PHYSICAL GEOGRAPHY



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Book: Physical Geography (Lumen)

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Licensing

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2.1: Introduction to Physical Geography

Learning Objectives

This chapter has several goals and objectives:

- Develop an understanding of geographic and scientific knowledge and inquiry.
- Describe the basic model of the scientific method and how scientists use it to understand the natural world.
- Explain the importance of understanding location.
- Compare and contrast the various types of geospatial technologies used today.

Physical Geography, also called **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.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 physical geography and earth science.

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2.2: Scientific and Geographic Inquiry

Scientific Inquiry



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 that can be systematically observed and careful evidenced collected. Then they use logical reasoning and some imagination to develop a testable idea, called a **hypotheses**, along with explanations to explain the idea. Finally, scientists design and conduct experiments based on their hypotheses. Scientists seek to understand the natural world by asking questions and then trying to answer the questions with evidence and logic. A **scientific question** must be testable and supported by empirical data, 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 how to understand the consequences of adding excess greenhouse gases into the atmosphere.

Scientific research may be done to build knowledge or to solve problems and lead to **scientific discoveries** and 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. Some ideas are not testable. For example, supernatural phenomena, such as stories of ghosts, werewolves, or vampires, cannot be tested. Scientists describe what they see, whether in nature or in a laboratory.

Science is the realm of facts and observations, not moral judgments. 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; heir 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 and 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 because accepted ideas in science become more reliable as they survive more tests.

Geographic Inquiry

Geography is the study of the physical and cultural environments of the earth. What makes geography different from other disciplines is it's focus on spatial inquiry and analysis. Geographers also try to look for connections between things such as patterns, movement and migration, trends, and so forth. This process is called **geographic** or **spatial inquiry**.

In order to to this, geographers go through a geographic methodology that is quite similar to the scientific method, but again with a geographic or spatial emphasis. This method can be simplified in a six step geographic inquiry process.

1. **Ask a geographic question.** This means to ask questions about spatial relationships in the world around you.
2. **Acquire geographic resources.** Identify data and information that you need t answer your question.
3. **Explore geographic data.** Turn the data into maps, tables, and graphs, and look for patterns and relationships.
4. **Analyze geographic information.** Determine what the patterns and relationships mean with respect to your question.

"Knowing where something is, how its location influences its characteristics, and how its location influences relationships with other phenomena are the foundation of geographic thinking. This mode of investigation asks you to see the world and all that is in it in spatial terms. Like other research methods, it also asks you to explore, analyze, and act upon the things you find. It also is important to recognize that this is the same method used by professionals around the world working to address social, economic, political, environmental, and a range of scientific issues" (ESRI).

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2.3: Scientific Method

You have probably learned that the **scientific method** is a series of steps that help to investigate. To answer those questions, 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. This video of The Scientific Method Made Easy explains scientific method succinctly and well.

https://youtu.be/zcavPAFiG14

Scientific Questioning

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

- What makes Mount St. Helens more explosive and dangerous than the volcano on Mauna Loa, Hawaii?
- What makes the San Andreas fault different than the Wasatch Fault?
- Why does Earth have so many varied life forms but other planets in the solar system do not?
- What impacts could a warmer planet have on weather and climate systems?

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. 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?

Scientific 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; 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.

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.

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. 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 re-calibrated. 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.



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For an interactive animation of how Darwin used finches to explain the origin of species using the Galapagos islands finches, click here. 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.

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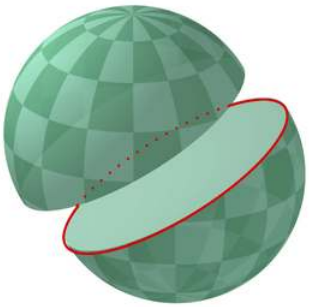
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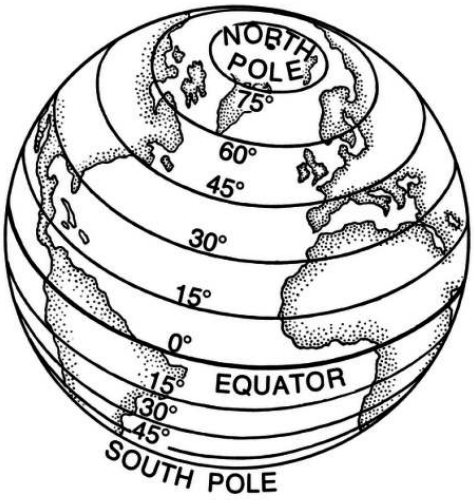
2.4: Geographic Grid System

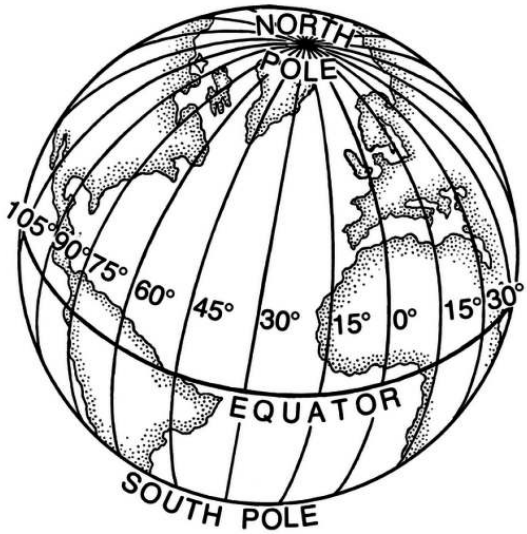


Geography is about spatial understanding, which requires an accurate grid system to determine absolute and relative location. **Absolute location** is the exact *x*– and *y*– coordinate on the Earth. **Relative location** is the location of something relative to other entities. For example, when you use your GPS in your smart phone or car, say Google Maps, you put in an absolute location. But as you start driving, the device tells you to turn right or left relative to objects on the ground: "Turn left on exit 202" is relative to the other exit points. Or if you give directions to your house, you often use relative locations to help them understand how to get to your house.

Great and Small Circles

Much of Earth's grid system is based on the location of the North Pole, South Pole, and Equator. The poles are an imaginary line running from the axis of Earth's rotation. The **plane of the equator** is an imaginary horizontal line that cuts the earth into two equal halves. This brings up the topic of great and small circles. A **great circle** is any circle that divides the earth into a circumference of two equal halves. It's also the largest circle that can be drawn on a sphere. The line connecting any points along a great circle is also the shortest distance between those two points. Examples of great circles include the Equator, all lines of longitude, the line that divides the earth into day and night called the **circle of illumination** , and the **plane of ecliptic**, which divides the earth into equal halves along the equator. **Small circles** are circles that cut the earth, but not into equal halves. Examples of small circles include all lines of latitude except the equator, the Tropical of Cancer, Tropic of Capricorn, the Arctic Circle, and Antarctic Circle.





Latitude and Longitude

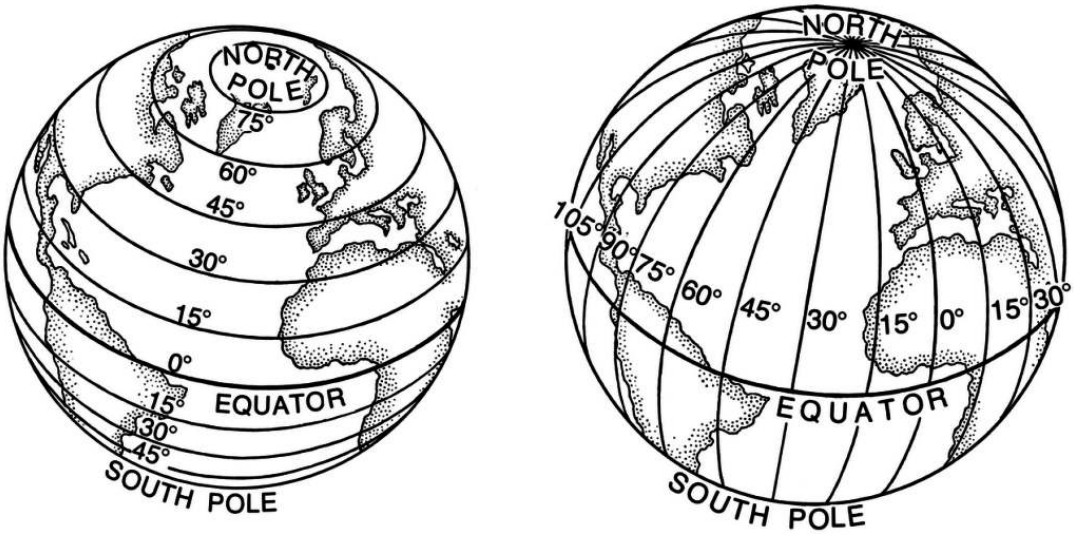
Many think that latitude is a line connecting points on the earth and it's not. **Latitude** is actually an angular measurement north or south of the equator. So 30 degrees north means a point that is 30 degrees north of the equator. Latitude is also expressed in degrees, minutes, and seconds; 360 degrees in a circle, 60 minutes (') in a degree, and 60 seconds (") in a minute. When you use

Google Earth, the coordinate locations are in this degrees/minutes/seconds format. Latitude varies from 0 degrees (equator) to 90 degrees north and south (the poles). A line connecting all points of the same latitude is called a **parallel**, because the lines run parallel to each other. The only parallel that is also a great circle is the equator. All other parallels are small circles. The following are the most important parallel lines:

- Equator, 0 degrees
- Tropic of Cancer, 23.5 degrees N
- Tropic of Capricorn, 23.5 degrees S
- Arctic Circle, 66.5 degrees N
- Antarctic Circle, 66.5 degrees S
- North Pole, 90 degrees N (infinitely small circle)
- South Pole, 90 degrees S (infinitely small circle)

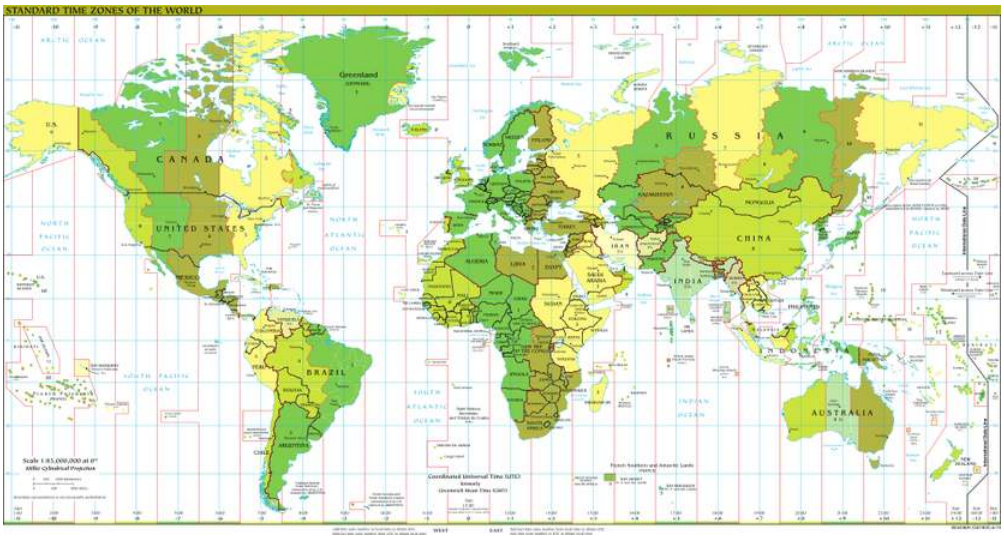
Latitude is also sometimes described as **zones of latitude**. Some of these zones of latitude include:

- Low latitude—generally between the equator and 30 degrees N
- Midlatitude—between 30 degrees and 60 degrees N and S
- High latitude—latitudes greater than about 60 degrees N and S
- Equatorial—within a few degrees of the equator
- Tropical—within the tropics (between 23.5 degrees N and 23.5 degrees S
- Subtropical—slightly pole-ward of the tropics, generally around 25-30 degrees N and S
- Polar—within a few degrees of the North or South Pole



Longitude is the angular measurement east and west of the Prime Meridian (image on the right). Like latitude, longitude is measured in degrees, minutes, and seconds. Lines connecting equal points of longitude are called **meridians**. But unlike parallels, meridians do not run parallel to each other. Rather they are farthest apart from each other at the equator and merge toward each other toward the poles. The problem with longitude is that there isn't a natural baseline like the equator is for latitude. For over a hundred years, nations used their own "prime meridian" which proved problematic for trade. But in 1883 an international conference in Washington D.C. was held to determine a global prime meridian. After weeks of debate, the Royal Observatory at Greenwich, England was determined as the **Greenwich Meridian** or also called the **prime meridian** for the world. So today, longitude starts at the Prime Meridian and measures east and west of that line.

At 180 degrees of the Prime Meridian in the Pacific Ocean is the **International Date Line**. The line determines where the new day begins in the world. Now because of this, the International Date Line is not actually a straight line, rather it follows national borders so that a country isn't divided into two separate days (and we think hour time zones are a pain). If you look at the map below, the International Date Line is to the right in a dark, black line. Note how it is drawn to make sure nations are not divided by the International Date Line.



Time Zones

This is also a good time to take a look at **time zones** around the world. If you refer back to the map above, you can see the different time zones in the various colors. Since the earth rotates 360 degrees in a 24 hour period, the earth rotates 15 degrees every hour creating 24 time zones. In an ideal world, each time zone would follow lines of longitude every 15 degrees (7.5 degrees in each direction from the center of the time zone). But because of political boundaries, time zones are not divided up so perfectly and vary greatly in shape and width. Greenwich, England was chosen in the mid-nineteenth century as the starting point of time worldwide. The reason was because at the time, England was the superpower of the time both militarily and economically. So the meridian that ran through Greenwich became zero degrees or the **prime meridian**. Because of the earth's rotation in reference to the prime meridian, locations east of the new meridian meant time was ahead while locations west of the meridian were behind in time in reference to Greenwich, England. Ultimately, when you combine parallel and meridian lines, you end up with a **geographic grid system** that allows you to determine your exact location on the planet.

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2.5: Geospatial Technology

Data, data, data . . . data is everywhere. It's collected every time you go to the grocery store and use their card to reduce the costs, when you click on a link on Facebook, or when you do any kind of search on a search engine like Google, Bing, or Yahoo!. It is used by your state department of transportation when you are driving on a freeway or when you use an app on a smart phone. Futurists believe that in the near future, face recognition technology will allow a sales representative know what types of clothes you like to buy based on a database of your recent purchases at their store and others. Now there are two basic types of data you need to know: spatial and non-spatial data. **Spatial data**, also called **geospatial data**, is data that can be linked to a specific location on Earth. Geospatial data is becoming "big business" because it isn't just data, but data that can be located, tracked, patterned, and modeled based on other geospatial data. Census information that is collected every 10 years is an example of spatial data. **Non-spatial data** is data that cannot be specifically traced to a specific location. This might include the number of people living in a household, enrollment within a specific course, or gender information. But non-spatial data can easily become spatial data if it can be linked in some way to a location. Geospatial technology specialists have a method called **geocoding** that can be used to give non-spatial data a geographic location. Once data has a spatial component associated with it, the type of questions that can be asked dramatically changes.

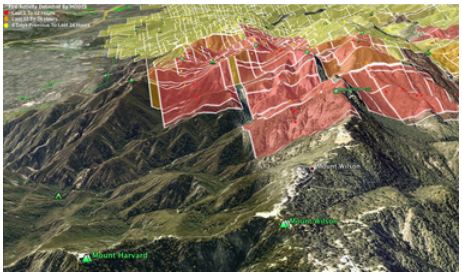
Remote Sensing



Remote sensing can be defined as human's ability to study objects without being in direct physical contact with them. So for example, your eyes are a form of *passive remote sensing* because they are "passively" absorbing electromagnetic energy within the visible spectrum from distant objects and your brain is processing that energy into information. There are a variety of remote sensing platforms or devices, but they can basically be categorized into the following that we will look at throughout the course. **Satellite imagery** is a type of remotely sensed imagery taken of the Earth's surface, which is produced from orbiting satellites that gather data via electromagnetic energy. Next is **areal photography**, which is film-based or digital photographs of the Earth, usually from an airplane or non-piloted drone. Images are either taken from a vertical or oblique position. Third is **radar**, which is an interesting form of remote sensing technology that uses microwave pulses to create imagery of features on Earth. This can be from a satellite image or ground-based Doppler radar for weather forecasting. Finally, a fast growing realm of remote sensing is called **Light Detection and Ranging** or **Lidar**, which is a form of remote sensing that measures distance of objects using laser pulses of light.

Global Positioning Systems

Another type of geospatial technology is global positioning systems (GPS) and a key technology for acquiring accurate control points on Earth's surface. Now to determine the location of that GPS receiver on Earth's surface, a minimum of four satellites are required using a mathematical process called **triangulation**. Normally the process of triangulation requires a minimum of three transmitters, but because the energy sent from the satellite is traveling at the speed of light, minor errors in calculation could result in large location errors on the ground. Thus, a minimum of four satellites is often used to reduce this error. This process using the geometry of triangles to determine location is used not only in GPS, but a variety of other location needs like finding the epicenter of earthquakes.A user can use a GPS receiver to determine their location on Earth through a dynamic conversation with satellites in space. Each satellite transmits orbital information called the **ephemeris** using a highly accurate atomic clock along with its orbital position called the **almanac**. The receiver will use this information to determine its distance from a single satellite using the equation $D = rt$, where D = distance, r = rate or the speed of light (299,792,458 meters per second), and t = time using the atomic clock. The atomic clock is required because the receiver is trying to calculate distance, using energy that is transmitted at the speed of light. Time will be fractions of a second and requires a "time clock" up the upmost accuracy.



