verified people's worst fears about the dangers of harnessing nuclear power (**Figure** below).



Figure 29.22

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. 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.

KQED: Nuclear Energy Use

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The

future of nuclear power is murky. Find out more at: http://science.kqed.org/quest/audio/new-nuclear/



Click on the image above for more content

Lesson Summary

•Fossil fuels are non-renewable sources of energy that produce environmental damage.
•Coal, oil, and natural gas are fossil fuels formed from the remains of living organisms.
•Coal is the largest source of energy for producing electricity.
•Oil and natural gas are important energy sources for vehicles and electricity generation.
•Nuclear energy is produced by splitting atoms. It also produces radioactive wastes that are very dangerous for many years.

Review Questions

1.What is a hydrocarbon?
2.How do fossil fuels form?
3.Why is anthracite harder and cleaner than other kinds of coal?
4.What byproduct of nuclear energy has caused concerns about the use of this resource and why?
5.What are two important fuels that comes out of the oil refining process?
6.Which chemical element exposed in surface coal mining can cause environmental problems in nearby bodies of water?
7.Why does natural gas need to be processed before it can be used as a fuel?
8.What characteristic of gasoline is most important in making it a useful fuel for transportation? Explain.
9.Since nuclear power is clean, why is it not used more extensively in the United States?

Further Reading / Supplemental Links

•Perry, Mildred, "Coal." Encyclopedia of Earth, 2007. Available on the Web at: http://www.eoearth.org/article/Coal .

Points to Consider

•What are the main categories of non-renewable energy discussed in this chapter?
•Why is nuclear energy considered non-renewable?
•Are non-renewable energy sources equally harmful? What are the advantages of using them?
•Are renewable energy sources harmful or beneficial for the environment?

Section 3

Renewable Energy Re-

Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources and understand why they are renewable.
- Discuss how the Sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Discuss why some renewable energy sources cost less than others do and why some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.

Vocabulary

- biofuel
- conduction
- radiation

Introduction

Fossil fuels have the advantage of being cheap and transportable, but they cause environmental damage and will eventually run out. Renewable energy sources, by definition, will not run out, and most do not cause much pollution. But renewable energy sources do have a downside, too. Both the advantages and disadvantages of solar, water, wind, biomass, and geothermal energy will be described in this lesson.

Solar Power

The Sun is Earth's main source of energy, making the development of solar power a natural choice for an alternative energy source.

Solar Energy

Energy from the Sun comes from the lightest element, hydrogen, fusing together to create the second lightest element, helium. Nuclear fusion 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 year. Unlike energy from fossil fuels, which almost always come from a central power plant or refinery, solar power can be harnessed locally (**Figure** below). 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.

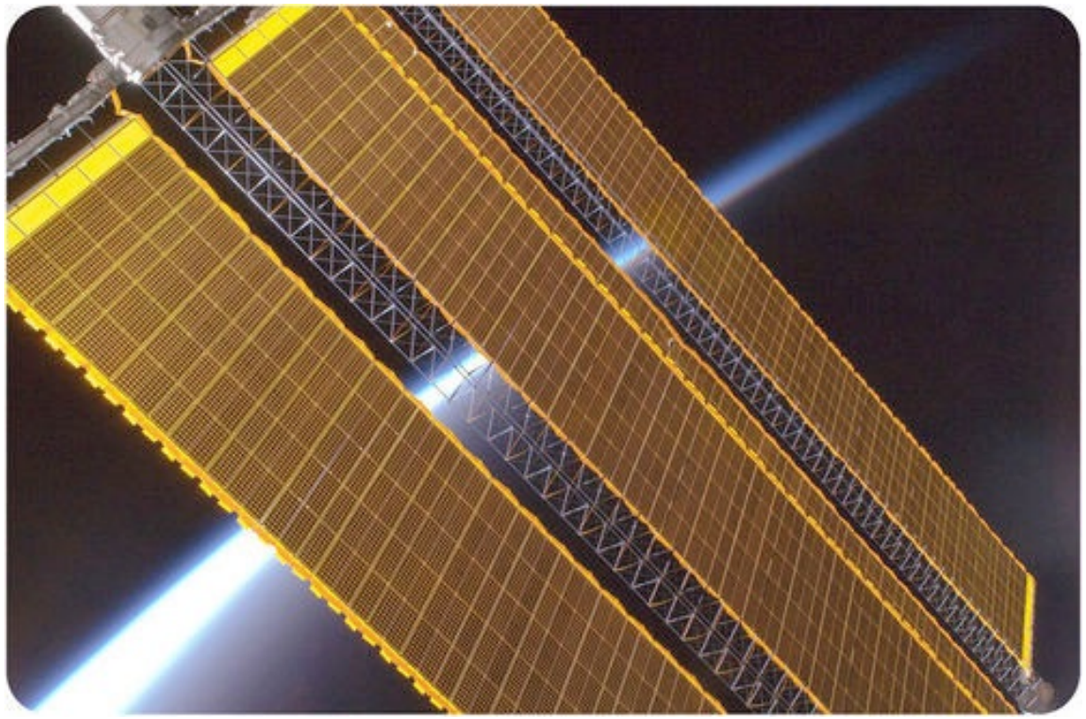


Figure 29.23

Solar panels supply power to the International Space Station.

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** below). A liquid, such as oil or water, flows through this receiver and is heated to a high temperature 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 29.24

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 at night. 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** below).

•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 29.25

This experimental car is one example of the many uses that engineers have found for solar energy.

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** below).

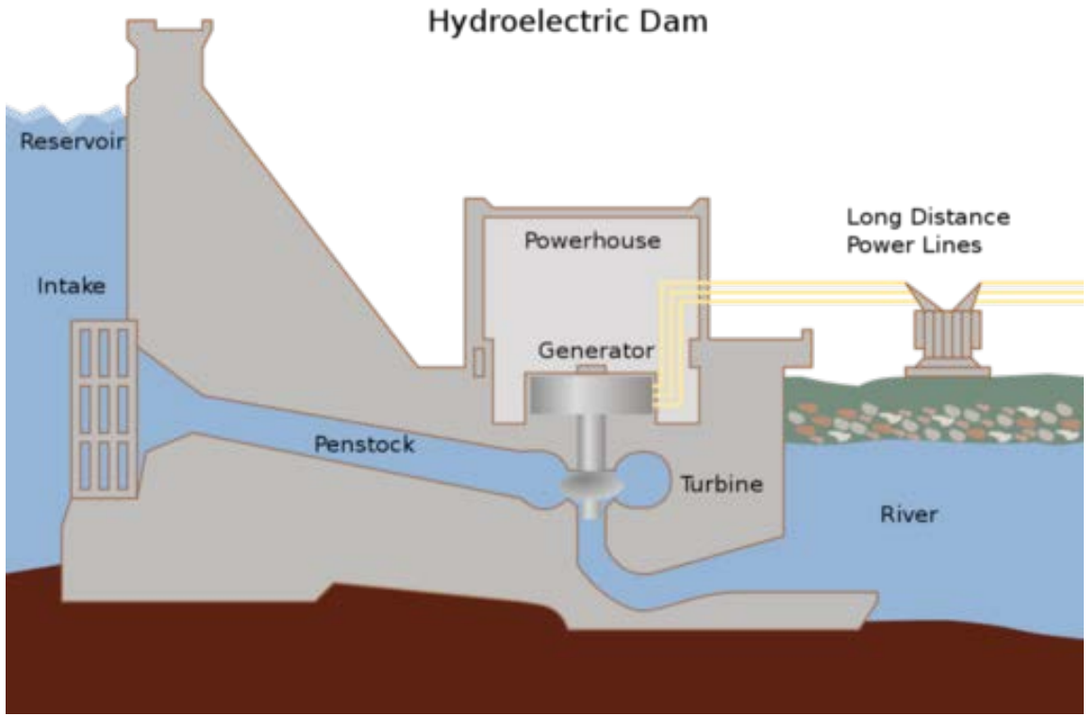


Figure 29.26

A cross-section of a hydroelectric plant.

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have

already been dammed (**Figure** below). In California, about 14.5% of the total electricity comes from hydropower. The state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges where large streams descend down a steep grade.



Figure 29.27

Hydroelectric dams like this one use the power of moving water to create electricity.

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** below).



Figure 29.28

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.

KQED: Harnessing Power from the Sea

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



Click on the image above for more content

Wind Power

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 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 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** below).



Figure 29.29

Wind turbines like the ones shown here 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 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** below).

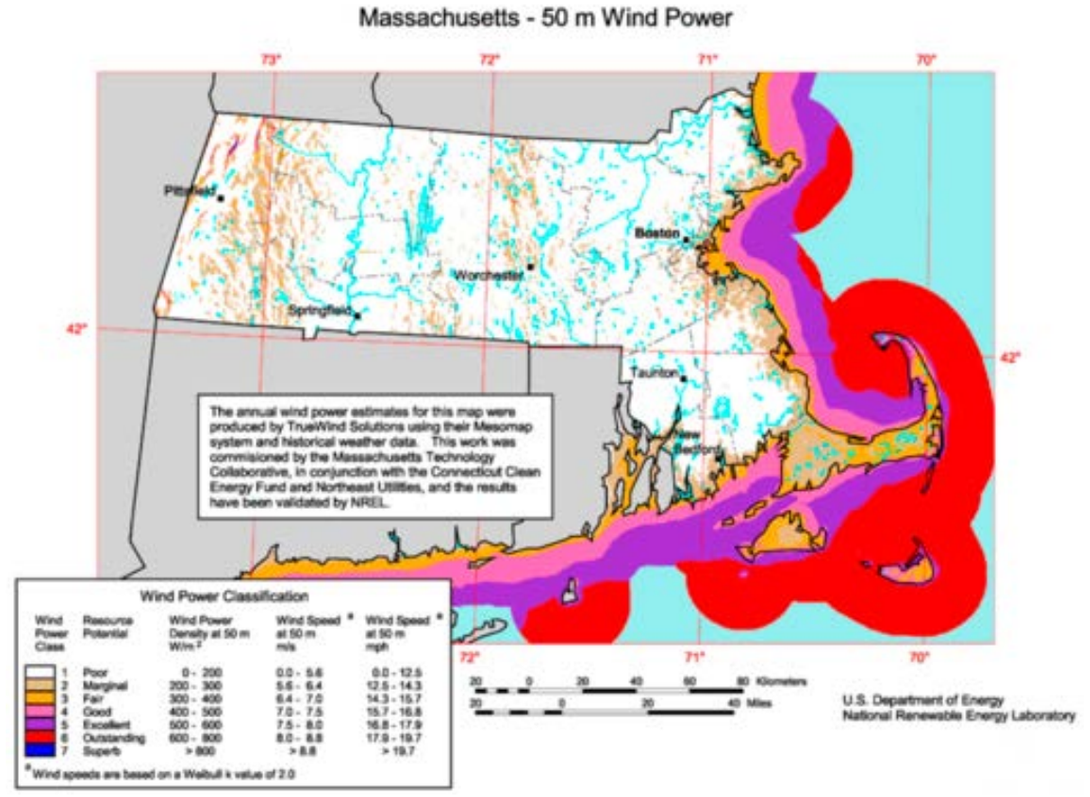


Figure 29.30

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.

Geothermal Power

Geothermal energy comes from heat deep below the surface of the Earth. 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** below).



Figure 29.31

A geothermal energy plant in Iceland. Iceland gets about one fourth of its electricity from geothermal sources.

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, north of San Francisco. The source of heat is thought to be a large magma chamber lying beneath the area.

KQED: Geothermal Heats Up

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



Click on the image above for more content

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** below). The advantage to biofuels is that they burn more cleanly than fossil fuels. As a result, they create less pollution and less carbon dioxide. Critics say, however, that the amount of energy, fertilizer, and land needed to produce the crops used make biofuels only a slightly better alternative than fossil fuels.



Figure 29.32

Biofuels, such as ethanol, are added to gasoline to cut down the amount of fossil fuels that are used.

KQED: How Green is Biomass Energy?

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. Learn more at: http://science.kqed.org/quest/audio/how-green-is-biomass-energy/ .



Click on the image above for more content

KQED: From Waste to Watts: Biofuel Bonanza

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. Learn more at: http://science.kqed.org/quest/video/from-waste-to-watts-biofuel-bonanza/



Click on the image above for more content

KQED: Biofuels: Beyond Ethanol

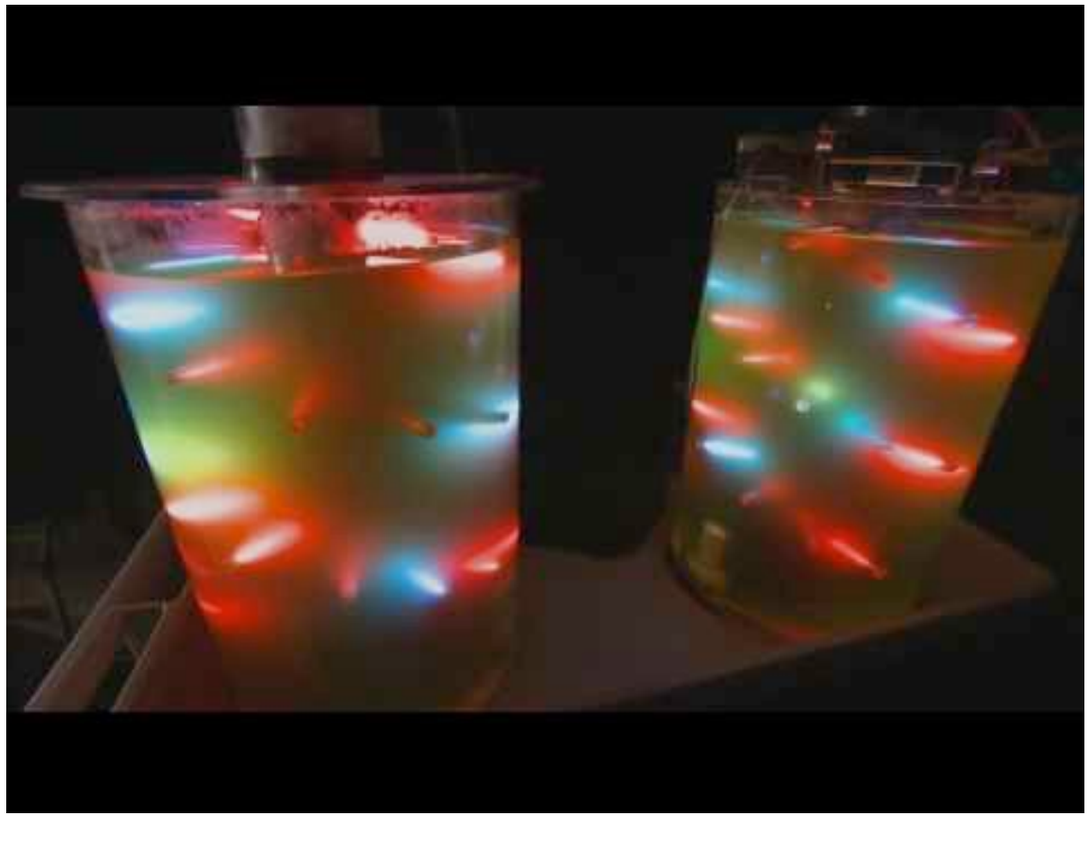
To generate biomass energy, break down the cell walls of plants to release the sugars and then ferment those sugars to create fuel. Corn is a very inefficient source; scientists are looking for much better sources of biomass energy. Learn more at: http://science.kqed.org/quest/video/biofuels-beyond-ethanol/ .



Click on the image above for more content

Algae Power

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, its much easier to convert to a usable fuel and its carbon neutral. Learn more at: http://science.kqed.org/quest/video/algae-power/ .



Click on the image above for more content

Power Up with Leftovers

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. Learn more at: http://science.kqed.org/quest/audio/power-up-with-leftovers/



Click on the image above for more content

Lesson Summary

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

Review Questions

1.If you turn on the burner on a gas stove under a pan of cold water, energy moves from the burner to the pan of water. What is this type of energy transfer called? How does this energy move?
2.If solar power needs sunshine, how can solar power be a viable option for power?
3.If you burn wood in a fireplace, which type of energy resource are you using?
4.Which form of energy is an important factor in making electricity from water power?
5.Most of the energy that travels from the Sun to the Earth arrives in the form of visible light. What is this movement of energy called?

6.Explain how mirrors are used in some solar energy plants.
7.Explain how wind power uses kinetic energy.
8.NIMBY means "Not in My Backyard." How do various green energy projects, like Cape Wind, qualify as NIMBY projects?

Further Reading / Supplemental Links

•Cleveland, Cutler, "Energy Transitions Past and Future." Encyclopedia of Earth, 2007. Available on the Web at: http://www.eoearth.org/article/Energy_transitions_past_and_future .