There is a technology that exists that can bring together remote sensing data, GPS data points, spatial and non-spatial data, and spatial statistics into a single, dynamic system for analysis and that is a **geographic information system** (GIS). A GIS is a powerful database system that allows users to acquire, organize, store, and most importantly analyze information about the physical and cultural environments. A GIS views the world as overlaying physical or cultural layers, each with quantifiable data that can be analyzed. A single GIS map of a national forest could have layers such as elevation, deciduous trees, evergreens, soil type, soil erosion rates, rivers and tributaries, major and minor roads, forest health, burn areas, regrowth, restoration, animal species type, trails, and more. Each of these layers would contain a database of information specific to that layer.Nearly every discipline, career path, or academic pursuit uses geographic information systems because of the vast amount of data and information about the physical and cultural world. Disciplines and career paths that use GIS include: conservation, ecology, disaster response and mitigation, business, marketing, engineering, sociology, demography, astronomy, transportation, health, criminal justice and law enforcement, travel and tourism, news media, and the list could endlessly go on.Now, GIS primarily works from two different

spatial models: raster and vector. **Raster** based GIS models are images much like a digital picture. Each image is broken down into a series of columns and rows of pixels and each pixel is **georeferenced** to somewhere on Earth's surface is represents a specific numeric value—usually a specific color or wavelength within the **electromagnetic spectrum**. Most remote sensing images come into a GIS as a raster layer. The other type of GIS model is called a vector model. **Vector** based GIS models are based on the concept of points that are again georeferenced (i.e. given an x-, *y*-, and possibly *z*-location) to somewhere specific on the ground. From points, lines can be created by connecting a series of points and areas can be created by closing loops of vector lines. For each of these vector layers, a database of information can be attributed to it. So for example, a vector line of rivers could have a database associated with it such as length, width, stream flow, government agencies responsible for it, and anything else the GIS user wants tied to it. What these vector models represent is also a matter of **scale**. For example, a city can be represented as a point or a polygon depending on how zoomed in you are to the location. A map of the world would show cities as points, whereas a map of a single county may show the city as a polygon with roads, populations, pipes, or grid systems within it.



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2.6: Summary

Physical geography is the spatial study of our home planet and all of its components: its lands, waters, atmosphere, and interior. Like other sciences, physical geography is a science that is grounded in scientific knowledge using the scientific method as the fundamental way to understand the environment.Geographers and all spatial scientists require a strong background in understanding in the way humans have partitioned the earth to determine location. In order to do that, a series of lines representing angular measurements on the earth were established, known as the geographic grid system. Once that has been done, spatial knowledge can be collected and analyzed based on geographic or spatial data. This allows us to understand spatial concepts of patterns, distributions, and flows based on location and spatial boundaries.Often times this geographic data must be collected and analyzed using a high-tech and dynamic technology called geospatial technology. This technology encompasses powerful remote sensing technology, global positioning systems, and geographic information systems.

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CHAPTER OVERVIEW

3: The Universe

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3.2: Video- The History of Our World in 18 Minutes
3.3: Expanding Universe
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3.11: Measuring Distant Stars

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3.1: Introduction to the Universe

Learning Objectives

This chapter has several goals and objectives:

- Understand the scientific ideas of how the universe formed and is expanding
- Compare and contrast the difference and similarities between dark matter and dark energy
- Describe star systems and the various types of galaxies
- Explain the phenomenal power within stars
- Classifying and measuring distant 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. 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.

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3.2: Video- The History of Our World in 18 Minutes



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Thoughts to consider while watching this video:

- How does the Universe create complexity?
- What are the believed conditions needed for life to exist anywhere in the universe?
- What makes humans different from other forms of life on earth?

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3.3: Expanding 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 realize 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 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 that we now call **galaxies**.

Hubble showed that the universe was much larger than our own galaxy. Today, we know that the universe contains about a hundred billion galaxies, about the same number of galaxies as there are stars in the Milky Way Galaxy. 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. Today we know know that the universe in nearly 14 billion years old.

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.

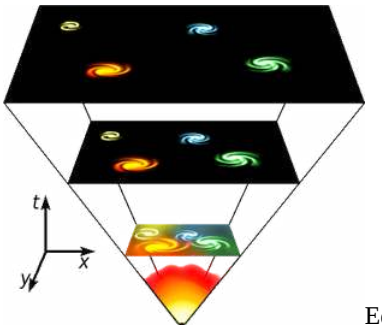
While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in Figure below. This shift of absorption bands toward the red end of the spectrum is known as redshift.

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. What astronomers are noticing is that all the galaxies have a redshift, strongly indicating that all galaxies are moving away from each other causing the Universe to expand.

Redshift can occur with other types of waves too, 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. Check out this animation of the Doppler Effect.



The Expanding Universe



Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called **Hubble's Law**. The law states that the farther away a galaxy is, the faster it is moving away from us. What this leads to is the hypothesis that the universe is expanding. Check out this animation demonstrating the expanding universe. The figure here by NASA shows a simplified diagram of the expansion of the universe. If you look closely at the diagram, you that on the left was the formation of the universe and the energy is quite high. Over the course of the 13.7 billion years, the energy begins to cool enough to create trillions of stars and over time develop into galaxies. Over time, the galaxies continue to cool and expand farther apart from each other.

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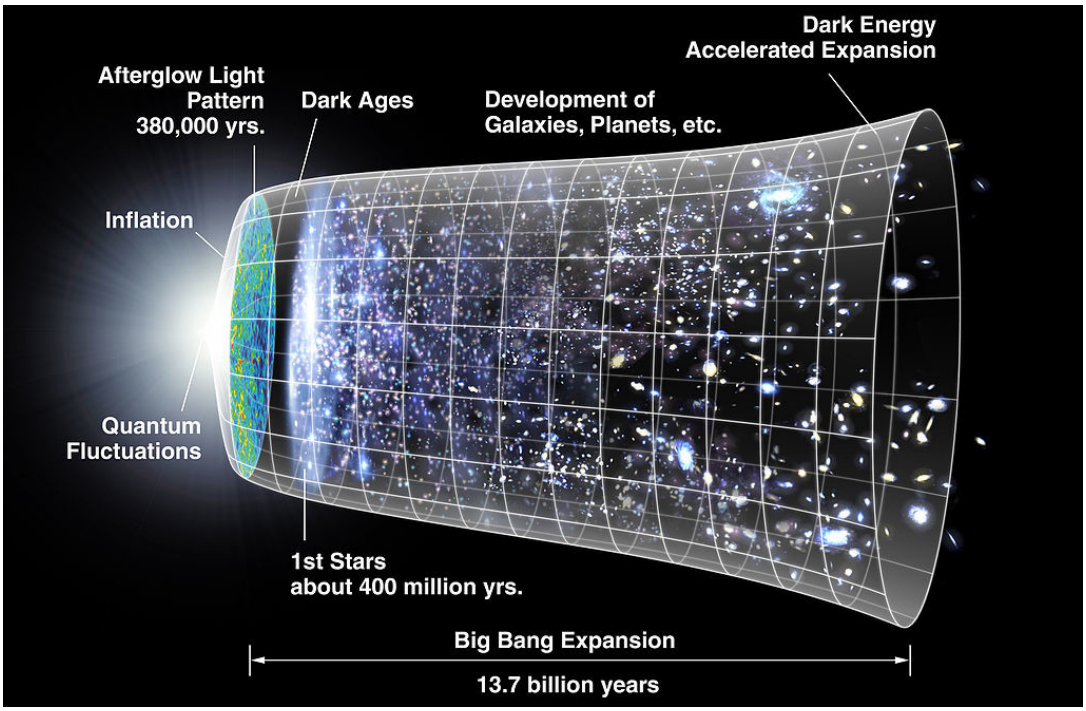
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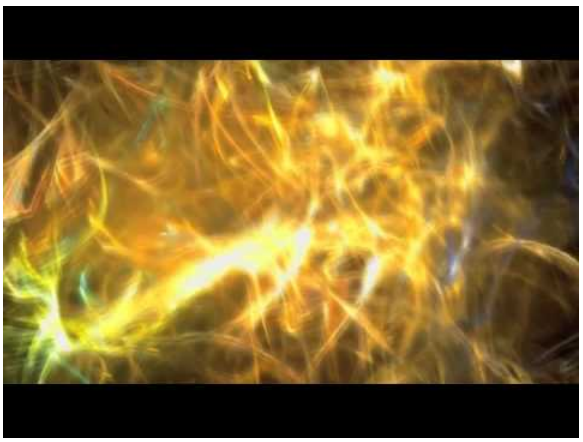
3.4: Formation of the Universe

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 13.7 billion years ago. Everything that is now in the universe was squeezed into a very small volume. Imagine all of the known universe in a single, hot, chaotic mass. An enormous explosion—a big bang—caused the universe to start expanding rapidly. All the matter and energy in the universe, and even space itself, came out of this explosion. What came before the Big Bang? There is no way for scientists to know since there is no remaining evidence.





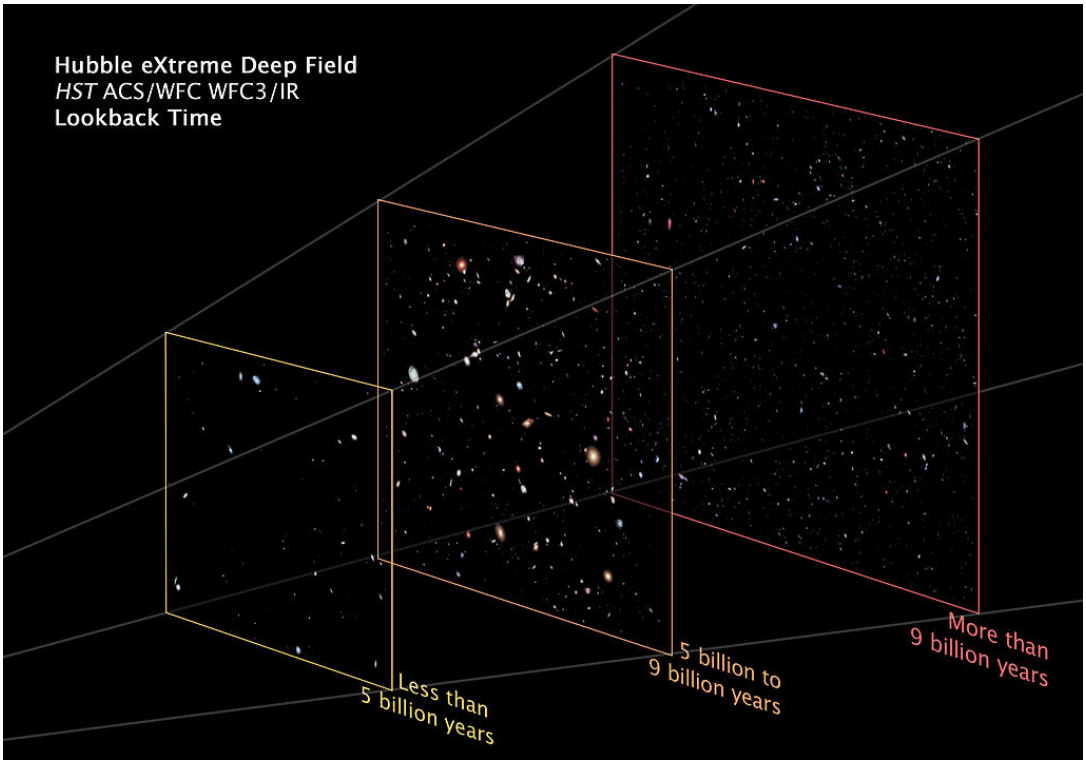
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In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a few seconds, protons, neutrons, and electrons could form. After a few minutes, those particles began to come together to create hydrogen. Energy in the universe was great enough to initiate nuclear fusion and create helium. The first neutral atoms that included electrons did not form until about 380,000 years after the Big Bang. Matter was 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.





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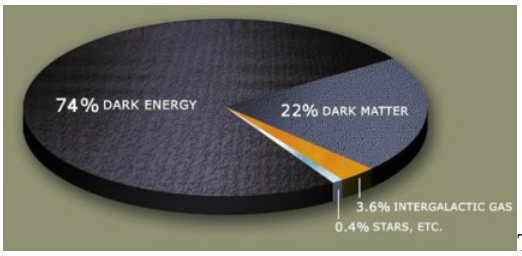
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3.5: Dark Matter and Dark Energy



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, such as dark energy and dark matter.

Dark Matter

The things we observe in space are objects that emit some type of electromagnetic radiation. However, scientists think that matter that emits light makes up only a small part of the matter in the universe. The rest of the matter, about 80 percent, is dark matter. Dark matter emits no electromagnetic radiation so we can't observe it directly. However, astronomers know that dark matter exists because its gravity affects the motion of objects around it. When astronomers measure how spiral galaxies rotate, they find that the outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than they can see.Gravitational lensing occurs when light is bent from a very distant bright source around a super-massive object. To explain strong gravitational lensing, more matter than is observed must be present. 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 astrophysical 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.

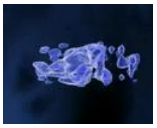
Most scientists who study dark matter think that the dark matter in the universe is a combination of MACHOS and some type of exotic matter such as WIMPs. Researching dark matter is an active area of scientific research, and astronomers' knowledge about dark matter is changing rapidly.

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**. Some scientists think that dark energy makes up as much as 72 percent of the total energy content of the universe.



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3.6: Star Systems

 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**. The image shown here is a famous star cluster classed M45, also known as Pleides, which can be seen with the naked autumn sky.Although the star humans know best is a single star, many stars—in fact, more than half of the bright stars in our galaxy—are star 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.

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. Pleiades is an open cluster that is also called the Seven Sisters. 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.

 **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.

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3.7: Types of Galaxies

Galaxies are the biggest groups of stars and can contain anywhere from a few million stars to many billions of stars (you can learn more here, from NASA). 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, looks like only a dim, fuzzy spot but that fuzzy spot contains one trillion stars.

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. Several arms spiral outward in the Pinwheel Galaxy and are appropriately called **spiral arms**. Spiral galaxies have lots of gas and dust and lots of young stars.Other galaxies are egg-shaped and called **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.Most elliptical galaxies contain very little gas and dust because they had already formed. However, some elliptical galaxies contain lots of dust. Why might some elliptical galaxies contain dust?

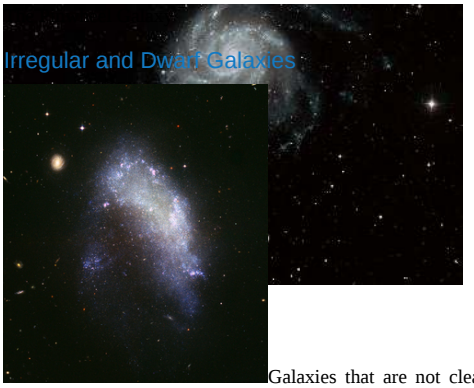


The Andromeda Galaxy



The Sombrero Galaxy





Galaxies that are not clearly elliptical galaxies or spiral galaxies are **irregular galaxies**. Most irregular galaxies were once spiral or elliptical galaxies that were then deformed either by gravitational attraction to a larger galaxy or by a collision with another galaxy. **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 spiral galaxy, Andromeda. Next to our closest galaxy neighbor are two dwarf elliptical galaxies that are companions to the Andromeda Galaxy. One is a bright sphere to the left of center, and the other is a long ellipse below and to the right of center. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.



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On January 5, NASA released an image of the Andromeda galaxy, our closest galactic neighbor, captured by the NASA/ESA Hubble Space Telescope. The full image is made up of 411 Hubble images, takes you through a 100 million stars and travels over more than 40,000 light years. Well, a section of it anyway.

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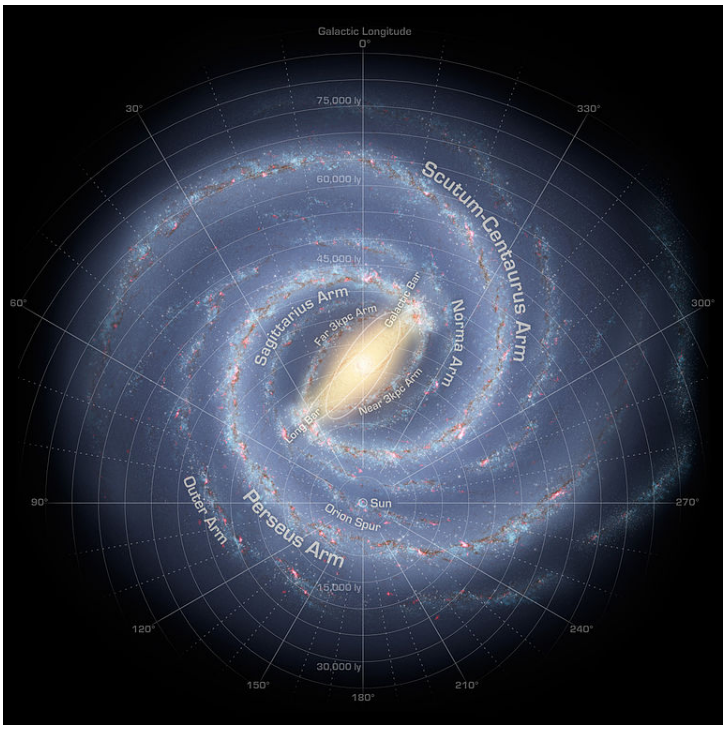
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3.8: Milky Way Galaxy

 On a dark, clear night, you will see a milky band of light stretching across the sky. This band is the disk of a galaxy, the Milky Way Galaxy, is our galaxy and is made of millions of stars along with a lot of gas and dust.