Points to Consider

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

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8.Courtesy of the US Geological Survey. Map of the US coal producing regions in 1996 . Public Domain
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31.Gretar Ívarsson. A geothermal energy plant in Iceland . Public Domain
32.Michael Coté. Ethanol information sign in California . CC BY 2.0

Earth Science Glossary

A

A

abiotic
: Non-living features of an ecosystem include space, nutrients, air, and water.

abrasion
: A form of mechanical weathering that occurs whenever one rock hits another.

absolute age
: The actual age of a material in years.

abyssal plains
: Very flat areas that make up most of the ocean floor.

acid rain
: Rain that has a pH of less than 5.0.

active volcano
: A volcano that is currently erupting or is just about to erupt.

adaptation
: A trait that an organism inherits that helps it survive in its natural environment.

adaptive radiation
: An explosion in the diversity of species as vacant niches are filled. This often occurs after a mass extinction.

advection
: Horizontal movement of a fluid or the transport of a substance in the flow.

air mass
: A large mass of air with the same temperature and humidity characteristics.

air pressure
: The force of air pressing on a given area.

albedo
: The amount of light that reflects off a surface; snow and ice have high albedo.

alkaline
: Also called basic. Substances that have a pH of greater than 7.0.

alluvial fan
: Curved, fan-shaped, coarse-sediment deposit that forms when a stream meets flat ground.

alpine (valley) glacier
: A glacier found in a valley in the mountains.

altitude
: Distance above sea level.

amber
: Fossilized tree sap.

amino acid
: Organic molecules that are the building blocks of life.

amniote egg
: An egg that contains all the nutrients needed for the developing embryo and is protected by a shell.

amplitude
: The height of a wave from the center to the top of the crest (or the bottom of the trough).

anticline
: A fold that arches upward; older rocks are in the center and younger rocks are at the outside.

anticyclone
: Wind system that rotates around a high pressure center.

aphotic zone

The zone in the water column deeper than 200 m where sunlight does not penetrate.

apparent polar wander
: The path on the globe showing where the magnetic pole appeared to move over time.

aquaculture
: Agriculture of the sea; farmed fish, seafood and aquatic plants.

aquifer
: A layer of rock, sand, or gravel that holds large amounts of ground water.

arch
: An erosional landform that is produced when waves erode through a cliff.

asterism
: A group or cluster of stars that appear close together in the sky.

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.

astronomer
: Scientists who study the universe beyond Earth.

atmosphere
: The layer of gases that surrounds a planet.

atom
: The smallest unit of a chemical element.

atomic mass
: The number of protons and neutrons in an atom.

aurora
: A spectacular light display that occurs in the ionosphere near the poles.

avalanche
: Mass of snow that suddenly moves down a mountain under the influence of gravity.

axis
: An imaginary line that runs from the North Pole to South Pole, and it includes the center of Earth.

B

B horizon
: The subsoil; the zone where iron oxides and clay minerals accumulate.

barometer
: An instrument for measuring atmospheric pressure.

barrier island
: Long, narrow island composed of sand; nature's first line of defense against storms.

base level
: Where a stream meets a large body of standing water, usually the ocean.

basin
: A circular anticline; oldest rocks are in the center and the youngest are on the outside.

batholith
: An enormous body of granitic rock.

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.

beach
: The sediments on a shore.

bed load
: Sediments moved by rolling or bumping along the stream bed.

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.

binary star
: A system of two stars that orbit a common center of mass.

bioaccumulation
: The accumulation of toxic substances within organisms so that the concentrations increase up the food web.

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

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

biodiversity
: The number of species of plants, animals and other organisms within a particular habitat.

biofuel
: A fuel made from living materials, usually crop plants.

biomass
: The total mass of living organisms in a given region.

biome
: The living organisms that are found within a climate zone that make that zone distinct.

biotic
: Living features of an ecosystem include viruses, plants, animals, and bacteria.

biozone
: A rock unit that is defined by a characteristic index fossil or fossil assemblage.

black hole
: The super dense core left after a supergiant explodes as a supernova.

blizzard
: A large snowstorm with high winds.

body fossil
: The remains of an ancient organism. Examples include shells, bones, teeth, and leaves.

body waves
: Seismic waves that travel through the body of a planet; e.g. primary or secondary waves.

bottom trawling
: Fishing by dragging nets along the ocean floor.

Bowen's Reaction Series
: The order in which minerals undergo partial melting or fractional crystallization, which depends on temperature and the composition of the mineral.

brackish
: Water that is a mixture of freshwater and saltwater.

breakwater
: Structure built in the water parallel to the shore to protect from strong incoming waves.

C

C

C horizon
: The lowest layer of soil; partially altered bedrock.

caldera
: Circular-shaped hole into which a volcano collapses during an eruption.

cap-and-trade
: 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.

capillary action
: Water moves from wet to dry regions in soil.

carbohydrate
: Organic compound that supplies energy to the body; includes sugars, starches and cellulose.

carbon sequestration
: Removal of carbon dioxide from the atmosphere, so that it does not act as a greenhouse gas in the atmosphere.

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.

carbon tax
: A tax placed on energy sources that emit carbon to discourage their use and to raise funds to research alternative energy sources.

carnivore
: Animals that only eat other animals for food.

carrying capacity
: The number of individuals of a given species a particular environment can support.

cast
: A mold filled with sediment and hardened to create a replica of the original fossil.

catadioptric telescope
: Telescopes that use a combination of mirrors and lenses to focus light.

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.

cementation
: When fluids deposit ions to create a cement that hardens loose sediments.

chaparral
: Scrubby woody plants and widely scattered trees typical of the Mediterranean climate.

chemical bond
: The force that holds two atoms together.

chemical compound
: A substance in which the atoms of two or more elements bond together.

chemical energy
: Energy that is stored in the chemical bonds in molecules.

chemical sedimentary rocks
: Rocks that form from the hardening of chemical precipitates.

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.

chemosynthesis
: The breakdown of chemicals to produce food energy.

Chinook winds (Foehn winds)
: Winds that form when low pressure draws air over a mountain range.

chromosphere
: Thin layer of the Sun's atmosphere that lies directly above the photosphere; glows red.

cinder cone
: A small volcano composed of small rock fragments piled on top of one another.

clastic
: Fragments or clasts of preexisting rock; a sedimentary rock made of clasts.

cleavage
: The tendency of a mineral to break along certain planes to make smooth surfaces.

climate
: The long-term average of weather.

cloud
: Tiny water or ice particles that are grouped together in the atmosphere.

coal
: A solid fossil fuel from ancient dead organisms used for electricity.

cold front
: A front in which a cold air mass pushes a warm air mass upward.

column
: A cave deposit formed by the merging of a stalactite and a stalagmite.

comet
: A small, icy, dusty object with a bright tail in orbit around the Sun.

commensalism
: A relationship in which one species benefits and the other species is not harmed.

community
: All of the populations of organisms in an ecosystem.

compaction
: When sediments are squeezed together by the weight of sediments and rocks on top of them.

compass
: Hand-held device with a magnetic needle used to find magnetic north.

compass rose
: Figure on a map or nautical chart for displaying locations of north, south, east, and west.

competence
: A measure of the largest particle a stream can carry.

competition
: A rivalry between two species, or individuals of the same species, for the same resources.

composite volcano
: A large, steep-sided composed of alternating layers of ash and lava flows.

compression
: Stresses that push toward each other, causing a decrease in the space a rock takes up.

conceptual model
: An abstract, mental representation of an object or system.

condensation
: The change in a substance from a gas to a liquid, releases energy.

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.

confining stress
: Stress from the weight of material above a buried object; reduces volume.

confluence
: Where two streams join together.

conserve
: To reduce the use of a natural resource so that it will last longer.

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.

constructive forces
: Forces that cause landforms to grow. Crustal deformation and volcanic eruptions are two examples.

consumer
: An organism that uses other organisms for food energy.

consumptive water use
: Water use in which the water is lost to the ecosystem.

contact metamorphism
: Changes in a rock that result from temperature increases when a body of magma contacts a cooler existing rock.

continent
: Land mass above sea level.

continental arc
: A line of volcanoes on a continent resulting from subduction beneath the continent.

continental climate
: A more variable climate dominated by a vast expanse of land.

continental crust
: The crust that makes up the continents; thicker and less dense than oceanic crust.

continental divide
: A divide that separates water that goes to different oceans.

continental drift
: The early 20th century hypothesis that the continents move about on Earth's surface.

continental glacier
: A sheet of ice covering a large area that is not confined to a valley.

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.

continental rifting
: A divergent plate boundary that breaks up a continent.

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.

control
: Factors that are kept the same in an experiment so that only the independent variable is tested.

convection

The movement of material due to differences in temperature.

convection cell
: A circular pattern of warm material rising and cool material sinking.

convection zone
: Layer of the Sun that surrounds the radiative zone where energy moves as flowing cells of gas.

convergent plate boundary
: A location where two lithospheric plates come together.

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.

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

corona
: Outermost layer of the Sun; a plasma that extends millions of kilometers into space.

cosmology
: The study of the universe.

covalent bond
: Electrons shared between atoms.

crater
: Bowl-shaped depressions on the surface of the Moon caused by impact from meteorites.

craton
: The ancient Precambrian felsic continental crust that forms the cores of continents.

creep
: Exceptionally slow movement of soil downhill.

crescent
: Phase of the moon when it is less than half full but still slightly lit.

crest
: The highest point of a wave.

cross-cutting relationships
: One of Steno’s principles that states that an intrusion or fault is younger than the rocks that it cuts through.

crude oil
: Unrefined oil as it is taken from the ground; a fossil fuel.

crust
: The rocky outer layer of the Earth's surface. The two types of crust are continental and oceanic.

crystal
: A solid in which all the atoms are arranged in a regular, repeating pattern.

crystallization
: The formation of mineral grains from cooling magma.

cyanobacteria
: Single celled prokaryotes that were extremely abundant in the Precambrian and that changed the atmosphere to one containing oxygen.

cyclone
: Wind system that rotates around a low pressure center.

D

D

dark energy
: An as yet undiscovered form of energy that we cannot see.

dark matter
: Matter in the universe that doesn't emit light.

daughter product
: The product of the radioactive decay of a parent isotope.

day
: The time it takes for a planet to rotate once on its axis.

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.

deflation
: Wind removes finer grains of silt and clay, causing the ground surface to subside.

deforestation
: Cutting down and/or burning trees in a forested area.

deformation
: Strain. The change of shape that a rock undergoes whe it has been altered by stresses.

delta
: A triangular-shaped deposit of sediments that forms where a river meets standing water.

density
: The amount of matter in a certain amount of space; mass divided by volume.

dependent variable
: The variable in an experiment that is being measured as the independent variable is changed.

desert
: Areas receiving very little precipitation; plants are scarce but well adapted.

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.

destructive forces
: Forces that modify or destroy landforms. Agents of erosion include water, wind, ice, and gravity.

dew point
: The temperature at which air is saturated with water vapor; when it has 100% humidity.

differentiation
: The separation of planetary materials by density to create distinctly different layers.

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.

direction
: The location of something relative to something else.

dissolved load
: The elements carried in solution by a stream.

divergent plate boundary

A location where two lithospheric plates spread apart.

divide

A ridge that separates one water basin from another.

dome

A circular anticline; oldest rocks are in the center and youngest are on the outside.

Doppler Effect

A change in the frequency of a wave relative to an observer moving in relationship to the source of the wave.

dormant volcano

A volcano that is not currently erupting, but that has erupted in the recent past.

downwelling

Sinking water because of higher density.

drip irrigation

Pipes and tubes that deliver small amounts of water directly to the soil at the roots of plants.

drought

A long period of lower than normal rainfall for a particular region.

dwarf galaxy

A small galaxy containing a few million to a few billion stars.

dwarf planet

A planet-like object that has not cleared its orbit of other objects.

E

E

earthquake
: Ground shaking caused by the release of energy stored in rocks.

echo sounder
: A device that uses sound waves to measure the depth of the seafloor.

ecosystem
: All of the living things in a region and the physical and chemical factors that they need.

effusive eruption
: A relatively gentle, non-explosive volcanic eruption.

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.

elastic deformation
: Strain that alters the shape of a rock but that is not permanent.

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.

electromagnetic (EM) radiation
: Energy transmitted through space as a wave.

electromagnetic spectrum
: The full range of electromagnetic radiation.

electromagnetic waves
: Waves with both electrical and magnetic properties; travel by radiation.

electron
: Tiny negatively charged particles that orbit the nucleus.

element
: A pure chemical substance with one type of atom.

elevation
: Height of a feature measured relative to sea level.

ellipse
: A shape that looks like a slightly squashed circle.

elliptical galaxy
: An oval or egg shaped galaxy with older stars and little gas and dust.

end moraine
: Unsorted pile of glacial till that marks points where the glacier was stationary.

energy
: The ability to do work or change matter.

energy efficiency
: The amount of useful work that is done by a unit of energy.

epicenter
: The point on the Earth's surface directly above the focus of the earthquake.

erosion
: The transport of weathered materials and sediments by water, wind, ice, or gravity.

eruption
: The release of lava, tephra, and gases from a volcano.

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.

eukaryote
: A cell with a separate nucleus to hold its DNA and RNA.

evaporation
: The change in a substance from a liquid to a gas by the addition of energy.

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.

exosphere
: The outermost layer of the atmosphere; the gas molecules are extremely far apart.

explosive eruption
: A potentially devastating eruption of rock, lava, ash, and gas exploding from a volcano.

export
: To send a resource or product to another country.

extinct
: A species dies out either by simply dying out or by evolving into another species.

extinct volcano
: A volcano that has not erupted in recorded history, and is unlikely to erupt again.

extrusive
: Igneous rocks that form at Earth's surface from rapidly cooling lava.

F

F

facies
: Characteristic sedimentary rock layers that indicate the processes and environments in which they were formed.

fault
: A fracture along which one side has moved relative to the other.

felsic
: A type of igneous rock that is made mostly of light minerals such as quartz and feldspar.

fissure
: A crack in the ground that may be the site of a volcanic eruption.

flood
: An overflow of water in a location.

focus
: The point where rocks rupture during an earthquake.

fog
: Air condensed below its dew point that is near the ground like a cloud.

fold
: A bend in a set of rocks caused be compression.

foliation
: Flat layers in rocks due to squeezing by pressure.

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.

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.

fossilization
: The process of becoming a fossil.

fractional crystallization
: The crystallization of a fraction of the minerals in magma depending on temperature.

fracture
: (minerology) The way a mineral breaks when it is not broken along a cleavage plane.
: (structural geology) A break in rock caused by stresses, with or without movement of material.

frequency
: The number of wavelengths that pass a given point every second.

fresh water
: Water with a low concentration of salts; found in streams, lakes, ground, ice, atmosphere.

front
: The meeting place of two air masses with different characteristics.

fuel
: Material that releases energy as it changes chemically.

fuel cell

An energy cell in which chemical energy is converted into electrical energy.

G

G

galaxy
: A very large group of stars held together by gravity; few million to a few billion stars.

Galilean moons
: The four largest moons of Jupiter discovered by Galileo.

gamma ray
: A penetrating form of electromagnetic radiation.

gas giants
: The four large outer planets composed of the gases hydrogen and helium.

gasification
: A technology that cleans coal before it is burned, which increases efficiency and reduces emissions.

gemstone
: Any material that is cut and polished to use in jewelry.

geocentric model
: Model used by the ancient Greeks that puts the Earth at the center of the universe.

Geographic Information System (GIS)
: An information system that links data to a particular location.

geologic map
: A map showing the geologic features, such as rock units and structures, of a region.

geologic time scale
: A division of Earth's history into blocks of time distinguished by geologic and evolutionary events.

geostationary orbit
: A satellite at just the right distance above Earth so that it orbits at the same rate that Earth spins and stays above a single location.

geyser
: A fountain of hot water and steam that erupts onto the surface.

gibbous
: Phase of the moon when it is more than half lit but not completely full.

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.

glaciers
: Large sheets of flowing ice.

Global Positioning System (GPS)
: A set of satellites that allows a receiver to know its exact location.

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.

globular cluster
: Groups of tens to hundreds of thousands of stars held together by gravity.

gradient

The slope of a stream.

Great Red Spot

An enormous, oval-shaped, long-lived storm on Jupiter.

Green Revolution

Changes in the way food is produced since World War II that have resulted in enormous increases in production.

greenhouse effect

The trapping of heat by greenhouse gases in the atmosphere; moderates temperatures.

greenhouse gas

Gases such as carbon dioxide and methane that absorb and hold heat from the sun's infrared radiation in the atmosphere.

greenstone

A metamorphosed volcanic rock that forms at a subduction zone.

groin

Long, narrow piles of stone or timbers built perpendicular to the shore to trap sand.

ground moraine

Thick layer of sediment deposited under a glacier.

groundwater

Fresh water that moves through pore spaces and fractures in soil and rock beneath the land surface.

gyre

Five loops created by surface ocean currents.