Shape and Size

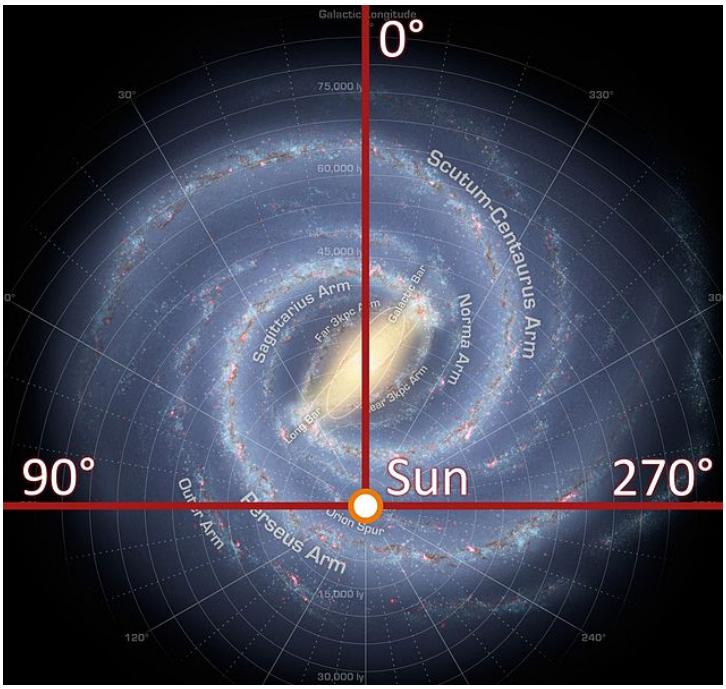
Although it is difficult to know what the shape of the Milky Way Galaxy is because we are inside of it, astronomers have identified it as a typical spiral galaxy containing about 100 billion to 400 billion stars.



Like other spiral galaxies, our galaxy has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across and 3,000 light-years thick. Most of the Galaxy's gas, dust, young stars, and open clusters are in the disk. What data and 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.
2. The velocities of stars and gas in the galaxy show a rotational motion.
3. The gases, color, and dust are typical of spiral galaxies.

The central bulge is about 12,000 to 16,000 light-years wide and 6,000 to 10,000 light-years thick. The central bulge contains mostly older stars and globular clusters. Some recent evidence suggests the bulge might not be spherical, but is instead shaped like a bar. The bar might be as long as 27,000 light-years long. The disk and bulge are surrounded by a faint, spherical halo, which also includes 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 significant place. 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. Earth is about 26,000 light-years from the center of the galaxy, a little more than halfway out from the center of the galaxy to the edge.Just as Earth orbits the Sun, the Sun and solar system orbit the center of the Galaxy. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago. Astronomers have recently found that at the center of the Milky Way, and most other galaxies, is a supermassive black hole, though a black hole cannot be seen.

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3.9: Star Energy

Nuclear Fusion



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.Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a nuclear fusion reaction, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy.In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as **electromagnetic radiation**, including visible light, heat, ultraviolet light, and radio waves.

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. When these particles collide head-on, new particles are created. This process simulates the nuclear fusion that takes place in the cores of stars. The process also simulates the conditions that allowed for the first helium atom to be produced from the collision of two hydrogen atoms in the first few minutes of the universe.

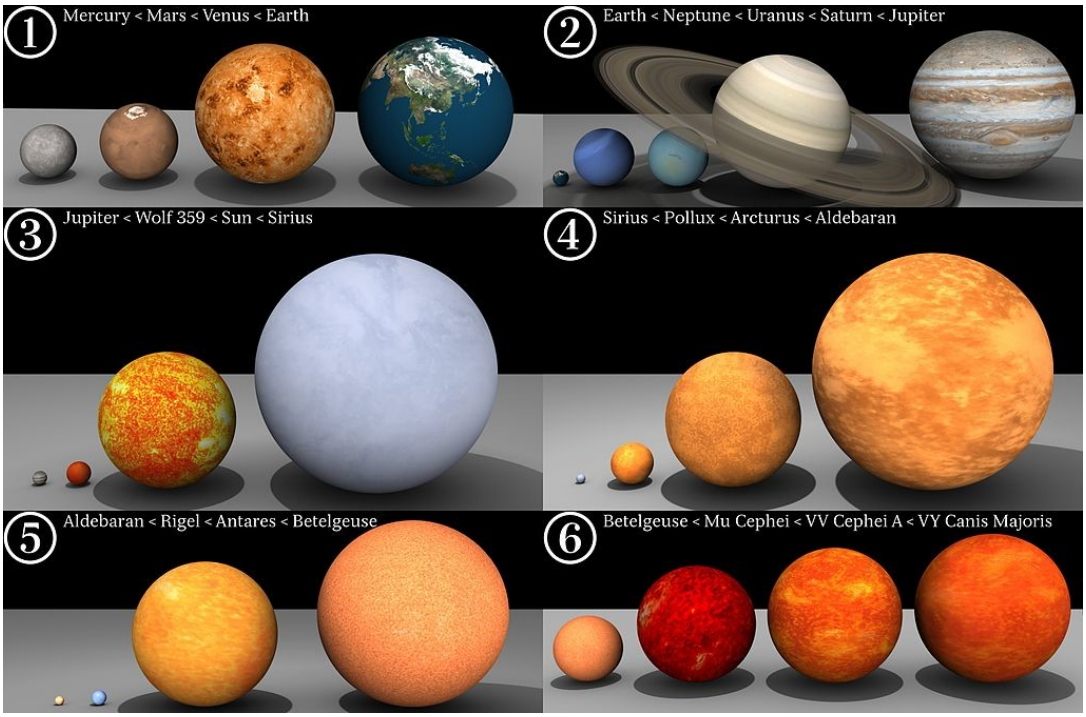
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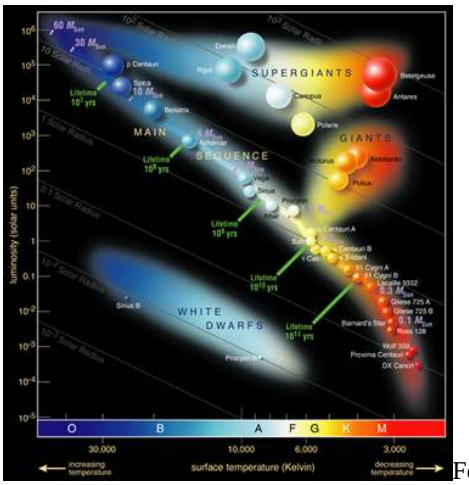
3.10: Star Classification

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.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. 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.



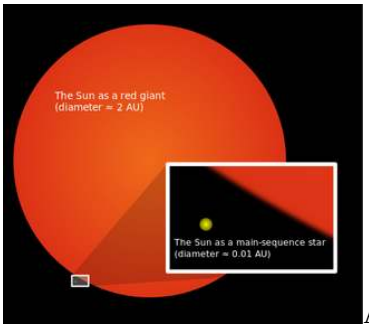
As NASA notes, stars have a life cycle that is expressed similarly to the life cycle of a living creature: they are born, grow, change over time, and eventually die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes. To learn more about star formation from the European Space Agency (ESA), click here.

The Main Sequence



For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence star**. This term comes from the **Hertzsprung-Russell diagram** shown here. 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. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years. 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.

Red Giants and White Dwarfs



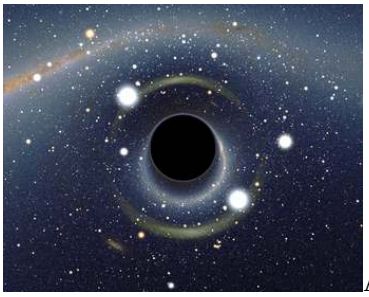
As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. A blue giant star has exhausted its hydrogen fuel and is a transitional phase. When the light elements are mostly used up the star can no longer resist gravity and it starts to collapse inward. 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. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf**. A white dwarf will ultimately fade out.

Supergiants and Supernovas



A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become **red supergiants**.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. A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were created by nuclear fusion in stars.

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 four times the mass of the Sun, the star becomes a neutron star. A **neutron star** is made almost entirely of neutrons, relatively large particles that have no electrical charge.If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a black hole. **Black holes** are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges. The video below on the left demonstrates what it would be like to observe a supernova, while the other TED Talk is on hunting black holes.



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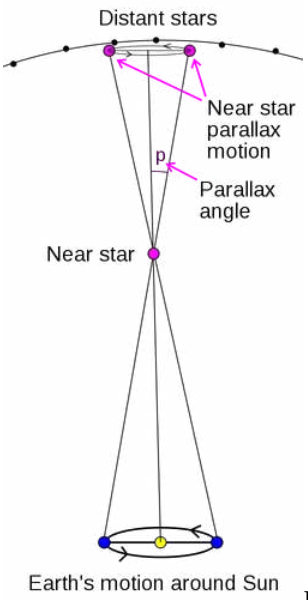
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3.11: Measuring Distant Stars

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.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. Check out this great parallax exercise. 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.

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CHAPTER OVERVIEW

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4.2: Earth as a Planetary Body
4.3: Earth’s Motions
4.4: Earth’s Surface Features
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4.6: The Rock Cycle
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4.9: Metamorphic Rock
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4.1: Introduction to the Planet Earth

Learning Objectives

This chapter has several goals and objectives:

- Describe Earth as a planetary body.
- Explain the various motions of Earth and the results of those motions.
- Compare continental and oceanic features on the surface of the Earth.
- Describe the three major types of rock features and how the rock cycle describes their creation.

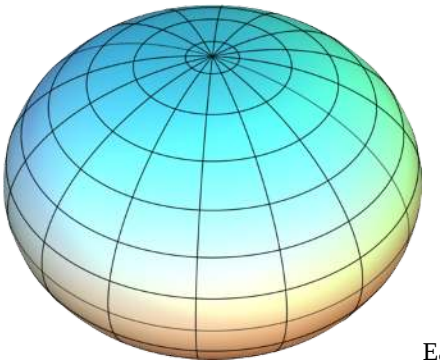
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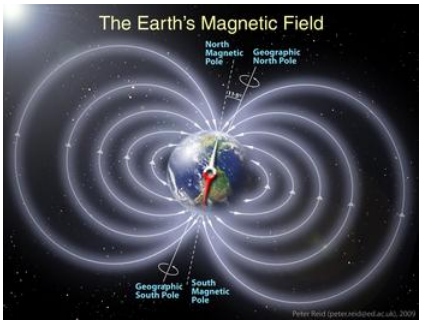
4.2: Earth as a Planetary Body

Earth's Shape



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 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). When the earth is cut in equal halves, each half is called 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. There are many other ways that early scientists and mariners knew that Earth was not flat.



Even the ancient Greeks knew that Earth was round by observing the arc shape of the shadow on the Moon during a lunar eclipse. 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 has a **magnetic field** 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. Earth's magnetic field extends several thousand kilometers into space. The magnetic field shields the planet from harmful radiation from the Sun.

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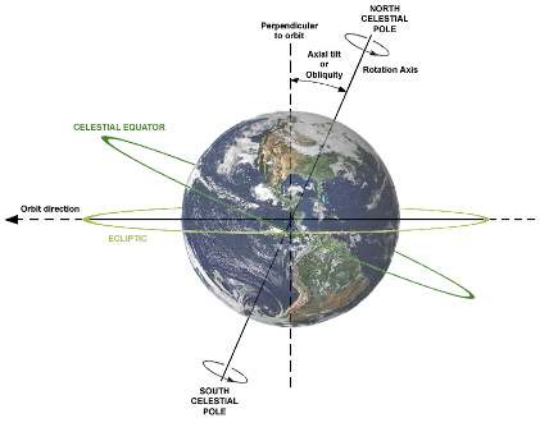
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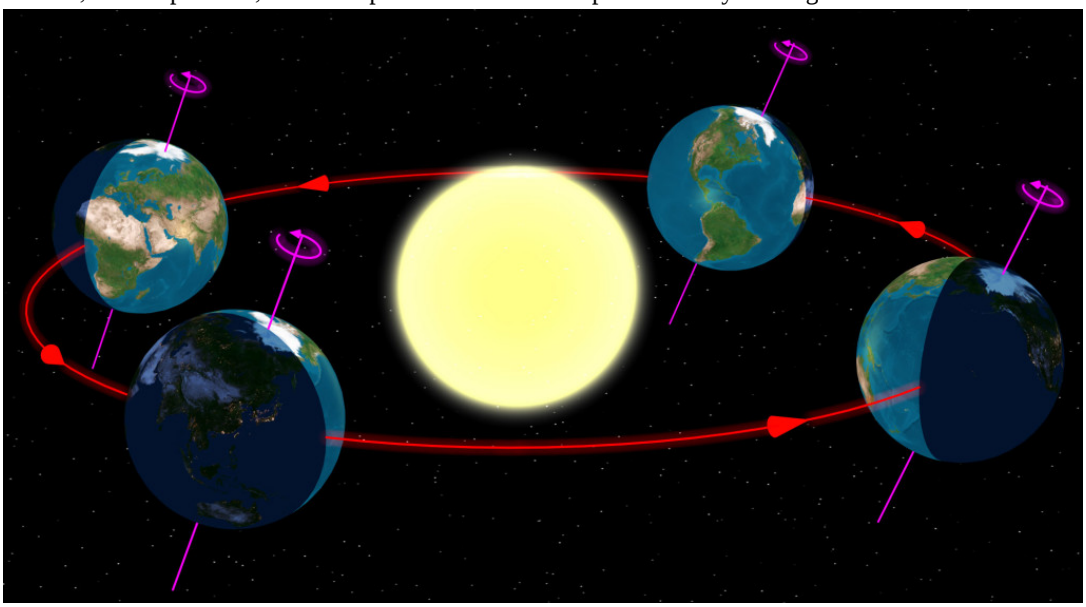
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4.3: Earth's Motions

Earth's Rotation



Imagine a line passing through the center of Earth that goes through both the North Pole and the South Pole. This imaginary line is called an **axis**. Earth spins around its axis, just as a top spins around its spindle. This spinning movement is called Earth's **rotation**. At the same time that the Earth spins on its axis, it also orbits, or revolves around the Sun. This movement is called **revolution**.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. 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 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.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 1/2oon 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.

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4.4: Earth’s Surface Features



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.

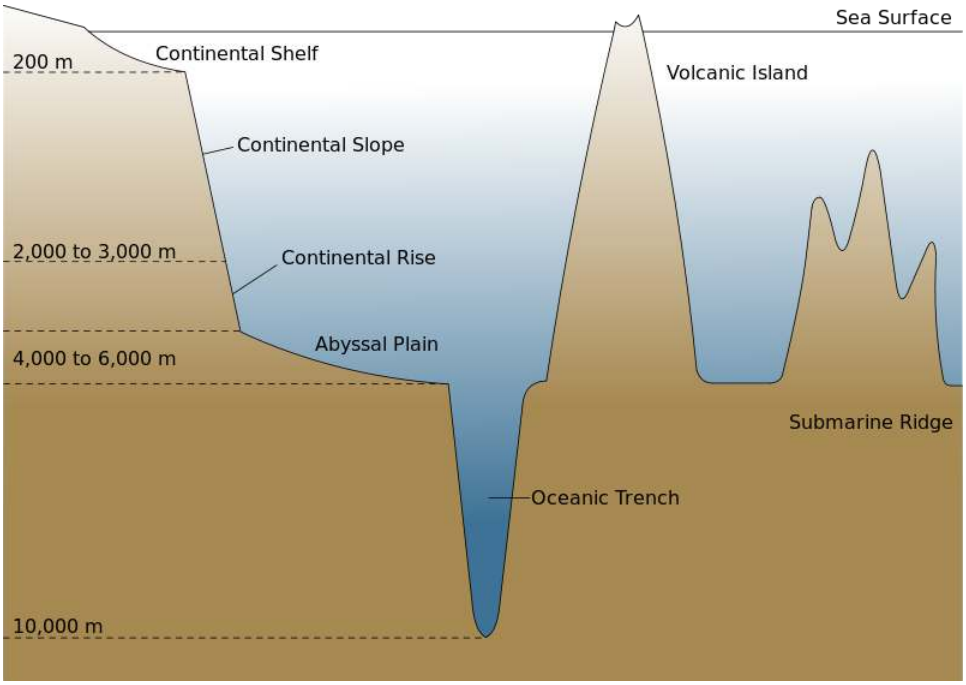
- The continents are large land areas extending from high mountaintops to sea level.
- The ocean basins extend from the edges of the continents down steep slopes to the ocean floor and into deep trenches.

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. 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. 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.

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.

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4.5: Defining Rock Types

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.

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. 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.

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.

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.

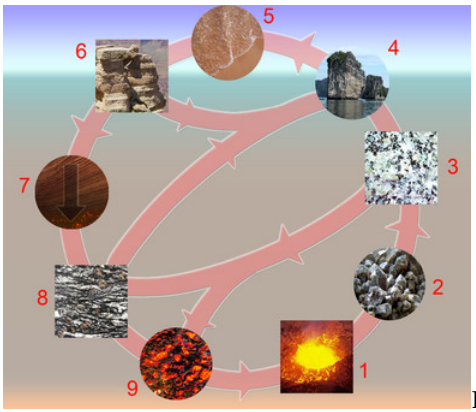
Igneous rocks form from cooling magma. Magma that erupts onto Earth's surface is lava. The chemical composition of the magma and the rate at which it cools determine what rock forms as the minerals cool and crystallize. Sedimentary rocks form by the compaction and cementing together of sediments, broken pieces of rock-like gravel, sand, silt, or clay. Those sediments can be formed from the weathering and erosion of preexisting rocks. Sedimentary rocks also include chemical precipitates, the solid materials left behind after a liquid evaporates. Metamorphic rocks form when the minerals in an existing rock are changed by heat or pressure within the Earth.