H

habitat
: Where an organism lives, with distinctive features such as climate or resource availability.

haboob
: Desert sandstorms that form in the downdrafts of a thunderstorm.

half-life
: The amount of time required for half of the atoms of a radioactive substance to decay to the daughter product.

hanging valley
: A cliff where a large glacier cut off the U-shaped valley of a tributary glacier.

hardness
: The ability of a mineral to resist scratching.

headwaters
: The location where a stream forms, often high in the mountains.

heat
: Energy associated with the movement of atoms or molecules that can be transferred.

heat wave
: A period of prolonged excessively hot weather for a particular region.

heliocentric model
: Model proposed by Copernicus that put the Sun at the center of the universe.

hemisphere
: One half of a sphere.

herbivore
: An animal that only eats producers.

high pressure zone
: A region where relatively cool, dense air is sinking.

high tide
: The highest water levels during a day caused by the gravitational pull of the Moon.

hot spring
: A stream of hot water that flows out of the ground continuously.

hotspot
: A plume of hot material that rises through the mantle and can cause volcanoes.

humidity
: The amount of water vapor held in the air.

humus
: The partially decayed remains of plants and animals; forms the organic portion of soil.

hurricane
: Cyclone that forms in the tropics and spins around a low-pressure center.

hybrid vehicle
: A very efficient vehicle that is powered by an internal combustion engine, an electric motor and a rechargeable battery.

hydrocarbon
: A chemical compound containing hydrogen and carbon that is used for energy.

hydrogen bond

A weak intermolecular connection between two polar molecules.

hydrologic (water) cycle
: The movements of water in and between reservoirs (e.g. oceans, clouds, streams, ice, and ground water).

hydrolysis
: Hydrogen or hydroxide ions replace the cations in a mineral to change the mineral.

hydrothermal vent
: A stream of heated water that enters into the ocean at a mid-ocean ridge.

hypothesis
: A good working explanation for a problem that can be tested.

I

ice cap
: Permanent ice that is found mostly around Greenland and Antarctica.

ice core
: Cylinder of ice extracted from a glacier or ice sheet.

ice wedging
: Water enters a crack, expands as it freezes, and wedges the rock apart.

igneous rock
: A rock formed from cooled magma.

impermeable
: Something that water cannot penetrate.

import
: To receive a resource or product from another country.

independent variable
: The variable in an experiment that is controlled and changed by the researcher.

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.

Industrial Revolution
: A time when mass production and fossil fuel use started to grow explosively.

infrared light
: Electromagnetic waves with frequencies between radio waves and red light.

inner planets
: The four planets inside the asteroid belt: Mercury, Venus, Earth, and Mars.

inorganic
: Not organic; not involving life or living organisms. For example, the rock and mineral portion of the soil.

insolation
: The amount of solar radiation striking a given area over a given period of time.

insulation
: A material that inhibits conduction of heat or electricity.

intermediate
: A type of igneous rock that is in between felsic and mafic.

intertidal zone
: The part of the ocean closest to the shore, between low and high tide.

Intertropical Convergence Zone (ITCZ)
: A low pressure zone where the Hadley Cells at the equator meet.

intraplate activity
: Geologic activity that takes place away from plate boundaries.

intrusive
: Igneous rocks that form inside the Earth from slowly cooling magma.

invasive species
: A species of organism that spreads in an area where it is not native. People often introduce invasive species either purposefully or by accident.

inversion
: A situation in which warm air lies above cold air.

invertebrate
: Animal with no backbone.

ion
: An atom with one or more electrons added or subtracted; it has an electrical charge.

ionic bond
: A chemical bond in which atoms give or accept atoms.

ionosphere
: An ionized layer within the thermosphere.

irregular galaxy
: A galaxy that is neither spiral nor elliptical.

island arc
: A line of ocean island volcanoes resulting from subduction beneath oceanic lithosphere.

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.

isotope
: A chemical element that has a different number of neutrons.

J

J

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.

joint
: A break in rock along which there is no movement.

K

katabatic winds
: Winds that move down a slope.

key bed
: A distinctive, widespread rock layer that formed at a single time.

kinetic energy
: The energy that an object in motion has because of its motion.

Kuiper belt
: A region beyond the orbit of Neptune that contains millions of frozen objects.

Section 12

L

L

La Niña
: A natural climate variation in which the trade winds are stronger than normal and surface water off of South America is cold.

lahar
: A volcanic mudflow containing ash, rock, and water from melting snow or rainfall that races down river valleys during an eruption.

lake
: A large body of freshwater drained by a stream; naturally occurring or human-made.

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.

land breeze
: A wind that blows from land to sea in winter when the ocean is warmer than the land.

landform
: A physical feature that is part of the landscape, such as a hill or peninsula.

landslide
: Rapid movement downslope of rock and debris under the influence of gravity.

latent heat
: Energy absorbed or released as material changes from solid to liquid or liquid to gas.

lateral continuity
: A sedimentary rock layer that extends sideways as wide as the basin in which it forms.

lateral moraine
: Glacial till formed from debris that falls at the edges of a glacier.

laterite
: Nutrient poor, red, tropical soil that forms in rainforest areas.

latitude
: The location of a place between the north and south pole relative to the equator.

lava
: Molten rock that has reached the Earth's surface.

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.

law of conservation of energy
: Law stating that energy cannot be created or destroyed.

leaching
: The process of removing dissolved minerals as they are carried to lower layers in soil.

leaf litter
: Dead leaves, branches, bark, and other plant parts that accumulate on the floor of a forest.

levee
: A raised structure designed to hold back the waters of a stream or river in the case of a flood.

light-year
: The distance light can travel in one year; 9.5 trillion kilometers.

lightning
: A huge discharge of electricity typical of thunderstorms.

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.

limnology
: The study of freshwater bodies and the organisms that live in them.

liquefacation
: Clay, silt, and sand saturated with water become like quicksand, lose their strength, and behave more like a liquid than a solid.

lithification
: The creation of rock from sediments.

lithosphere
: The layer of solid, brittle rock that makes up the Earth's surface; the crust and the uppermost mantle.

loam
: Soil texture that forms from a roughly equal combination of sand, silt and clay.

location
: Where an object is on Earth, best described in three dimensions.

loess
: Extremely fine-grained, wind-borne deposit of silts and clays; forms nearly vertical cliffs.

longitude
: The location of a place relative to the Prime Meridian, which runs north-south through Greenwich, England.

longshore current
: Local surface currents that move along a shoreline in the direction of prevailing winds.

low Earth orbit
: Satellites that orbit relatively close to Earth.

low pressure zone
: A region where relatively warm, lower density air is rising.

low tide
: The lowest water levels during a day when high tide is one-quarter of the way around Earth’s sphere.

LUCA (Last Universal Common Ancestor)
: The last life form that was the ancestor to all life that came afterward

lunar
: Related to the Moon.

lunar eclipse
: An eclipse that occurs when the Moon moves through the shadow of the Earth and is blocked from view.

luster
: The way light reflects off of the surface of the mineral.

M

mafic
: A type of igneous rock that is made mostly of dense, dark minerals, such as olivine and pyroxene.

magma
: Molten rock deep inside the Earth.

magma chamber
: A region below a volcano where magma and gases collect.

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.

magnetic polarity
: The direction of the Earth's magnetic field. A compass today will point north, which is normal polarity; south is reversed.

magnetite
: A magnetic mineral that takes on Earth's magnetic polarity as it crystallizes.

magnetometer
: An instrument that measures the magnetic field intensity.

magnetosphere
: Charged particles beyond the atmosphere that are held in place by Earth's magnetic field.

main sequence star
: A star that is fusing hydrogen atoms to helium; a star in the main portion of its “life.”

manganese nodule
: Rocks on the seafloor that contain valuable minerals, especially manganese.

mantle
: The middle layer of the Earth; made of hot rock that circulates by convection.

map
: A 2-dimensional representation of Earth's surface.

maria
: The dark parts of the Moon’s surface, made up of ancient basaltic eruptions.