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4.6: 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." 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.

In the rock cycle the three main rock types are igneous, sedimentary, and metamorphic. 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.

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.

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.

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4.7: Igneous Rocks

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



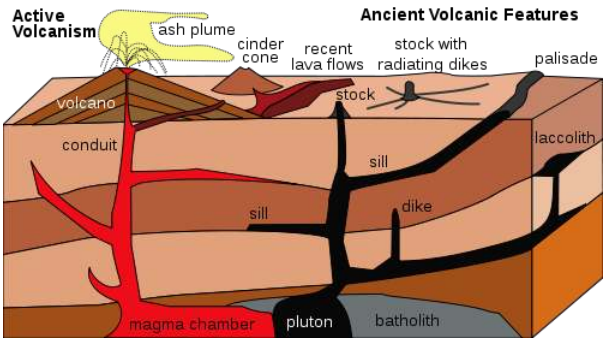
The rock beneath the Earth's surface is sometimes heated to high enough temperatures that it melts to create magma. Different magmas have different composition and contain whatever elements were in the rock that melted. Magmas also contain gases. The main elements are the same as the elements found in the crust. 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. 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.

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.



Intrustive Igneous Rock



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.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. Yosemite is a classic example of intrusive igneous rock. The molten magma never reached Earth's surface, so the molten material had millions of years to cool down slowly to form granite. Later, geologic forces and erosion have caused those granite plutons to surface as they are today.

Extrusive Igneous Rock



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. 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.Cooling rate and gas content create a variety of rock textures. Lavas that cool extremely rapidly may have a glassy texture. Those with many holes from gas bubbles have a vesicular texture.

Human Use of Igneous Rock

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. **Pumice** 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.

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4.8: Sedimentary Rocks



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.

Streams carry huge amounts of sediment. 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.

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 a process called **lithification**. 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.

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.

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.

Human Use of Sedimentary Rock

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.

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4.9: Metamorphic Rock



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. 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.

Extreme pressure may also lead to foliation, the flat layers that form in rocks as the rocks are squeezed by pressure. Foliation normally forms when pressure is exerted in only one direction. Metamorphic rocks may also be non-foliated. Quartzite and limestone are nonfoliated. The two main types of metamorphism are both related to heat within Earth:

- **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.
- **Contact metamorphism**: Changes in a rock that is in contact with magma because of the magma's extreme heat.

Quartzite is very hard and is often crushed and used in building railroad tracks. Schist and slate are sometimes used as building and landscape materials. Graphite, the "lead" in pencils, is a mineral commonly found in metamorphic rocks.

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4.10: Video- The Story of the Earth

This documentary by National Geographic is an hour and a half long, but it will take you through the entire history of our planet. It's definitely worth your time!

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CHAPTER OVERVIEW

5: Plate Tectonics

5.1: Introduction to Plate Tectonics
5.2: Understanding Earth’s Interior
5.3: The Composition and Structure of Earth
5.4: Theory of Continental Drift
5.5: Sea Floor Spreading
5.6: Earth’s Tectonic Plates
5.7: Tectonic Plate Boundaries
5.8: Earth’s Changing Surface
5.9: Plate Tectonics Theory

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5.1: Introduction to Plate Tectonics

Learning Objectives

This chapter has several goals and objectives:

- Compare and describe each of these Earth layers: lithosphere, oceanic crust, and continental crust.
- Describe how convection takes place in the mantle and compare the two parts of the core and describe why they are different from each other.
- Explain the concepts of the following hypothesis: continental drift hypothesis, seafloor spreading hypothesis, and the theory of plate tectonics.
- Describe the three types of tectonic plate and how the processes lead to changes in Earth's surface features.

Essential Questions

- What is the driving force of plate tectonics and how does this impact earthquakes and volcanoes around the world?
- How does the theory of plate tectonics help explain the different types of earthquakes and volcanoes around the planet?

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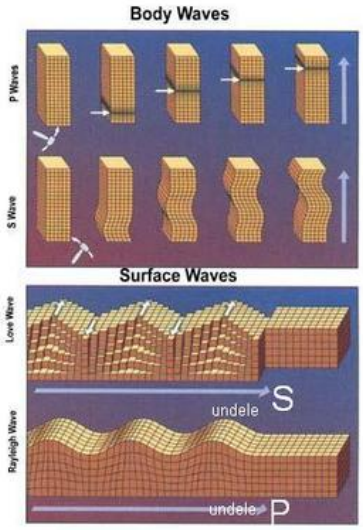
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5.2: Understanding Earth's Interior

Before you can learn about plate tectonics, you need to know something about 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.Humans have never drilled past Earth's crust, and yet we know a lot about the composition of the earth's interior. 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, recorded by seismographs, 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, called **seismic waves**. Seismic waves travel outward in all directions from where the ground breaks at an earthquake. Seismograph stations measure the energy released by these earthquakes, but there are two that scientists are most interested with in regards to understanding the interior of the earth.

Primary waves (also called **P-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. 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 104o to 140o from the earthquakes focus.

Secondary waves (also called **S-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. 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. Other clues to Earth's interior includes the fact that we know that Earth's overall density is higher than the density of crustal rocks, so the core must be made of something dense, like metal. Also, since Earth has a magnetic field, there must be metal within the planet. Iron and nickel are both magnetic. Finally, 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.

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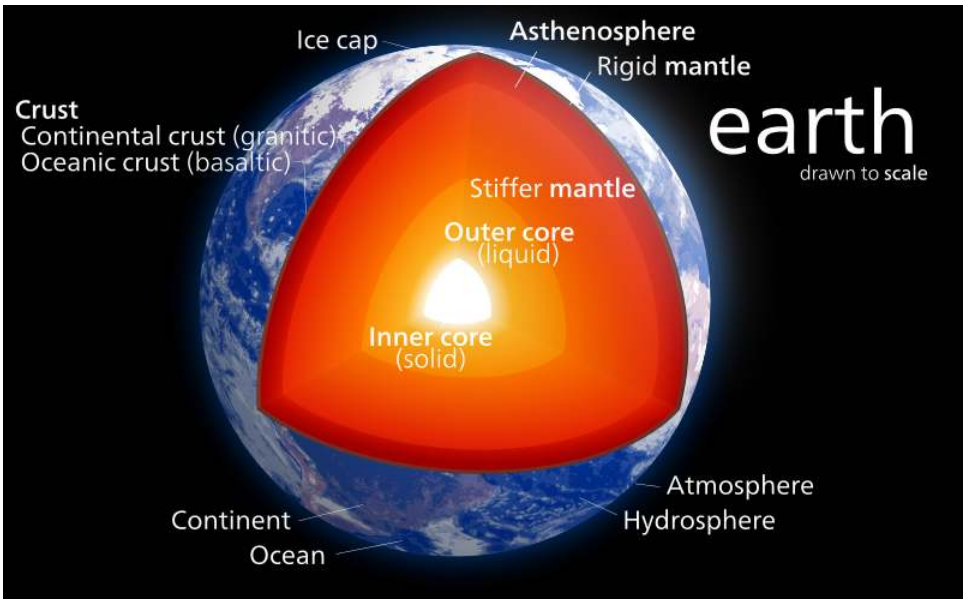
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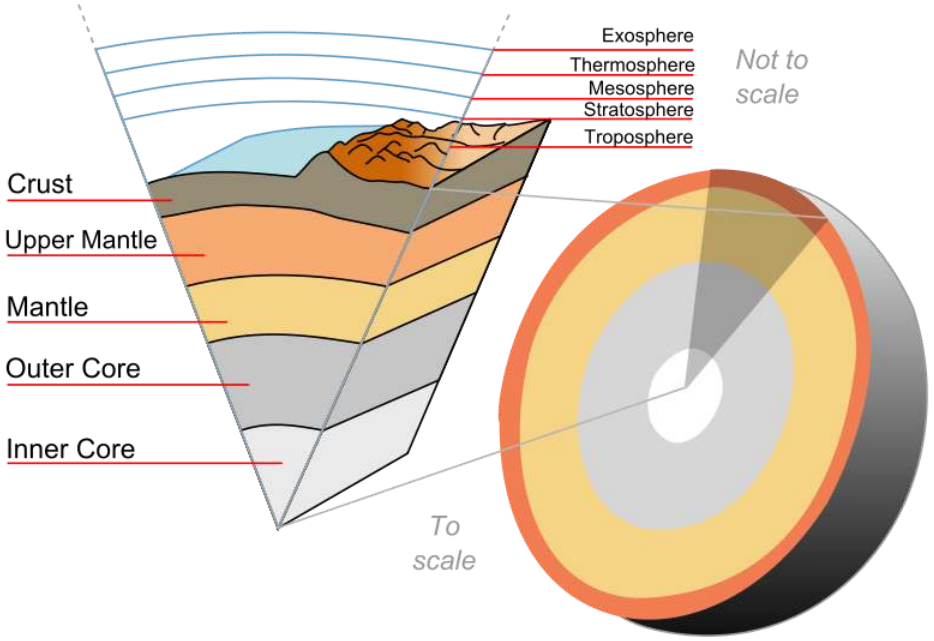
5.3: The Composition and Structure of Earth

Core, mantle, and crust are divisions based on composition. The crust makes up less than 1 percent of Earth by mass, consisting of oceanic crust and continental crust is often more felsic rock. The mantle is hot and represents about 68 percent of Earth's mass. Finally, the core is mostly iron metal. The core makes up about 31% of the Earth. Lithosphere and asthenosphere are divisions based on mechanical properties. The **lithosphere** is composed of both the crust and the portion of the upper mantle that behaves as a brittle, rigid solid. The **asthenosphere** is partially molten upper mantle material that behaves plastically and can flow. This animation by Earthquide shows the layers by composition and by mechanical properties.



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. There are two very different types of crust, each with its own distinctive physical and chemical properties.**Oceanic crust** is composed of magma that erupts on the seafloor to create basalt lava flows or cools deeper down to create the intrusive igneous rock gabbro. 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 igneous rocks of the oceanic crust. 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.The lithosphere is the outermost mechanical layer, which behaves as a brittle, rigid solid. The lithosphere is about 100 kilometers thick. 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. Peridotite is rarely found at Earth's surface.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: conduction and convection. Conduction is defined as the heat transfer that occurs 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. Convection is the process of a material that can move and flow may develop convection currents.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.

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Core

At the planet's center lies a dense metallic core. Scientists know that the core is metal for a few reasons. 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 percent iron metal with nickel metal making up much of the remaining 15 percent. Also, metallic meteorites are thought to be representative of the core.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 S-waves stop at the inner core. 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.

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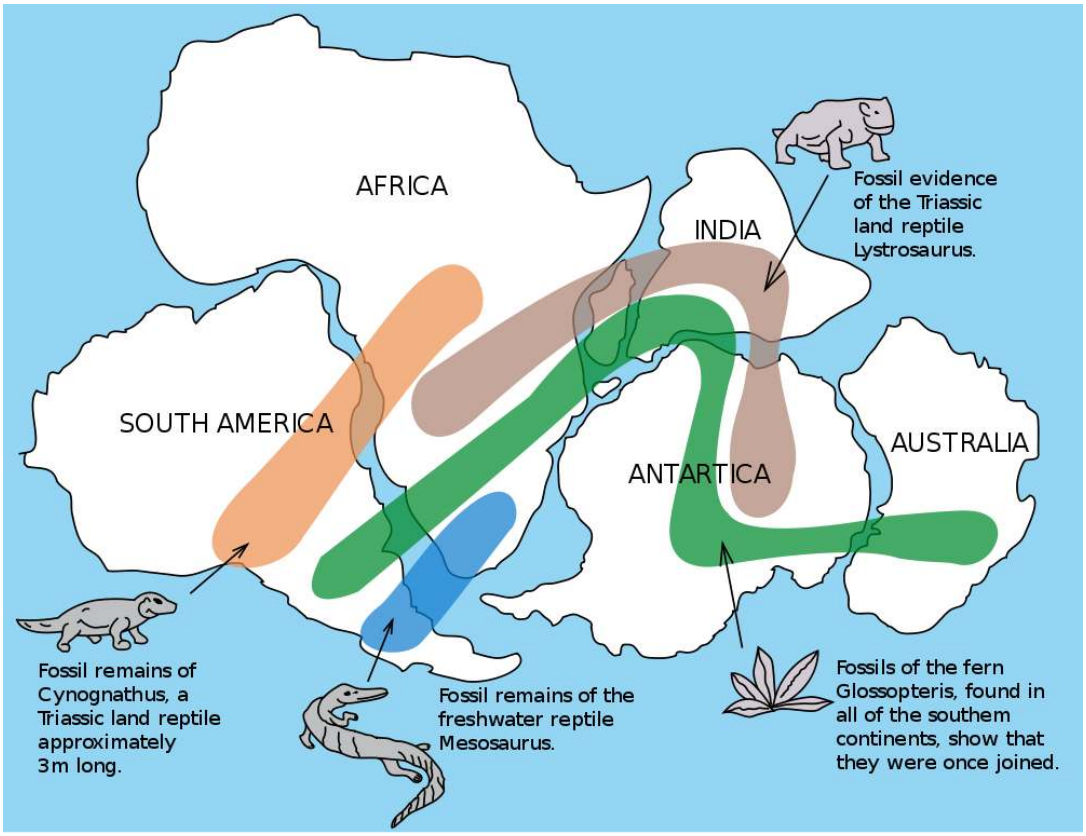
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5.4: Theory of Continental Drift

The continental drift hypothesis was developed in the early part of the 20th century, mostly by Alfred Wegener. Wegener said that continents move around on Earth's surface and that they were once joined together as a single supercontinent. While Wegener was alive, scientists did not believe that the continents could move.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 and many can be pieced together like a puzzle. The easiest link is between the eastern Americas and western Africa and Europe, but the rest can fit together too.

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. For one, 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. Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.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. 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. For example, the fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind. The reptile Mesosaurus could only swim in fresh water. was a swimming reptile but could only swim in fresh water. *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the equator. This would indicate that the glaciers either formed in the middle of

the ocean and/or covered most of the Earth. Today glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later had drifted to new locations on the continents.Although Wegener's evidence was sound, most geologists at the time rejected his hypothesis of continental drift. Scientists argued that there was no way to explain how solid continents could plow through solid oceanic crust. Wegener's idea was nearly forgotten until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents.

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Puzzling new evidence came in the 1950s from studies on the Earth's magnetic history. Scientists used magnetometers, devices capable of measuring the magnetic field intensity, to look at the magnetic properties of rocks in many locations. 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 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.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. 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, or 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. For example, 400-million-year-old magnetite in Europe pointed to a different north magnetic pole than the same-aged magnetite in North America. Around 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 and behold, it worked. There has only been one magnetic north pole and the continents have drifted. They named the phenomenon of the magnetic pole that seemed to move but actually did not apparent polar wander. This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.

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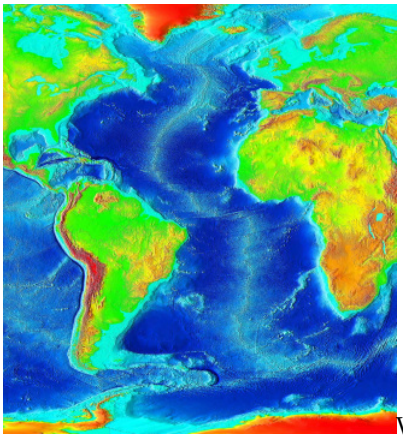
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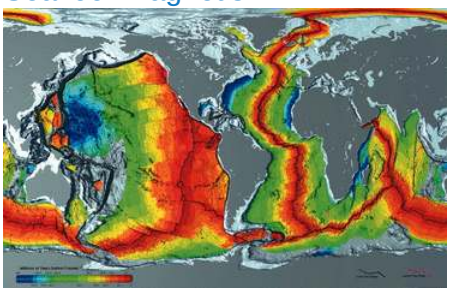
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5.5: Sea Floor Spreading

Seafloor Bathymetry

 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.During World War II, battleships and submarines carried echo sounders to locate enemy submarines. 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. This animation shows how sound waves are used to create pictures of the seafloor and ocean crust.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. What was discovered was a large chain of mountains along the deep seafloor, called mid-ocean ridges. Scientists also discovered deep sea trenches along the edges of continents or in the sea near chains of active volcanoes. Finally, large, flat areas called abyssal plains we found. When they first observed these bathymetric maps, scientists wondered what had formed these features.

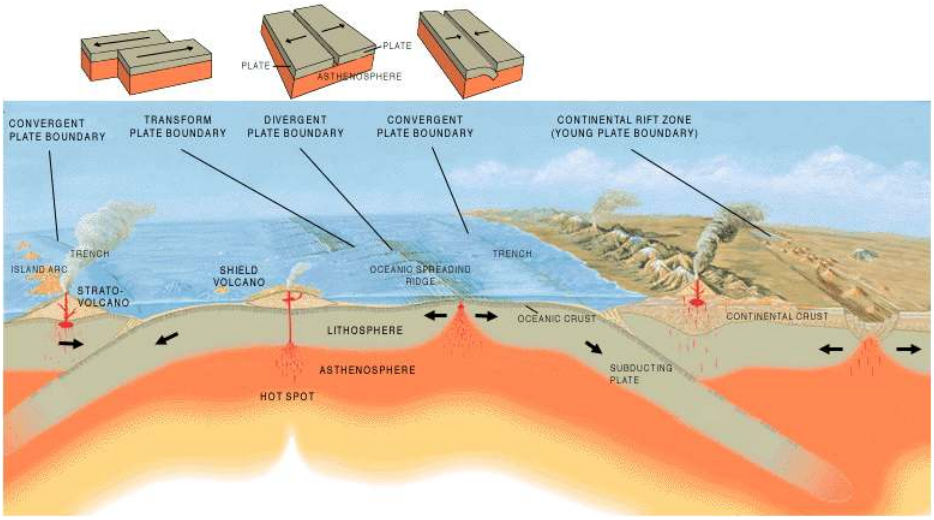
Seafloor Magnetism



Sometimes, for reasons unknown, the magnetic poles switch positions. North becomes south and south becomes north. During normal polarity, the north and south poles are aligned as they are now. With reversed polarity, the 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. These stripes also forms a mirror image of itself on either side of the mid-ocean ridges. But the stripes end abruptly at the edges of continents, sometimes at a deep sea trench. 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
Distance from axis	Becomes older	Becomes thicker	Becomes thicker	Becomes cooler

A map of sediment thickness is found here. The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old. 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.



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. 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 and as more lava erupts, it pushes the seafloor horizontally away from ridge axis.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. Scientists now know that 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.

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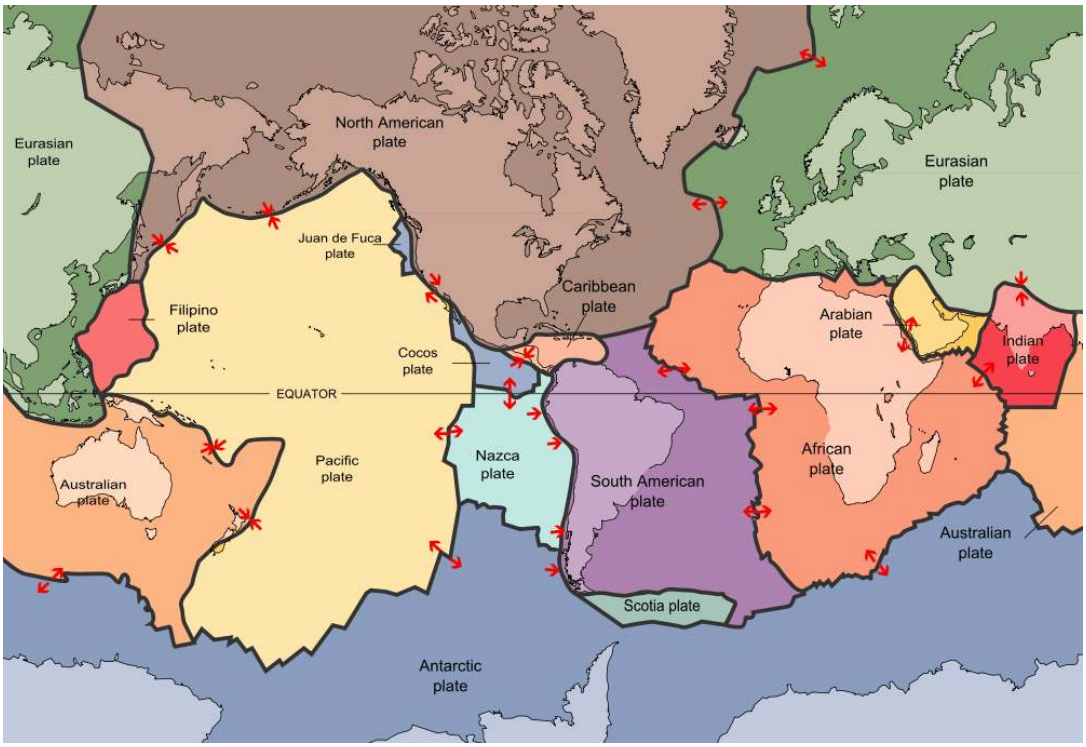
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5.6: Earth's Tectonic Plates

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. Scientific data and observation now allows us to merge the ideas of continental drift and seafloor spreading into the theory of plate tectonics.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 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 these tectonic plates. Mid-ocean ridges, trenches, and large faults mark the edges of these plates along with where earthquakes occur.



The lithosphere is divided into a dozen major and several minor plates. 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. Movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading? Picture two convection cells side-by-side in the mantle. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor. 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. The material sinks to the core and moves horizontally. The material heats up and reaches the zone where it rises again.





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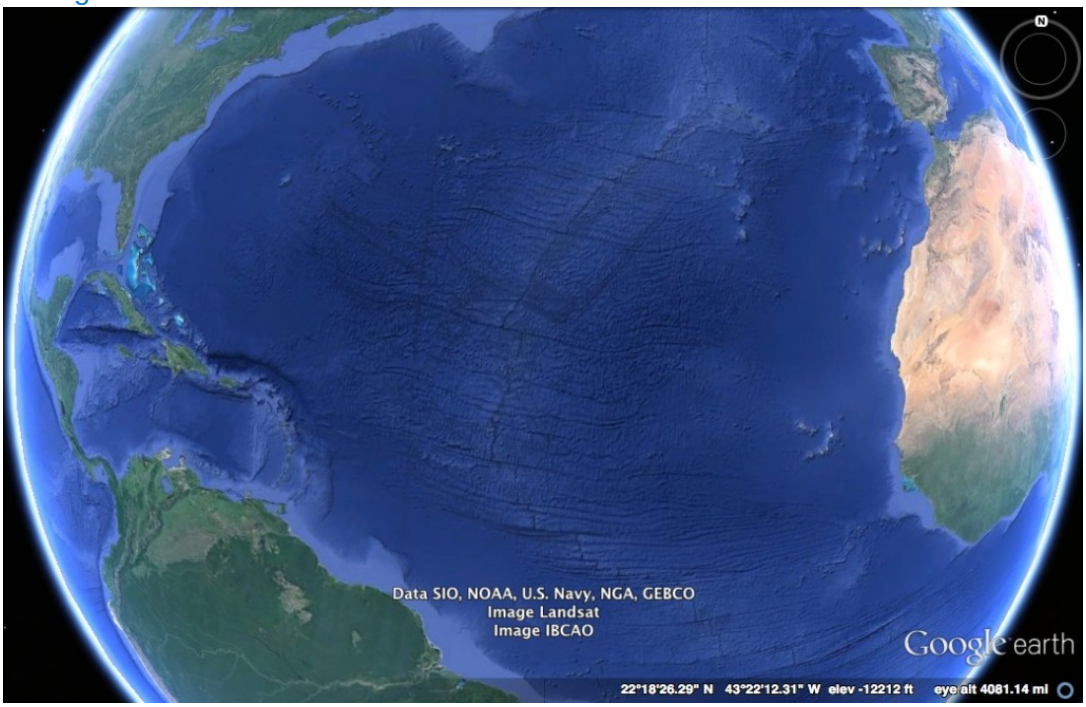
5.7: Tectonic Plate Boundaries

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

The 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. Here is an animation from the United States Geologic Survey (USGS) of divergent plate boundary at mid-ocean ridge and another animation by IRIS.As divergence occurs, shallow earthquakes can occur along with volcanoes along the rift areas. When the process begins, a valley will develop such as the Great Rift Valley in Africa. Over time that valley can fill up with water creating **linear lakes**. If divergence continues, a sea can form like the Red Sea and finally an ocean like the Atlantic Ocean. Check out the eastern half of Africa and notice the lakes that look linear. Eastern Africa is tearing apart from these linear lakes, to the Great Rift Valley, and up to the Red Sea. The ultimate divergent boundary is the Atlantic Ocean, which began when Pangea broke apart.

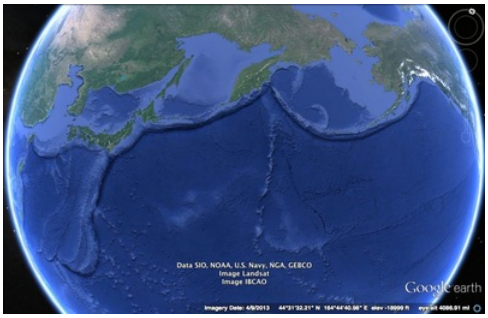

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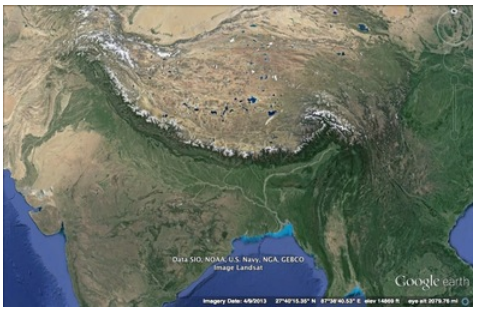
Convergent Plate Boundaries



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 the creation of magma and earthquakes.**Ocean-to-continent convergence** occurs when oceanic crust converges with continental crust, forcing the denser oceanic plate to plunge beneath the continental plate. This process called **subduction**, occurs along oceanic trenches called **subduction zones** where lots of intense earthquakes and volcanic eruptions can occur. The denser, subducting plate begins to heat up under extreme pressure near the mantle and melts to create causes melting in the volcanoes. These coastal volcanic mountains are found in a line above the subducting plate. The volcanoes are known as a continental arc. The movement of crust and magma causes earthquakes. Click here for a map of earthquake epicenters at subduction zones.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. The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.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.

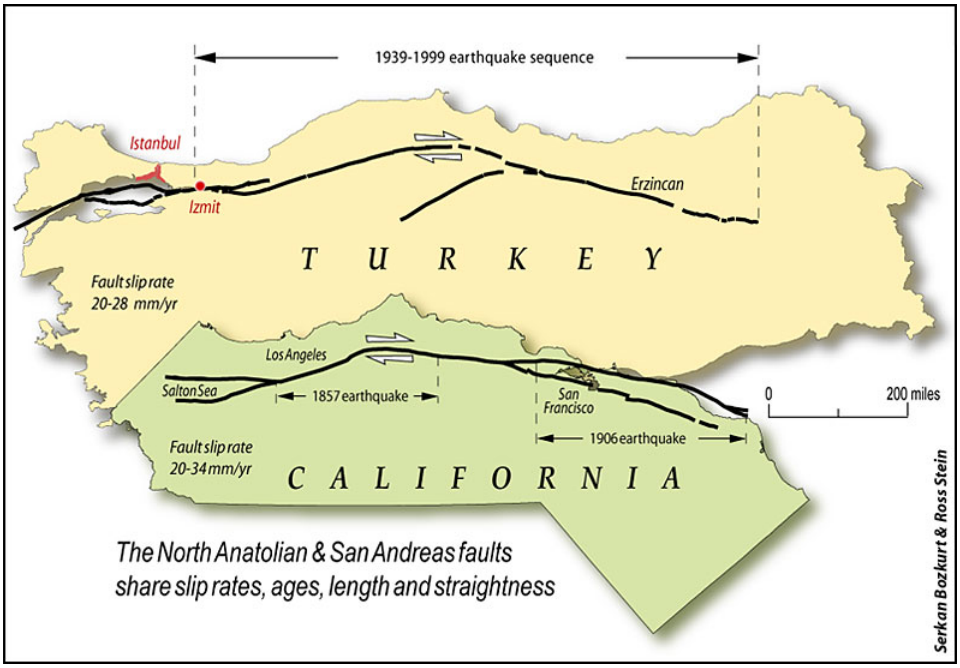


An **oceanic-to-oceanic plate boundary** occurs when two oceanic plates converge, causing the older, denser plate will subduct into the mantle. An ocean trench marks the location where the plate is pushed down into the mantle. The line of volcanoes that grows on the upper oceanic plate is an island arc.The Ring of Fire is a ring around the Pacific Ocean of subduction zones, which most are oceanic-to-oceanic convergence. Here is an animation of an ocean continent plate boundary. Along these subduction zones, volcanic islands (also called volcanic arcs) form. Examples of these regions include Japan, Indonesia, and the Aleutian Islands.

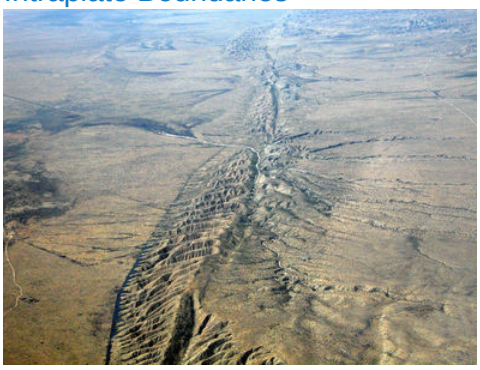


When two continental plates converge, instead of subduction, the two similar tectonic plates will buckle up to create large mountain ranges like a massive car pile-up. This is called **continental-to-continental convergence**, and geologically creates intense folding and faulting rather than volcanic activity.Examples of mountain ranges created by this process are the Himalayan mountains as India is colliding with Asia, the Alps in Europe, and the Appalacian mountains in the United States as the North American plate collided with the African plate when Pangea was forming. The Kashmir India earthquake of 2005 that killed over 80,000 people occurred because of this process. And most recently, the 2008 earthquake in China which killed nearly 85,000 people before the Summer Olympics was because of this tectonic force. 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 occur when two tectonic plates slide (or grind) past parallel to each other. The most famous **transform boundary** is the **San Andreas Fault** where the Pacific plate that Los Angeles and Hawaii are on is grinding past the North American plate that San Francisco and the rest of the United States is on at the rate of 3 inches a year. Recently, geologists have stated that San Francisco should expect another disastrous earthquake in the next 30 years. Another important transform boundary is the **North Anatolian Fault** in Turkey. This powerful fault last ruptured in 1999 in Izmit, Turkey which killed 17,000 people in 48 seconds.



Intraplate Boundaries



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. 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. Geologists use some hotspot chains to tell the direction and the speed a plate is moving.Hotspot magmas rarely penetrate through thick continental crust. One exception is the Yellowstone hotspot.

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5.8: 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, where are the mountain ranges located? Using what you have learned about plate tectonics, try to answer the following questions:

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.

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.

This animation shows the movement of continents over the past 600 million years beginning with the breakup of Rodinia.

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5.9: 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.



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CHAPTER OVERVIEW

6: Tectonic Forces

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6.2: Causes and Types of Tectonic Stress
6.3: Geologic Structures
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6.1: Introduction to Tectonic Forces

Learning Outcomes

This chapter has several goals and objectives:

- Describe the causes of tectonic stress and how they influence earthquakes and volcanoes.
- Understand where earthquakes and volcanoes are located around the world and why.
- Explain geologic structures that lead to folding and faulting of the physical landscape.
- Determine how the composition of magma determines the explosiveness of the volcanic eruption.
- Describe the various types of fault lines and volcanoes and the landforms they form.

Essential Questions

- Could humans live in places along the Wasatch Front without the Wasatch fault and the earthquakes it causes?
- How does plate tectonics explain where and why earthquakes and volcanoes occur where they do?
- What role do earthquakes and volcanoes have on civilization? What benefits do they bring us?
- How could understanding Earth's tectonic forces help save lives?
- What beneficial roles do tectonic forces have ecologically and for humanity?

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6.2: Causes and Types of Tectonic Stress



Enormous slabs of lithosphere move unevenly over the planet's spherical surface, resulting in earthquakes. This chapter deals with 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 stress. Stress is the force applied to an object. In geosciences, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform called **confining stress**.
- Compression squeezes rocks together, causing rocks to fold or fracture. Compression is the most common stress at convergent plate boundaries.
- 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. **Shear** stress is the most common stress at transform plate boundaries.

When stress causes a material to change shape, it has undergone strain or deformation. Deformed rocks are common in geologically active areas. A rock's response to stress depends on the rock type, the surrounding temperature, and pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress. The rocks then have three possible responses to increasing stress: elastic deformation, plastic deformation, or fracturing. **Elastic deformation** occurs when the rock returns to its original shape when the stress is removed. When rocks under stress do not return to its original shape when the stress is removed, it is called **plastic deformation**. Finally, when a rock under stress breaks, it's called a **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.

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6.3: Geologic Structures

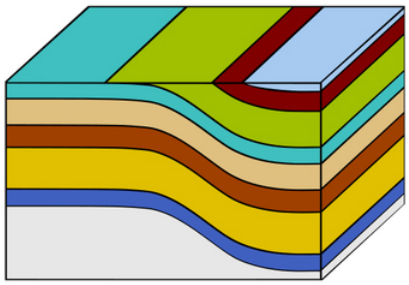
Sedimentary rocks are important for deciphering the geologic history of a region because they follow certain rules. First, sedimentary rocks are formed with the oldest layers on the bottom and the youngest on top. Second, sediments are deposited horizontally, so sedimentary rock layers are originally horizontal, as are some volcanic rocks, such as ash falls. Finally, sedimentary rock layers that are not horizontal are deformed in some manner. Often times looking like they are tiling into the earth.

You can trace the deformation a rock has experienced by seeing how it differs from its original horizontal, oldest-on-bottom position. This deformation produces geologic structures such as folds, joints, and faults that are caused by stresses.

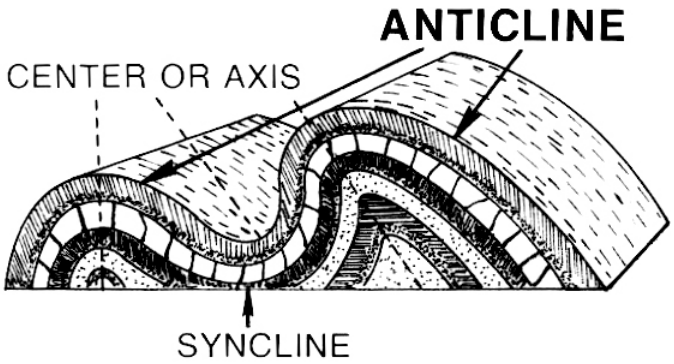
Folds



Rocks deforming plastically under compressive stresses crumple into folds. They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture. There are three major types of rock folding: monoclines, synclines, and anticlines. A **monocline** is a simple bend in the rock layers so that they are no longer horizontal. **Anticlines** are folded rocks that arch upward and dip away from the center of the fold. The oldest rocks are at the center of an anticline and the youngest are draped over them. When rocks arch upward to form a circular structure, that structure is called an **adome**. A **syncline** is a fold that bends downward, causing the youngest rocks are to be at the center and the oldest are on the outside. When rocks bend downward in a circular structure, that structure is called **abasin**. If the rocks are exposed at the surface, where are the oldest rocks located?