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.

maritime climate
: A moderate climate dominated by a nearby ocean.

marsh
: A shallow wetland with grasses and reeds, but there no trees. Water may be fresh, saline, or brackish.

mass movement
: Erosion in which soil or rock move downslope due to gravity.

mass wasting
: Erosion in which soil or rock move downslope due to gravity.

mathematical model
: A set of mathematical equations that simulates a natural system.

meander

A bend or curve in a stream channel.

mechanical weathering

Weathering that breaks rocks into smaller pieces without altering their chemical composition.

medial moraine

Lateral moraines that join together within a main glacier as tributary glaciers merge.

mesosphere

Layer between the stratosphere and thermosphere; temperature decreases with altitude.

metabolism

The chemical work of cells; the chemical reactions a living organism needs to live, grow and reproduce.

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.

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.

microbe

A microorganism.

microclimate

A local climate that is different from the regional climate.

microcontinent

A fragment of crust that is smaller than a continent.

microfossil

A fossil that must be studied with the aid of a microscope.

microwave

The shortest wavelength radio waves.

mid-latitude cyclone

A cyclone that forms in the middle latitudes at the polar front.

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.

Milankovitch cycles

Cycles adding up to variations of around 100,000 years regarding Earth’s position relative to the Sun that affect global climate.

Milky Way Galaxy

The spiral galaxy in which Earth and our solar system reside.

mineral

A naturally occurring inorganic, crystalline solid with a characteristic chemical composition.

mineralogist

A scientist who studies minerals.

model

A representation of an object or system that is easier to study and manipulate.

mold

An impression made in sediments by the hard parts of an organism.

molecular mass
: The mass of all the atoms in a molecule.

molecule
: The smallest unit of a compound; it is made of atoms.

monocline
: A bend in a set of rocks that causes them to be inclined relative to the horizontal.

monsoon
: Hot land draws cool air off a nearby sea creating large winds and often rain.

moon
: A celestial object that orbits a planet.

moraine
: Linear deposit of unsorted, rocky material on, under, or left behind by glacial ice.

mountain breeze
: A wind that blows from a mountain to a valley at night when mountain air is cooler.

mouth
: Where a stream enters a larger body of water such as a lake or an ocean.

mudflow
: Saturated soil that flows down river channels.

mutation
: A change in the genetic makeup of a population of organisms that can be beneficial, harmful, or neutral.

mutualism
: A symbiotic relationship between two species in which both species benefit.

Section 14

N

N

natural gas
: A fossil fuel composed of the hydrocarbon methane.

natural levee
: Coarse-grained deposits of sediments that build up along a stream's banks as it floods.

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.

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 ◦s relative to each other, relative to Earth.

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.

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.

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.

neutron
: A neutral particle in the nucleus of an atom.

neutron star
: The remnant of a massive star after it explodes as a supernova.

niche
: An organism's "job" within its community.

non-consumptive water use
: Water use that does not use up the water supply.

non-renewable 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.

nor'easter
: Mid-latitude cyclones that strike the northeastern United States.

normal fault
: A dip-slip fault in which the hanging wall drops down relative to the footwall.

nuclear energy
: Energy that is released from the nucleus of an atom when it is changed into another atom.

nuclear fusion
: The merging together of the nuclei of atoms to form new, heavier chemical elements; huge amounts of nuclear energy are released in the process.

nuclear fusion reaction

When nuclei of two atoms fuse together, giving off tremendous amounts of energy.

nucleic acid
: Biological molecules necessary for life; includes DNA and RNA

nucleus
: The center of an atom, made of protons and neutrons.

nutrients
: Ions that organisms need to live and grow.

O

occluded front
: A front in which a cold front overtakes a warm front.

ocean basin
: Areas covered by ocean water. The three major ocean basins are the Pacific, Atlantic, and Indian.

ocean trench
: The deepest parts of the ocean basins.

oceanic crust
: The crust that underlies the oceans; thinner and denser than continental crust.

oceanic zone
: The open ocean, where sunlight does not reach the seabed.

oil
: A liquid fossil fuel from ancient dead organisms used for transportation and other products.

omnivore
: An organism that consumes both producers and other consumers for food.

open cluster
: Groups of up to a few thousand stars loosely held together by gravity.

orbit
: To travel in a circular or elliptical path around another object.

orbiter
: The main part of the space shuttle that has wings like an airplane.

ore
: A type of rock that contains useful minerals.

ore deposit
: A mineral deposit that contains enough minerals to be mined for profit.

organic
: Something from living organisms.

original horizontality
: Sedimentary layers that were deposited horizontally.

orogeny
: A mountain building event, usually taking place over tens or hundreds of millions of years.

outcrop
: Exposed rock formations that are attached to the ground.

outer planets
: The four large planets beyond the asteroid belt in our solar system.

outgassing
: The transfer of gases from Earth's mantle to the atmosphere by volcanic eruptions.

over-consumption
: Resource use that is unsustainable in the long term; obtaining many more products than people need.

overpopulation
: When the population of an area exceeds its carrying capacity or when long-term harm is done to resource availability or the environment.

oxidation
: Oxygen reacts with another element to create a metal oxide.

ozone

Three oxygen atoms bonded together in an O_3 molecule. Ozone in the lower atmosphere is a pollutant but in the upper atmosphere protects life from ultraviolet radiation.

ozone hole

A region around Antarctica in which ozone levels are reduced in springtime because of the action of ozone-destroying chemicals.

ozone layer

A layer of the stratosphere where ozone gas is more highly concentrated.

P

P-waves
: Primary waves; arrive first at a seismograph.

paleogeography
: The arrangement of the continents; ancient geography.

paleontologist
: A scientist who studies Earth's past life forms.

parallax
: A method used by astronomers to calculate the distance to nearby stars, using the apparent shift relative to distant stars.

parasitism
: A symbiotic relationship between two species in which one species benefits and one species is harmed.

parent isotope
: An unstable isotope that will undergo radioactive decay.

partial melting
: The melting of some, but not all, of the minerals in a rock, depending on temperature.

pathogen
: Disease causing organisms.

pedalfer
: Fertile, dark soil that forms in mid latitude, forested regions.

pedocal
: Less fertile soil that forms in drier, grassland regions.

penumbra
: Outer part of shadow that remains partially lit during an eclipse.

permafrost
: Permanently frozen ground that is found in the polar regions.

permeability
: The interconnectedness of the pores within a rock or sediment.

permeable
: A material with interconnecting holes so that water can move through it easily.

permineralization
: Fossilization in which minerals in water deposit into empty spaces in an organism.

pesticide
: A chemical that kills a certain pest that would otherwise eat or harm plants that humans want to grow.

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.

photic zone
: The upper 200 m of the ocean, where sunlight penetrates.

photochemical smog
: This type of air pollution results from a chemical reaction between pollutants in the presence of sunshine.

photon
: A particle of light.

photosphere
: The visible surface of the Sun.

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.

physical model
: A physical representation of an object or system.

phytoplankton
: Tiny plants that photosynthesize and create food energy and oxygen.

placer
: Valuable metal found in modern or ancient stream gravels.

planet
: A round celestial object orbiting a star that has cleared its neighboring region of planetesimals.

planetary rings
: Rings of dust and rock encircling a planet in a thin plane.

plankton
: A diverse group of tiny animals and plants that freely drift in the water.

plasma
: A high energy, high temperature form of matter. Electrons are removed from atoms, leaving each atom with a positive electrical charge.

plastic deformation
: Strain in which the rock deforms but does not return to its original shape when the strain is removed.

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.

plate tectonics
: The theory that the Earth's surface is divided into lithospheric plates that move on the planet's surface. Plate tectonics is driven by convection currents within Earth's mantle.

platform
: A craton and its overlying younger sedimentary rocks.

plucking
: Removal of blocks of underlying bedrock as meltwater seeps into cracks and freezes.

pluton
: An igneous intrusive rock body that has cooled in the crust.

polar front
: The meeting zone between cold continental air and warmer subtropical air at around 50 ◦N and 50 ◦S.

polar molecule
: A molecule with an unevenly distributed electrical charge.

polar orbit
: A satellite orbit that goes over the North and South Poles, perpendicular to Earth's spin.

polar orbit satellite
: Orbit that moves over Earth's North and South poles as Earth rotates underneath so that the entire planet can be viewed in less than one day.

polar stratospheric clouds (PSC)
: Clouds that form in the stratosphere when it is especially cold; PSCs are necessary for the breakup of chlorofluorocarbons (CFCs).

pond
: A small body of freshwater, with no stream draining it; fed by an underground spring.

pool
: A deep, slow-moving part of a stream, usually wider than elsewhere on the stream.

population

All the individuals of a species that occur together in a given place and time.

porosity
: The small holes that exist between grains in a rock or sediment.

porphyritic
: Igneous rock texture in which visible crystals are found in a matrix of tiny crystals.

potential energy
: Energy stored within a physical system that has the potential to do work.

precipitate
: Solid substance that separates out of a liquid to form a solid, usually when the liquid evaporates.

precipitation
: Water that falls from the sky as rain, snow, sleet, or hail.

predator
: An animal that kills and eats other animals.

prey
: An animal that could be killed and eaten by a predator.

primary productivity
: The creation of food energy.