Monocline Diagram



Faults



A rock under enough stress will eventually fracture. If there is no movement on either side of a fracture, the fracture is called a **joint**. But if the blocks of rock on one or both sides of a fracture move, the fracture is called a

fault. Sudden motions along faults cause rocks to break and move suddenly, releasing the stored up stress energy to create an earthquake.A **slip** is the distance rocks move along a fault and 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. There are two types of **dip-slip faults**. In **normal faults**, the hanging wall drops down relative to the footwall. Normal faults can be huge and are often times responsible for uplifting mountain ranges in regions experiencing tensional stress.With **reverse faults**, the footwall drops down relative to the hanging wall. A type of reverse fault is a thrust fault, in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults.A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical and result from shear stresses. California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault.

Stress and Mountain Building

It is the shear power and strength of two or more converging continental plates smash upwards that create mountain ranges. Stresses from this uplift cause folds, reverse faults, and thrust faults, which allow the crust to rise upwards. Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges.

When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along normal faults. The result is alternating mountains and valleys, known as a basin-and-range.

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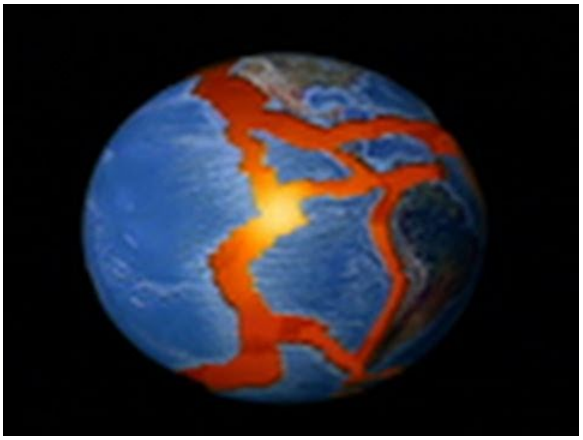
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6.4: Causes of Earthquakes

An **earthquake** is sudden ground movement caused by the sudden release of energy stored in rocks, called the **elastic rebound theory**. 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!

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus** (sometimes called the **hypocenter**). 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.



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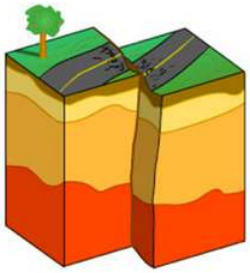
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6.5: Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of tectonic 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. Called the **Ring of Fire**, this is also the location of most volcanoes around the planet. About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate creating the largest mountain ranges in the world. The remaining 5% are scattered around other plate boundaries or are **intraplate earthquakes**.

Transform Plate Boundaries

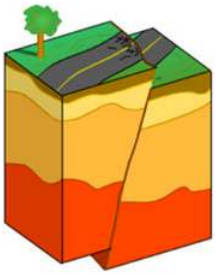

Strike-slip fault

Recall that transform plate boundaries occur where two tectonic plates are grinding parallel to each other rather than colliding or subducting. Deadly earthquakes occur at transform plate boundaries, creating **strike-slip faults**, because they tend to have shallow focuses where the rupture occurs. 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.During the 1989 World Series, a magnitude 7.1 earthquake struck Loma Prieta, near Santa Cruz, California, killing 63 people, injuring 3,756, and cost $6 billion. A few years later in Northridge, California, a magnitude 6.7 earthquake killed 72 people, injured 12,000 people, and caused $12.5 billion in damage. This earthquake occurred on an unknown fault, because it was a blind thrust fault near Los Angeles, California. Although California is prone to many natural hazards, including volcanic eruptions at Mt. Shasta or Mt. Lassen, and landslides on coastal cliffs, the natural hazard the state is linked with is earthquakes. New Zealand also has strike-slip earthquakes, about 20,000 a year, but 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.



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Convergent Plate Boundaries



Reverse fault

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle, creating **reverse** and **thrust faults**. 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 produces 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. 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. Check out this map of aftershocks. Recently, the New York Times created an interactive website of the Japan earthquake and tsunami.

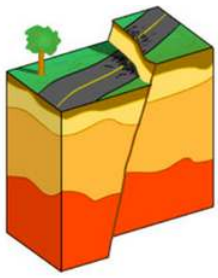
The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. Subduction of the Juan de Fuca plate beneath North America produces active volcanoes, but large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9.0. You can download this movie on the elastic rebound theory as applied to subduction zones.

Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge. The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.In Understanding Earthquakes: From Research to Resilience, scientists try to understand the mechanisms that cause earthquakes and tsunamis and the ways that society can deal with them.



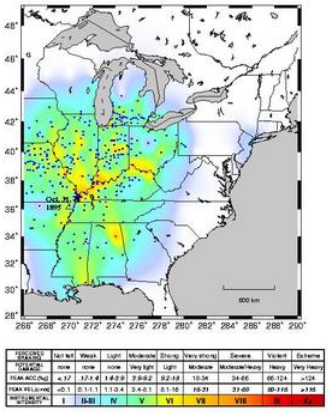
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Divergent Plate Boundaries



Normal fault

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. A classic example of **normal faulting** along divergent boundaries is the Wasatch Front in Utah and the entire Basin and Range through Nevada.



Intraplate Boundaries

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. A similar earthquake today would undoubtedly kill many people and cause a great deal of property damage.

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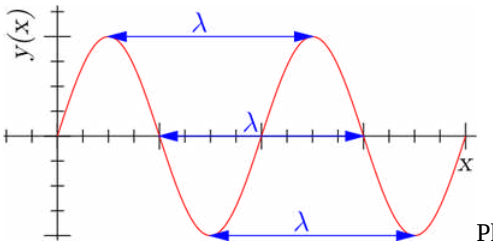
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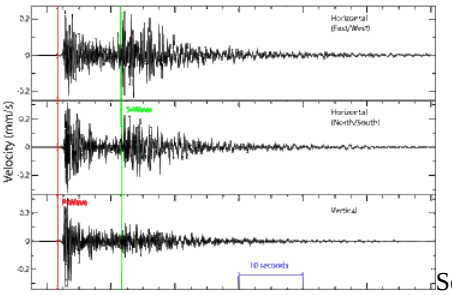
6.6: Seismic Waves



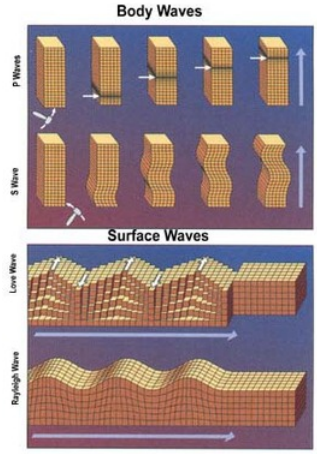
Physics shows us that energy is always transmitted in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The distance between waves from crest to crest (or trough to trough) is its **wavelength**.

The energy from earthquakes travels in seismic waves, which were 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. S-waves only move through solids. **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. In an earthquake, body waves produce sharp jolts, while rolling motions of surface waves do most of the damage in an earthquake.

Measuring Magnitude



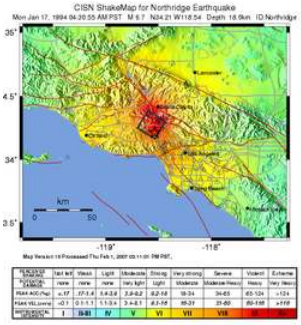
Seismograms record seismic waves. Over the past century, scientists have developed several ways of measuring earthquake intensity. The currently accepted method is the moment magnitude scale, which measures the total amount of energy released by the earthquake. At this time, seismologists have not found a reliable method for predicting earthquakes.A **seismograph** produces a graph-like representation of the seismic waves it receives and records them onto a **seismogram**. Seismograms contain information that can be used to determine how strong an earthquake was, how long it lasted, and how far away it was. Modern **seismometers** record ground motions using electronic motion detectors. The data are then kept digitally on a computer.



If a seismogram records P-waves and surface waves but not S-waves, the seismograph was on the other side of the Earth from the earthquake because those waves cannot travel through the liquid core of the earth. The amplitude of the waves can be used to determine the magnitude of the earthquake, which will be discussed in a later section.In order to locate an earthquake epicenter, scientists must 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.

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. Although useful for decades, this technique has been replaced by digital calculations. Seismic stations record ten earthquakes in this animation.

Measuring Earthquakes



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 The oldest of the scales is called the **Mercalli Intensity scale**. Earthquakes are described in terms of what nearby residents felt and the damage that was done to nearby structures. This scale is more qualitative in information because it's based on visual damage and not the actual energy released by the earthquake. Today these maps are still important and various seismological stations will create **shake maps** of the surface damage.With the invention of the seismograph station, the **Richter magnitude scale** was created. 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. Today, the moment magnitude scale has replaced the Richter scale. The **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 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.

Each scale has their benefits. As mentioned above, the Mercalli Intensity scale is based on how much damage someone would see. This is relative though because some places have strong building codes, and the rock material underneath will impact ground shaking without changing the energy released at the focus. 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. Today, most seismologists now use the moment magnitude scale.

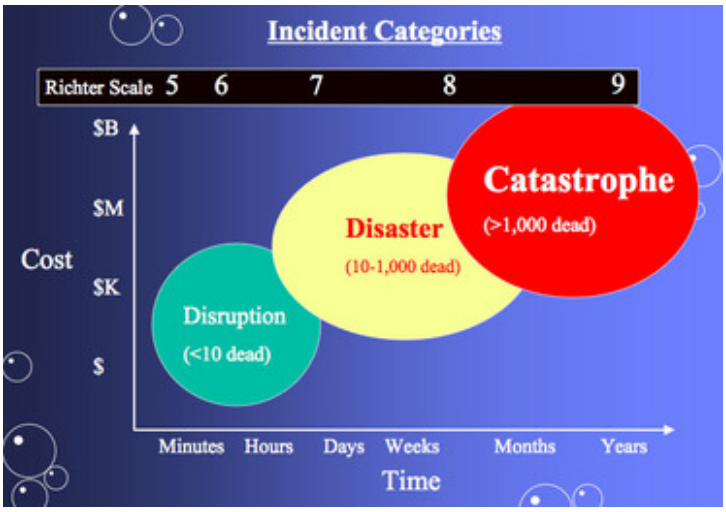
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6.7: Annual Earthquakes

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 table below). All but the Great Indian Ocean Earthquake of 2004 occurred somewhere around the Pacific Ocean basin.



Location	Year	Magnitude
Valdivia, Chile	1960	9.5
Prince Williams Sound, Alaska	1964	9.2
Great Indian Ocean Earthquake	2004	9.1
Kamchatka, Alaska	1952	9.0
Tohoku, Japan	2011	9.0

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6.8: Earthquake Prediction

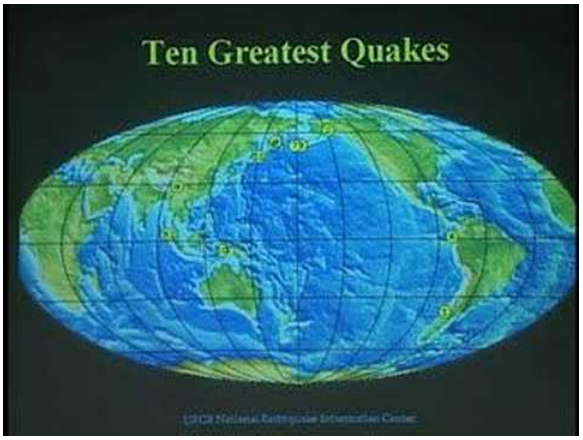
Scientists are a long way from being able to predict earthquakes. A good prediction must be accurate as to where an earthquake will occur, when it will occur, and at what magnitude it will be so that people can evacuate. An unnecessary evacuation is expensive and causes people not to believe authorities the next time an evacuation is ordered.

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. Earthquake-prone communities should always be prepared for an earthquake. These communities can implement building codes to make structures earthquake safe.

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. But so far scientists cannot predict when quakes will occur even to within a few years. 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.

The geology of California underlies the state's wealth of natural resources as well as its natural hazards. This video explores the enormous diversity of California's geology:



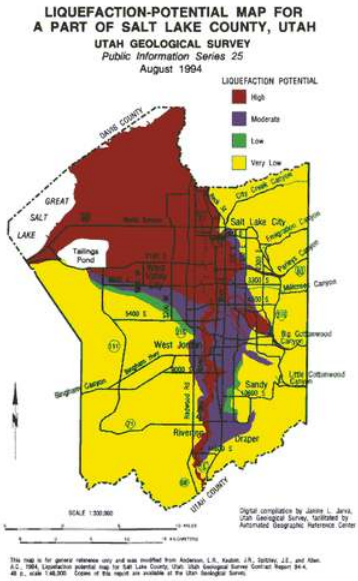
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Damage from Earthquakes



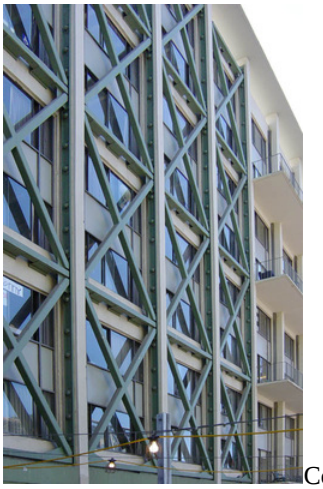
Earthquakes are natural disasters that cause enormous amounts of damage, second only to hurricanes. Earthquake-safe construction techniques, securing heavy objects, and preparing an emergency kit are among the precautions people can take to minimize damage.Earthquakes kill people and cause property damage. However, the ground shaking

almost never kills people, and the ground does not swallow someone up. 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.



There are a variety of ways earthquakes become deadly. Probably the greatest influence is **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. Oddly enough, size doesn't matter. Only about 2,000 people died in the 1960 Great Chilean earthquake, the largest earthquake ever recorded. The Indian Ocean earthquake of 2004 was one of the largest ever, but most of the 230,000 fatalities were caused by the tsunami, not the earthquake itself.Ground type is an important factor in earthquake damage. Solid bedrock vibrates less than soft sediments so there is less damage on bedrock. Sediments that are saturated with water under go **liquefaction** and become like quicksand. This will have dangerous implications for Salt Lake City and the Wasatch Front in Utah. Much of the Wasatch Front is loose soil, left over from the remnants of Lake Bonneville. Along the middle of the two mountain ranges, between the Wasatch Mountains and the Oquirrh Mountains, is the Jordan River which flows from Utah Lake northward to the Great Salt Lake. Near the river and surrounding floodplain, the water table is near the surface. When the ground shakes, the water near the surface shifts upward and over-saturates the soil making it extremely unstable. Earthquake effects on buildings are seen in this animation.

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.The key to earthquake safety are the structures we live in. It is often said that earthquakes don't kill people, it's the buildings that kill people. But the reason why not all buildings are not built

to withstand earthquakes is cost. 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. But this is the crucial factor in earthquake safety.

Let's compare Salt Lake City, UT and Port-au-Prince, Haiti. When Salt Lake City has its expected 7.0 magnitude earthquake, worst case scenario is that 3,000–4,000 will die. But on January 12, 2010, Haiti experienced a 7.0 magnitude earthquake that killed nearly 300,000 people. The difference—building codes.

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. Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams are used to hold down sway. Large buildings can also be placed on rollers so that they move with the ground. Earthquake prone areas should have building codes that require the use of correct building materials. Houses should also be built with wood and steel rather than brick and stone because they need to be able to bend and sway. New buildings should be built on layers of steel and rubber to absorb the shock of the waves. Connections, such as where the walls meet the foundation, must be made strong to withstand the shaking. In a multi-story building, the first story must be well supported.

To make older buildings more earthquake safe, retrofitting with steel or wood can reinforce a building's structure and its connections. Elevated freeways and bridges can also be retrofitted so that they do not collapse.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. 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.

Human-Induced Earthquakes

Can humans create earthquakes? Maybe not intentionally, but the answer is yes—and here's why. If a water reservoir is built on top of an active fault line, the water may actually lubricate the fault and weaken the stress built up within it. This may either create a series of small earthquakes or potentially create a large earthquake. Also the shear weight of the reservoir's water can weaken the bedrock causing it to fracture. Then the obvious concern is if the dam fails. Earthquakes can also be generated if humans inject other fluids into a fault such as sewage or chemical waste. Finally, nuclear explosions can trigger earthquakes. In fact, one way to determine if a nation has tested a nuclear bomb is by monitoring the earthquakes and energy released by the explosion.