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.

projection
: A way to represent a 3-dimensional surface in two dimensions.

prokaryote
: An organism that lacks a cell nucleus or membrane-bound organelles.

proton
: A positively charged particle in a nucleus.

pyroclastic flow
: Hot ash, gas, and rock that race down a volcano's slopes during an eruption.

Section 17

R

R

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.

radiation
: The movement of energy through empty space between objects by electromagnetic waves.

radiative zone
: Layer of the Sun immediately surrounding the core where energy moves atom to atom as electromagnetic waves.

radio telescope
: A radio antenna that collects radio waves or microwaves.

radio wave
: The longest wavelengths of the electromagnetic spectrum; 1 mm to more than thousands of kilometers.

radioactive isotope
: Substance that is unstable and likely to decay into another isotope.

radioactivity
: Emission of high-energy particles by unstable isotopes.

radiometric dating
: Process of using the concentrations of radioactive substances and daughter products to estimate the age of a material.

radiosonde
: A group of instruments that measure the characteristics of the atmosphere — temperature, pressure, humidity, etc. — as they move through the air.

rainforest
: The tropical wet biome where temperatures are warm and rain falls nearly every day.

rainshadow effect
: A location of little rain on the leeward side of a mountain range due to descending air.

reclamation
: Restoring a mined property to its pre-mining state.

red giant
: Stage in a star's development when the inner helium core contracts while the outer layers of hydrogen expand.

redshift
: Shift of wavelengths of light towards the red end of the spectrum; happens as a light source moves away from us.

reef
: A large underwater structure created from the calcium carbonate skeletons of coral.

reflecting telescope
: Telescopes that use mirrors to collect and focus light.

reflection
: Bouncing back. A wave bounces off a reflective surface, just as a light wave bounces off a mirror.

refracting telescope
: Telescopes that use convex lenses to collect and focus light.

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.

regional metamorphism

Changes in rock that occur because of high pressure over a large area.

relative age
: The age of an object in comparison with the age of other objects.

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.

relief
: Difference in height of landforms in a region.

renewable resources
: Resources that are limitless or that are replaced more quickly than we can use them.

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.

residual soil
: Soil that forms from the bedrock upon which it lies.

respiration
: The process in which organisms convert sugar into useful food energy. Respiration burns oxygen and produces carbon dioxide.

reverse fault
: A dip-slip fault in which the hanging wall pushes up relative to the footwall.

revolution
: The Earth's movement around the Sun in an orbital path.

rip current
: A strong surface current that returns to the ocean from the shore.

RNA world hypothesis
: RNA was the first nucleic acid and the only one at the beginning of life.

rock
: Mixture of minerals.

rock cycle
: The never-ending cycle in which one rock type changes into another rock type.

rocket
: A device propelled by particles flying out one end at high speed.

rotation
: The motion of the Earth spinning on its axis.

S

S

S-waves
: Secondary waves; arrive second at a seismograph.

salinity
: A measure of the amount of dissolved salt in water; average ocean salinity is 3.5%.

saltation
: The intermittent movement of bed load particles.

sand dune
: Sand deposit formed in regions of abundant sand and constant winds.

Santa Ana winds
: Hot winds that blow east to west into Southern California in fall and winter.

satellite
: An object, either natural or human made, that orbits a larger object.

savanna
: The tropical wet and dry biome, typified by grasses and widely scattered deciduous trees.

scavenger
: Animals that eat animals that are already dead.

scientific method
: A means of investigating a testable question using empirical information gathered from experiments, experience, or observations.

sea breeze
: A wind that blows from sea to land in summer when the land is warmer than the ocean.

sea level
: The average height of the ocean; the midpoint between high and low tide.

sea stack
: Isolated tower of rock that forms when a sea arch collapses.

seafloor spreading
: The mechanism for moving continents. The formation of new seafloor at spreading ridges pushes lithospheric plates on the Earth's surface.

seawall
: Structure built parallel to the shore on the beach to protect against strong waves.

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.

seismic waves
: Also called earthquake waves. Seismic waves transport the energy released during an earthquake. Seismic waves give scientists information on Earth's interior.

seismogram
: A seismogram is the printed record of seismic activity produced by a seismometer.

seismograph
: An older type of seismometer in which a suspended, weighted pen wrote on a drum that moved with the ground.

seismology

The study of seismic waves including earthquakes and the Earth's interior.

seismometer
: A seismometer is a machine that measures seismic waves and other ground motions.

sewage treatment
: Any process that removes contaminants from sewage or wastewater.

shadow
: Darkness that occurs where a light source is blocked.

shear
: Parallel stresses that move past each other in opposite directions.

shield
: The part of a craton that crops out at the surface.

shield volcano
: A shield-shaped volcano composed of fluid lavas.

silicates
: Minerals of silicon atoms bonded to oxygen atoms.

sinkhole
: Circular hole in the ground that forms as the roof of a cave collapses.

slash-and-burn
: A method of clearing land for farming that involves cutting trees and then burning the leftover debris. This is common in rainforests.

slash-and-burn agriculture
: Plants are slashed down and then burned to clear the land for agriculture.

slip
: The distance rocks move along a fault.

slip face
: Steeper, downwind side of a dune where sand grains fall down from the crest.

slump
: Downslope slipping of a mass of soil or rock, generally along a curved surface.

soil
: The top layer of Earth's surface containing weathered rocks and minerals and organic material.

soil horizon
: An individual layer of a complete soil profile; examples include A, B & C horizons.

soil profile
: The entire set of soil layers or horizons for a particular soil.

solar eclipse
: Occurs when moon passes directly between the Earth and Sun; the Moon’s shadow blocks the Sun from view.

solar flare
: A violent explosion on the Sun’s surface.

solar prominence
: Plasma loop flowing between sunspots.

solar system
: The Sun and all the objects that revolve around the Sun as a result of gravity.

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.

space probe
: An unmanned spacecraft that collects data by flying near or landing on an object in space.

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.

space telescope
: Telescopes in orbit above Earth's atmosphere.

species
: A classification of organisms that can or do interbreed and produce fertile offspring.

specific heat
: The amount of energy needed to raise the temperature of 1 gram of material by 1 ◦C.

spectrometer
: A tool that uses a prism to break light into its component colors.

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.

spit
: Long, narrow bar of sand that forms as waves transport sand along shore.

spring
: A point on the Earth’s surface where ground water bubbles up.

spring tide
: A large tidal range that occurs when the Moon, Sun, and Earth area aligned; this happens at full and new moon phases.

squall line
: A line of thunderstorms that forms at the edge of a cold front.

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.

star
: A glowing sphere of gases that produces light through nuclear fusion reactions.

star cluster
: A group of hundreds of thousands of stars.

star system
: Small groups of stars that are close together.

stationary front
: A stalled front in which the air does not move.

steppe
: The biome of semi-arid deserts, with bunch grasses, scattered low bushes and sagebrush.

storm surge
: Water that is pushed in a pile near shore by storm winds causing sea level to rise locally.

strain
: Deformation in a rock because of a stress that exceeds the rock's internal strength.

stratosphere
: Above the troposphere; temperature increases with altitude because of the presence of ozone.

streak
: The color of the powder of a mineral.

stream

A body of moving water, contained within a bank (sides) and bed (bottom).

stress

Force per unit area in a rock.

strike-slip fault

A fault in which the dip of the fault plane is vertical.

stromatolites

Reef like cyanobacteria that still exist today.

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.

sublimation

The change of a substance from a solid to a gas without going through the liquid phase.

subsidence

Sinking of the land surface because of the extraction of ground water.

subsoil

The B horizon of a soil profile; beneath the topsoil.

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.

supercontinent

A collection of continents that have come together because of the plate tectonics processes.

supercontinent cycle

The cycle in which the continents join into one supercontinent and then move apart to join together at the other side of the planet as another supercontinent.