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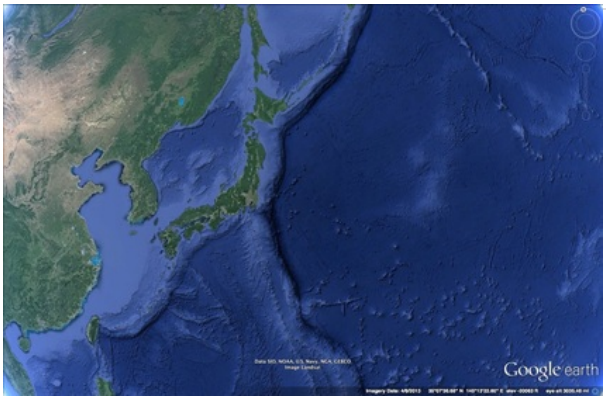
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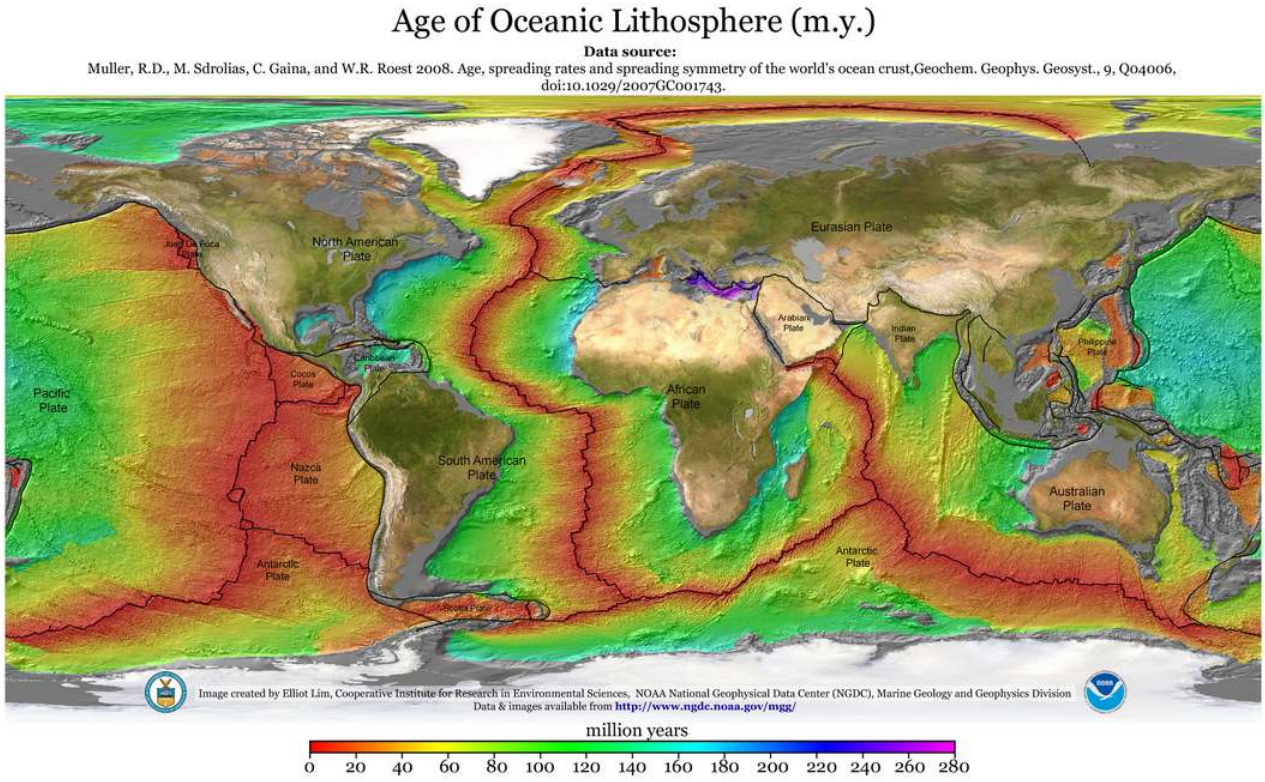
6.9: Where Volcanoes Are Located



Google Earth image of Japan and the oceanic-to-oceanic subduction zones.

Volcanos along Convergent Plate Boundaries

Volcanoes are a vibrant manifestation of plate tectonics processes. Volcanoes are common along convergent and divergent plate boundaries, but are also found within lithospheric plates away from plate boundaries. Wherever mantle is able to melt, volcanoes may be the result.Volcanoes erupt because mantle rock melts. The first stage in creating a volcano is when mantle rock begins to melt because of extremely high temperatures, lithospheric pressure lowers, or water is added.Along subducting plate boundaries, the crust heats up as it sinks into the mantle. Also, ocean 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 all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates.



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 and is why the region is called the Ring of Fire. A description of the Pacific Ring of Fire along western North America is below:

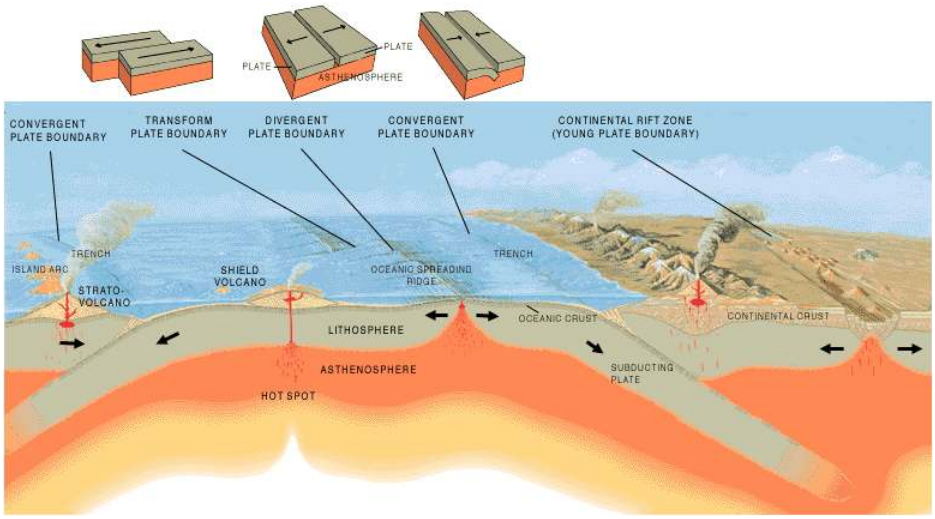
- Subduction at the Middle American Trench creates volcanoes in Central America.

- The San Andreas Fault is a transform boundary.
- Subduction of the Juan de Fuca plate beneath the North American plate creates the Cascade volcanoes like Mount St. Helens, Mount Rainer, Mount Hood and more.
- Subduction of the Pacific plate beneath the North American plate in the north creates the long chain of the Aleutian Islands volcanoes near Alaska.

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.

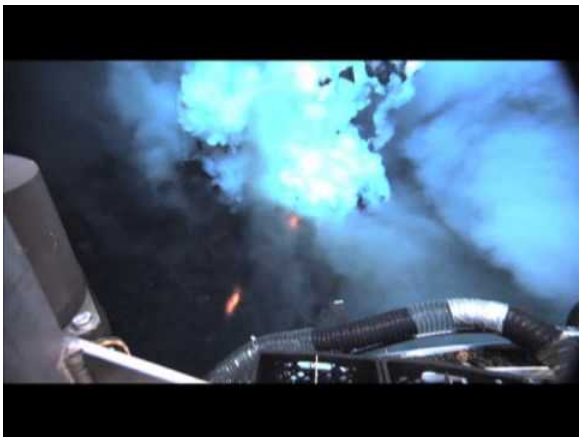


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Volcanoes along Divergent Plate Boundaries

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 allowing lava to erupt through long cracks or fissures. Scientists have captured incredible footage of “Deepest Ocean Eruption Ever Filmed” and other undersea volcanoes.



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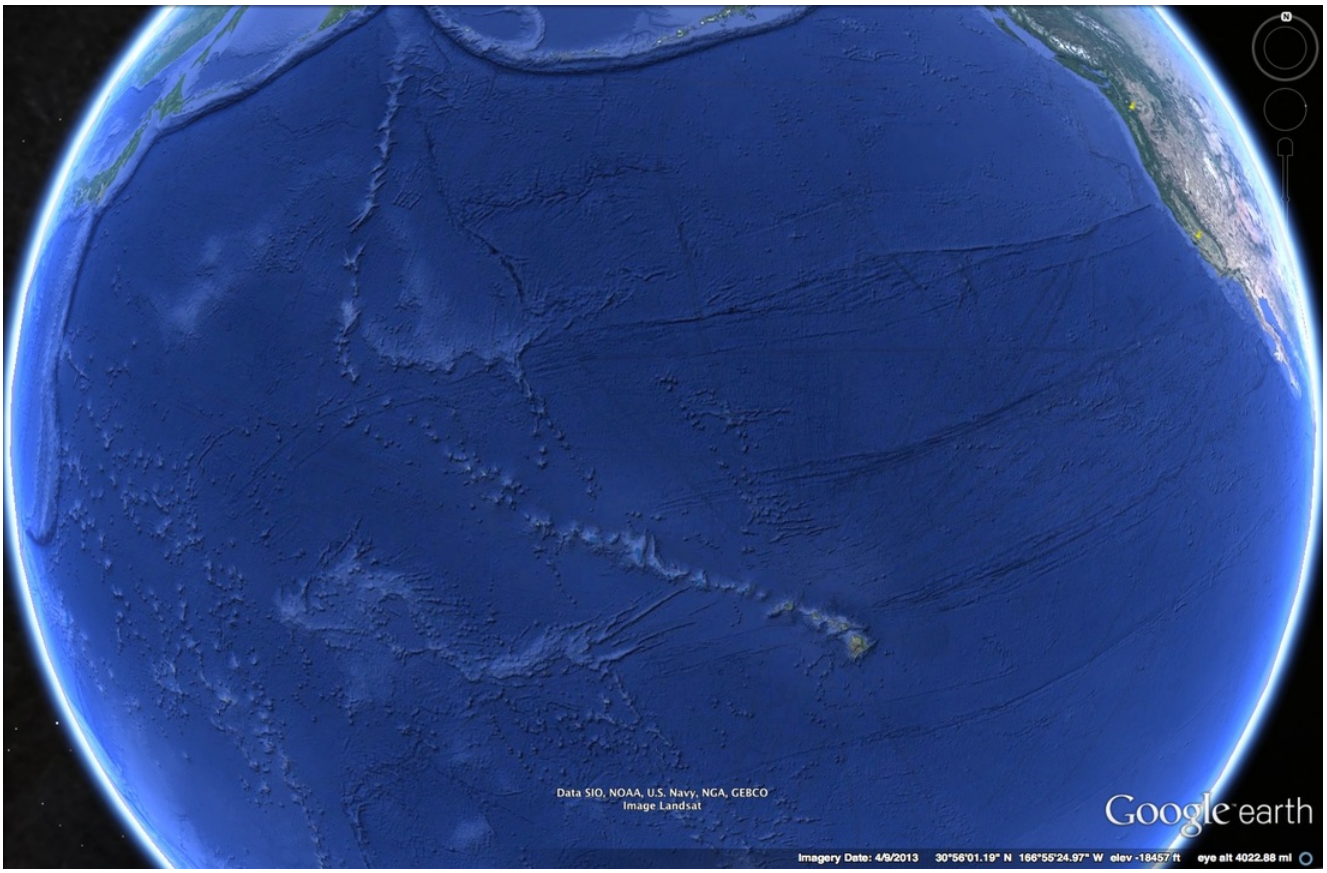
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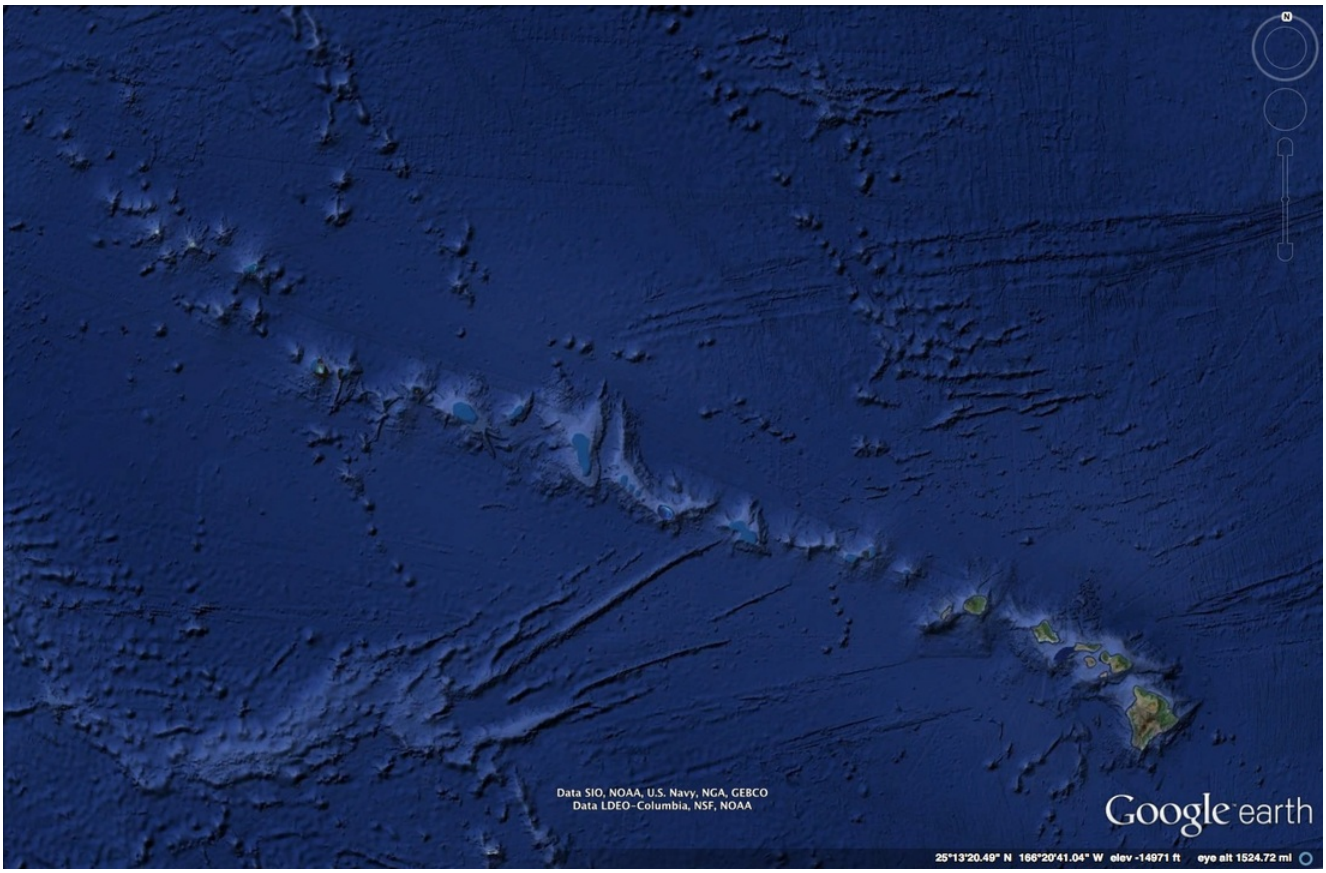
 Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands. Eruptions are found at divergent plate boundaries as continents break apart such as the East African Rift between the African and Arabian plates and the Great Basin and Range in the western United States. But those volcanoes of the ladder are now extinct.

Check out some dramatic time-lapsed photography of a volcanic eruption on Iceland. Iceland is a hot spot volcano and the surface manifestation of the mid-Atlantic ridge.

Volcanic Hotspots

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes are found in the middle of a tectonic plate. 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**.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. The video on the right is of the hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea. There are several key indicators to determine a hot spot 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.





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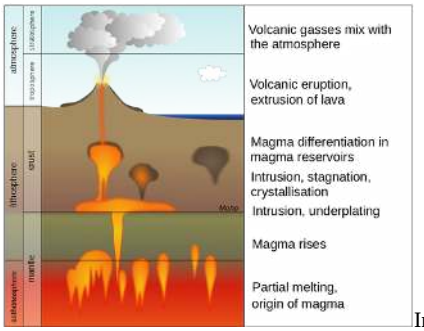
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6.10: Magma Composition



In 1980, Mount St. Helens blew up in the costliest and deadliest volcanic eruption in United States history. The eruption killed 57 people, destroyed 250 homes and swept away 47 bridges. Mount St. Helens today still has minor earthquakes and eruptions, and now has a horseshoe-shaped crater with a lava dome inside. The dome is formed of viscous lava that oozes into place.It should first be noted that **magma** is molten material inside the earth, whereas **lava** is molten material on the surface of the earth. The reason for the distinction is because lava can cool quickly from the air and solidify into rock rapidly, whereas magma may never reach the earth's surface. Volcanoes do not always erupt in the same way. Each volcanic **eruption** is unique, differing in size, style, and composition of erupted material. One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

Different minerals within a rocks melt at different temperatures and 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 of a volcano.

The words that describe composition of igneous rocks also describe magma composition. Mafic magmas are low in silica and contain more dark, magnesium and iron rich mafic minerals, such as olivine and pyroxene. Felsic magmas are higher in silica and contain lighter colored minerals such as quartz and orthoclase feldspar. The higher the amount of silica in the magma, the higher is its **viscosity**. Viscosity is a liquid's resistance to flow.

Viscosity determines what the magma will do. Mafic magma is not viscous and will flow easily to the surface. Felsic magma is viscous and does not flow easily. Most felsic magma will stay deeper in the crust and will cool to form igneous intrusive rocks such as granite and granodiorite. If felsic magma rises into a magma chamber, it may be too viscous to move and so it gets stuck. Dissolved gases become trapped by thick magma and the magma chamber begins to build pressure.

Explosive Eruptions



The type of magma in the chamber determines the type of volcanic eruption. 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 because of hot, gas-rich magma churning within its 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 creating volcanic ash called **tephra**. It should be noted that when looked under a microscope, the volcanic "ash" is actual microscopic shards of glass. That is why it is so dangerous to inhale the air following an eruption.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 1,000oC (1,800 degrees F).

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.



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Volcanic gases can form poisonous and invisible clouds in the atmosphere that could 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.



ugh 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 and reaches the surface through volcanic vents. Download this video of a lava stream within the vent of a Hawaiian volcano using a thermal camera.