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.

supernova

A tremendous explosion that occurs when the core of a star is mostly iron.

superposition

In a sequence of sedimentary rock layers, the oldest is at the bottom and the youngest is at the top.

supervolcano

A massive volcano that can produce unbelievably enormous, but rare, eruptions.

surface current

A horizontal movement of ocean water, caused by surface winds.

surface waves

Seismic waves that travel along the ground surface; they do the most damage.

suspended load

Solid particles that are carried in the main stream flow.

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.

swamp

A low-lying wetland where water moves very slowly and oxygen levels are low.

symbiosis

Relationships between two species in which at least one species benefits.

symbiotic

A relationship between organisms in which each benefits and none is harmed.

syncline

A fold in the rocks that bends downward, in which the youngest rocks are at the center.

T

taiga
: Vast, boreal forests of small, widely spaced trees typical of the subpolar climate.

talus slope
: A pile of angular rock fragments formed at the base of a cliff or mountain.

temperature
: A physical property of matter that expresses how hot or cold it is.

temperature gradient
: The change in temperature with distance.

tension
: Stresses that pull material in opposite directions.

tephra
: Fragments of material produced in a volcanic eruption.

terminal moraine
: Glacial till dumped at the furthest point reached by a glacier.

terrae
: The light parts of the Moon's surface, composed of high crater rims.

terrestrial planets
: The solid, dense, rocky planets that are the same as the inner planets.

theory
: A hypothesis that has been repeatedly tested that has no significant evidence against it.

thermal pollution
: Water pollution created by adding heat to water.

thermohaline circulation
: Temperature and salinity (density) driven currents that drive deep ocean circulation.

thermometer
: A device that measures temperature.

thermosphere
: The outer atmosphere where gases are extremely thinly distributed.

thrust
: The forward force produced by gases escaping from a rocket engine.

thrust fault
: A reverse fault in which the dip of the fault plane is nearly horizontal.

thunder
: The loud clap produced by lightning.

thunderstorm
: Storms caused by upwelling air; cumulonimbus clouds, thunder, and lightning.

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.

timber
: Trees that are cut for wood to be used for building or some other purpose.

topographic map

A map that shows elevations above sea level to indicate geographic feature.

topography
: Height of a feature relative to sea level.

topsoil
: The A horizon; the most fertile layer with humus, plant roots and living organisms.

tornado
: Violently rotating funnel cloud that grows downward from a cumulonimbus cloud.

trace fossil
: Evidence of the activity of an ancient organism; e.g. tracks, tubes, and bite marks.

transform fault
: An earthquake fault; one plate slides past another.

transform plate boundary
: The type of plate boundary where two plates slide past one another.

transpiration
: The release of water vapor into the air through the leaves of plants.

transported soil
: Soil that forms from weathered components transported to a different area.

travertine
: Beautiful deposit of calcium carbonate that forms around hot springs.

tree ring
: Rings of wood equaling one year of tree growth in a tree trunk.

trench
: A deep gash in the seafloor; the deepest places on Earth.

tributary
: The smaller of two streams that join together to make a larger stream.

trophic level
: Energy levels within a food chain or food web.

tropical
: A climate that is warm and humid.

tropical depression
: A low pressure cell that rises in the tropics; thunderstorms arise here.

tropical rainforest
: A warm, wet biome with abundant broadleaf evergreen trees and large biodiversity.

troposphere
: The lowermost layer of the atmosphere; temperature decreases with altitude.

trough
: The lowest point of a wave.

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.

tundra
: The treeless area of the arctic with very cold, harsh winters.

U

ultramafic
: A type of igneous rock that contains more than 90% mafic minerals.

ultraviolet (UV)
: Electromagnetic radiation having wavelengths shorter than the violet.

ultraviolet (UV) radiation
: High energy radiation from the Sun that can be dangerous to Earth's life.

umbra
: Inner cone shaped part of a shadow when all light is blocked during an eclipse.

unconformity
: A gap between rocks of very different ages. Unconformities are often marked by an erosional surface.

uniformitarianism
: Natural processes operated the same way throughout Earth's history as they do today.

universe
: Everything that exists; all matter and energy; also includes all of space and time.

uplift
: The upward rise of rock material.

upwelling
: Cold, nutrient-rich water that rises from oceanic depths.

V

valley breeze
: An uphill airflow.

variation
: Having many differences.

varve
: Paired deposit of light-colored, coarser sediments and darker, fine-grained sediments deposited in a glacial lake that represent an annual cycle.

vein
: Minerals that cooled from a fluid and filled cracks in a rock.

ventifacts
: Polished, faceted stones formed by abrasion by sand particles.

vertebrate
: Animals with a backbone.

vesicular
: Igneous rock texture with holes that indicate the presence of gas bubbles in the magma.

viscosity
: The thickness of a liquid; its resistance to flow.

visible light
: The portion of light in the electromagnetic spectrum that is visible to humans.

volcanic rock
: Rock that originates in a volcano or volcanic feature.

Section 22

W

W

warm front
: A front in which a warm air mass replaces a cold air mass.

water column
: A vertical column of ocean water, divided into different zones according to their depth.

water purification
: Any process used to produce safe drinking water by removing contaminants.

water table
: The upper surface of ground water.

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.

wave
: A change in the shape of water caused by energy from wind.

wave-cut cliff
: A sea cliff cut by strong wave energy.

wave-cut platform
: Level area formed by wave erosion as waves undercut cliffs.

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

weather
: The temporary state of the atmosphere in a region.

weather map
: A map showing weather conditions over a wide area at a given time.

weathering
: The chemical or physical breakdown of rocks, soils or minerals at Earth's surface.

well
: A circular hole that goes into an aquifer to allow people to access groundwater.

wetland
: Lands that are wet a large amount of the time.

white dwarf
: A small to mid-sized star that has collapsed.

X

X-ray
: A band of electromagnetic radiation between gamma and ultraviolet.

Y

year
: The time it takes for a planet to orbit the Sun.

Z

zooplankton
: Tiny animals that float at the surface their whole lives or only part of their lives.

Date	Accomplished	Country	Name of Mission
October 4, 1957	First artificial satellite, first signals from space	USSR	Sputnik 1
November 3, 1957	First animal in orbit (the dog Laika)	USSR	Sputnik 2
January 31, 1958	USA's first artificial satellite	USA	Explorer 1
January 4, 1959	First human-made object to orbit the Sun	USSR	Luna 1
September 13, 1959	First impact into another planet or moon (the Moon)	USSR	Luna 2
April 12, 1961	First manned spaceflight and first manned orbital flight (Yuri Gagarin)	USSR	Vostok 1
May 5, 1961	USA's first spaceflight with humans (Alan Shepherd)	USA	Mercury-Redstone 3 (Freedom 7)
February 20, 1962	USA's first orbital flight with humans (John Glenn)	USA	Mercury-Atlas 6 (Friendship 7)
December 14, 1962	First planetary flyby (Venus)	USA	Mariner 2
June 16, 1963	First woman in space, first woman in orbit (Valentina Tereshkova)	USSR	Vostok 6
March 18, 1965	First extra-vehicular activity ("spacewalk") (Aleksei Leonov)	USSR	Voskhod 2

orthoclase feldspar	plagioclase feldspar
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Specific Gravity Samples	Specific Gravity Measured

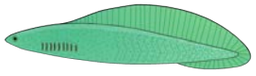
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Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic (fragments of non-organic sediments)
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Shale	Clastic
	Rock Salt	Chemical precipitate

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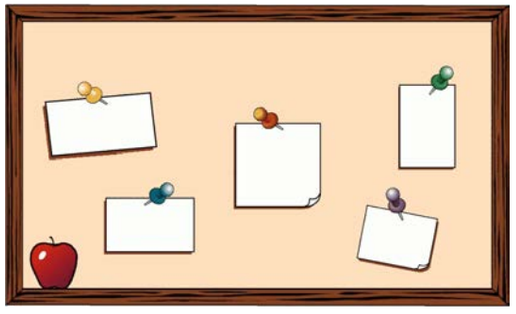




Picture	Rock Name	Type of Metamorphic Rock	Comments
	Slate	Foliated	Metamorphism of shale
	Phyllite	Foliated	Metamorphism of slate, but under greater heat and pressure than slate
	Schist	Foliated	Often derived from metamorphism of claystone or shale; metamorphosed under more heat and pressure than phyllite
	Gneiss	Foliated	Metamorphism of various different rocks, under extreme conditions of heat and pressure

Appendix

Interactive 28.1 KMHS Earth Science Padlet Wall



Dynamic Content

Interactive 28.2 Errors and Omissions



Please report any mistakes you may have found and help us improve this text.