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Low-viscosity lava flows down mountainsides. Differences in composition and where the lavas erupt result in lava types like a ropy form **pahoehoe** and a chunky form called **aa**. 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, road, or infrastructure.



Pahoehoe lava



Aa lava
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6.11: 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. If the volcano is considered **active**, it is currently erupting or shows signs of erupting soon. A **dormant** volcano means there is no current activity, but it has erupted recently. Finally, an **extinct** volcano means their is no activity and will probably not erupt again. 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. 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 rockfalls 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 (H_2O) can be measured at the site or, in some cases, from a distance using satellites. The amounts of gases and their ratios are calculated to help predict eruptions.

Remote Monitoring

Some gases can be monitored using satellite technology. Satellites also monitor temperature readings and deformation. As technology improves, scientists are better able to detect changes in a volcano accurately and safely.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.

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6.12: Types of Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber and they can differ in height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground. As you might expect, the shape of a volcano is related to the composition of its magma.

Composite Volcanoes



Composite volcanoes are some of the most dangerous volcanoes on the planet. They tend to occur along oceanic-to-oceanic or oceanic-to-continental boundaries because of subduction zones. They tend to be made of felsic to intermediate rock and the viscosity of the lava means that eruptions tend to be explosive. 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 and are sometimes called stratovolcanoes or andesite volcanoes. The result is the classic cone shape of composite volcanoes. Examples of composite volcanoes include Mount St. Helens, Mount Rainer, Mount Shasta, Mount Hood, and Mount Pinatubo.

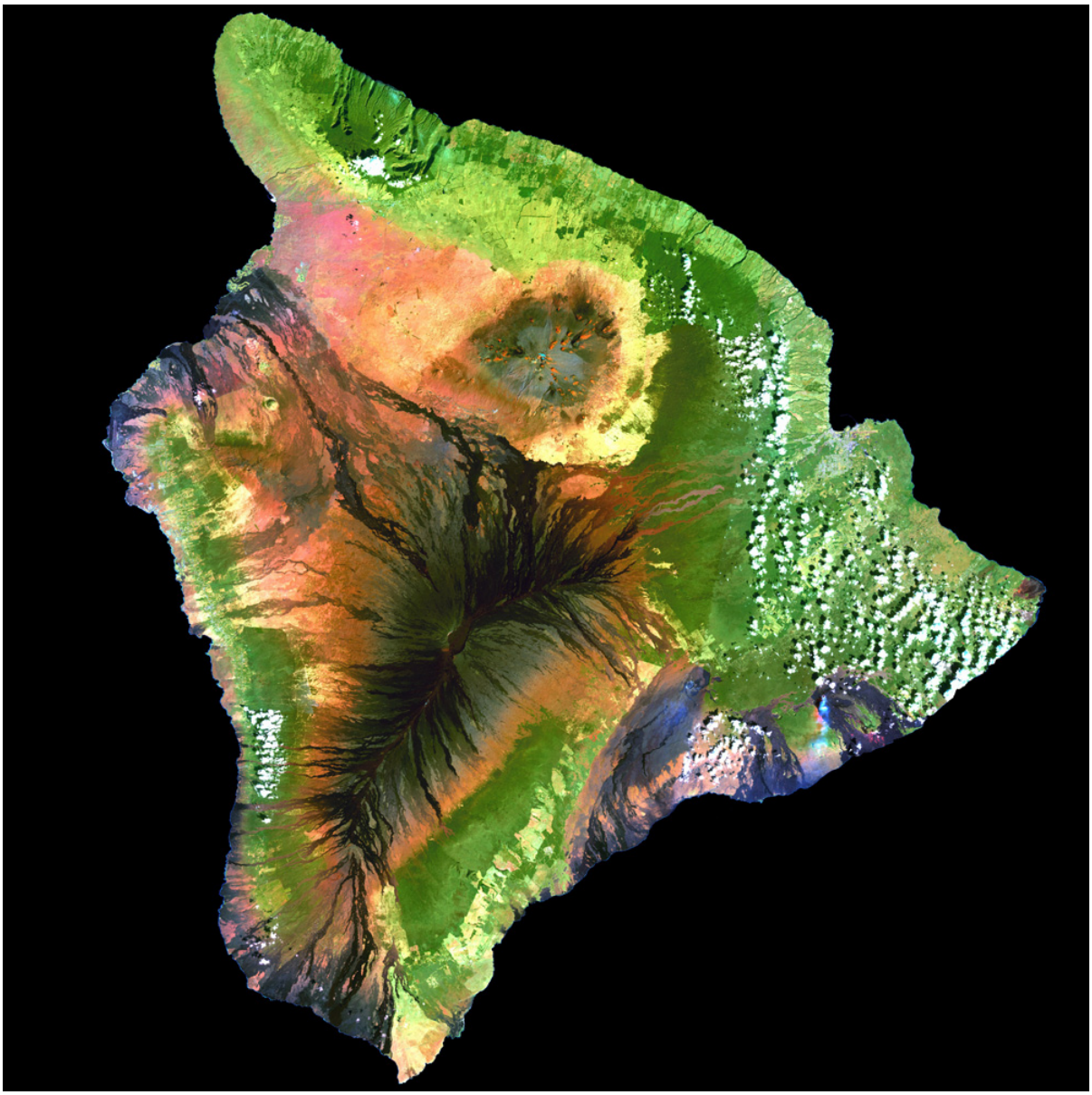
Sometimes composite volcanoes and other violent volcanoes can erupt so violently that they sometimes collapse in on themselves or actually blow themselves up to produce calderas. One of the most powerful volcanoes in the world—Yellowstone—is a massive caldera that has collapsed several times. Sometimes these calderas can fill up with water to produce beautiful lakes such as Mount Mazama (Crater Lake), in Oregon.



Shield Volcanoes



Shield volcanoes get their name from their shape. Although shield volcanoes are not steep, they may be very large. In fact, Mauna Loa, Hawaii is the tallest mountain in the world. From sea level, Mount Everest is the tallest, but when you consider from the ocean floor to the top of the island, Mauna Loa wins. Shield volcanoes are common at spreading centers or intraplate hot spots.The lava that creates shield volcanoes is fluid and flows easily and 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. Eruptions tend to be mild in comparison to other volcanoes, but lava flows can destroy property and vegetation. The low viscosity magma can flow not only on the surface as lava, but also underground in lava tubes. The most well known shield volcano is Hawaii.



There are two types of lava flows, pahoehoe which is a ropy type of lava that flows easily (low viscosity). The other type is called aa and is a blocky type of lava and has a higher viscosity and does not like to flow well.



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Cinder Cones



Cinder cones are the most common type of volcano. A cinder cone has a cone shape, but is much smaller than a composite volcano. Cinder cones rarely reach 300 meters in height but they have steep sides. Cinder cones grow rapidly, usually from a single eruption cycle. 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. Cinder cones are often found near larger volcanoes.

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 km3 for Mount St. Helens or 25 km3 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.

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. Fortunately, current activity at Yellowstone is limited to the region's famous geysers.Long Valley Caldera, south of Mono Lake in California, is the second largest supervolcano in North America. Long Valley

had an extremely hot and explosive rhyolite explosion 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.



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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.

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6.13: Volcanic Landforms and Geothermal Activity

Volcanic Landforms and Vents



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.The most obvious landforms created by lava are volcanoes, most commonly as cinder cones, composite volcanoes, and shield volcanoes or eruptions that take place through fissures. The eruptions that created the entire ocean floor are essentially fissure eruptions. Magma intrusions ALSO can create landforms. The image on the right is of Shiprock in New Mexico, which is the neck of an old volcano that has eroded away.

Lava Domes



Lava dome inside Mount St. Helen's crater.

When lava is viscous, it flows slowly. If there is not enough magma or enough pressure to create an explosive eruption, the magma may form a lava dome. But because the viscosity of the magma is so thick, the lava does not flow far from the vent. Lava flows often make mounds right in the middle of craters at the top of volcanoes.

Lava Plateaus and Land

A **lava plateau** forms when large amounts of fluid lava flows over an extensive area. When the lava solidifies, it creates a large, flat surface of igneous rock. Lava creates new land as it solidifies on the coast or emerges from beneath the water. 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.

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. Water heated below ground that rises through a crack to the surface creates a **hot spring**. The water in hot springs may reach temperatures in the hundreds of degrees Celsius beneath the surface, although most hot springs are much cooler.

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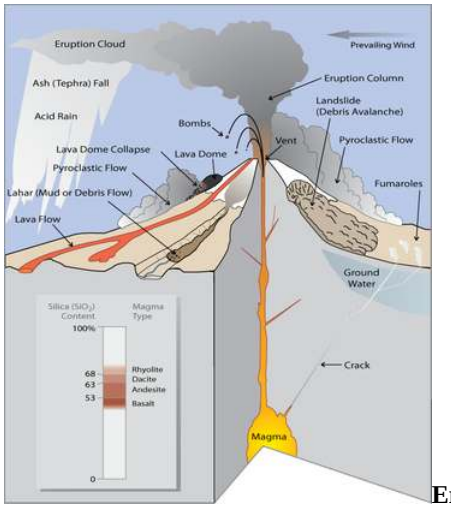
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6.14: Hazards and Benefits of Volcanic Activity

There are several hazards that volcanic activity can produce.



- **Eruption clouds** occur when massive quantities of ash is ejected into the atmosphere where it can reach heights of 50,000 feet. Eruption clouds have proven to be very dangerous for aviation jets because the ash can shut down the engines. The ash cloud can also be very hazardous in terms of air pollution.
- **Lahars** are volcanic mudflows. Lahars are very dangerous because they do not require a volcanic eruption yet can travel hundreds of miles. All that is required is loose pyroclastic material on the volcano that mixes with precipitation or melting snow.
- **Lava flows** are layers of molten rock that flow over the surface, later cooling and solidifying.
- **Lava bombs** are large chunks of pyroclastic material ejected from a volcano. Larger pyroclastic material is called blocks.
- **Pyroclastic flows** are some of the most dangerous hazards caused by composite volcanoes. Pyroclastic flows are superheated clouds of pyroclastic material (e.g. hot rock and tephra) ranging in size from small rocks to the size of houses that are over 1,000 degrees F traveling down a mountain at speeds up to 100 mph.
- **Tephra** (or **volcanic ash**) is fine particles of pyroclastic material that can be carried thousands of miles away by prevailing winds. Regions hundreds of miles away could suffer collapsed buildings is the falling ash accumulates enough. Tephra can also cool the entire planet if enough is ejected into the atmosphere.
- **Poisonous gases** such as carbon dioxide, carbon monoxide, and sulfur dioxide can travel down a volcano and asphyxiate (suffocating) wildlife and humans. In 1986, an invisible cloud of carbon dioxide traveled down a volcano in Africa asphyxiating 1,742 people and 3,000 cattle.

There are actually many benefits to volcanic activity. One of the major benefits is the fact that volcanic activity can create very fertile soil for agriculture. The problem is that many civilizations developed near volcanoes for this reason—with sometimes deadly effects. Volcanic activity can also create many mineral resources such as gold, sliver, nickel, copper, and lead. Volcanic rock is often used for landscaping, tile, and cement.

Some of the most amazing landscapes are near volcanoes. This is because volcanic activity builds land creating breathtaking scenery. So volcanoes are economically vital for many regions because of the recreational activity and tourism they bring.

Finally, a new but important trend is **geothermal power**. The heat generated by volcanoes can create electricity to power civilization. Geothermal power is a completely **renewable resource** free of pollution and energy dependency on fossil fuels. Iceland—the surface manifestation of the mid-Atlantic ridge—has a goal of powering the entire nation on geothermal energy. Geothermal energy is also being used in California, Kilauea, Hawaii, and now Utah.

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CHAPTER OVERVIEW

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7.1: Introduction to Weathering, Erosion, and Deposition

Learning Objectives

The goals and objectives of this chapter are to:

- Describe the basic processes, functions, and influences of weathering and erosion.
- Describe the various types of mass wasting processes.
- Compare the difference between fast and slow subsidence and how it may be limited.
- Describe how streams have the ability to erode and deposit sediment.
- Explain how groundwater can erodes limestone to form caves.
- Describe how wave actions erode coastlines and create coastal landforms.
- Explain how wind erodes and transports sediment in arid regions of the world.
- Describe how glaciers erode and carve out the landscape.

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7.2: Weathering Processes

Weathering is the process that changes solid rock into sediments. With weathering, rock is disintegrated into smaller pieces. Once these sediments are separated from the rocks, erosion is the process that moves the sediments away from it's original position. The four forces of erosion are water, wind, glaciers, and gravity. 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, down slope. These forces of erosion will be covered later.While plate tectonics forces work to build huge mountains and other landscapes, the forces of weathering and mass wasting gradually wear those rocks and landscapes away, called **denudation**. 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? What forces of weathering wear down that road, or rocks or mountains over time?

Mechanical Weathering

Mechanical weathering, also called physical weathering, breaks rock into smaller pieces. 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.There are many ways that rocks can be broken apart into smaller pieces. **Ice wedging**, also called **freeze-thaw weathering**, is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point. Ice wedging works quickly, breaking apart rocks in areas with temperatures that cycle above and below freezing in the day and night, and also that cycle above and below freezing with the seasons.Ice wedging breaks apart so much rock that large piles of broken rock are seen at the base of a hillside called talus. Ice wedging is common in Earth's polar regions and mid latitudes, and also at higher elevations, such as in the mountains. **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.

Now that you know what mechanical weathering is, can you think of other ways it could happen? Plants and animals can do the work of mechanical weathering. 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.

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases. With more surfaces exposed, there are more surfaces on which chemical weathering can occur.

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, one type of mineral changes into a different mineral. Chemical weathering works through chemical reactions that cause changes in the minerals.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.Remember that the most common minerals in Earth's crust are the silicate minerals. Many silicate minerals form in igneous or metamorphic rocks deep within the earth. 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. 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. **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.

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.

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. Minerals that are rich in iron break down as the iron oxidizes and forms new compounds. Iron oxide produces the red color in soils.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.

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7.3: Influences on Weathering

Rock and Mineral Type

Weathering rates depend on several factors. These include the composition of the rock and the minerals it contains as well as the climate of a region. 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. As the surrounding less resistant rocks were worn away, the resistant center of the volcano remained behind.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 degrees 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. This happens because plants and bacteria grow and multiply faster in warmer temperatures.

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7.4: Factors that Influence Mass Wasting



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Once rock material has been broken down into smaller, unstable pieces by weathering, the material has the potential to move down slope called **mass wasting** (also called a **mass movement** or a **landslide**) because of gravity. Before looking into the various types of landslides, the factors that influence them must be examined. Ultimately, this comes down to the dynamics of two factors: gravity and steepness of slope. The steeper the slope, the greater potential for gravity to pull objects down. The shallower the slope, the less effect gravity has on pulling objects down.

There are several factors that influence mass wasting, but ultimately it is a battle between friction and gravity. If the friction on a rock is stronger than gravity for a particular slope, the rock material will likely stay. But if gravity is stronger, the slope will fail.The steeper the slope, the stronger the friction or rock strength must be to resist down slope motion. The steepest angle a slope can be before the ground will slide is about 35 degrees, called the angle of repose. Many times we will cut through a slope to make room for a road or other forms of development. So to help prevent the slope from sliding along these cut areas, retaining walls must be build. More on this later.

Composition of Slope Material

Another factor that determines mass wasting is the slope's material. Mass wasting is more prone on slopes that contain clay and shale. Without going into great detail here, the shape and composition of individual clay particles can absorb water and prevent water from peculating through the ground. A layer of clay on a slope can prevent water from filtering through the slope. Instead, the water stays near the surface and saturates the ground. This can cause the surface layers to lose friction and slide.

Weight and Friction of Slope

A third factor that influences whether a slope will fail is the load or weight of that slope. Adding weight to a weakened slope can obviously cause it to slide easier, especially on steep slopes. This added weight tends to occur by building on top of weak slopes, increasing the steepness of the slope, or over-saturating the slope.Friction has been mentioned as a factor several times already, but there are a few more things must be said here. As already noted, as long as the friction along the slope is stronger than gravity, the ground is unlikely to slide. But if that friction is weakened, slope fail becomes more likely. There are several other ways friction can be reduced along a slope: wildfires, removal of vegetation, or adding too much water.Gravity is probably the ultimate driving force of mass wasting. The force of gravity pulls all things on the planet toward the center of the Earth. Without gravity, mass wasting would not occur. But unlike many of the other factors, humans have no influence or control on gravity.

Regional Climate Conditions

A region's climate can also determine the likelihood of a landslide. Climate is based on temperature and precipitation. Mass wasting is prone in the spring-time when snow melt, water saturation, and runoff is greatest. Also the type of climate will help determine the type of mass wasting. Humid climates tend to have slides, where water-saturated slopes fail and fall. Drier climates tend to have rocks that fall; especially early spring. Canyons and places prone to wildfires tend to have debris flows.

Water Content within Slopes

The amount of water in the soil is a major factor in the stability of a slope. When you build a sand castle, water is needed to build the walls and towers. That is because water has surface tension and is attracted to each other. This allows you to build towers greater than the angle of repose. So a little water can actually prevent slopes from sliding. But too much water lubricates the individual grains of sediment decreasing friction between each grain, so the possibility of mass wasting increases. The increase of water within the soils can come from over watering, pipe or swimming pool leaks, or prolonged stormy weather. In Utah and many mountainous regions, spring runoff of snow melt increases the water content within the soil.

Gravity

Finally, gravity is the driving force of mass wasting. The force of gravity pulls all things on the planet toward the center of the Earth. But unlike many of the other factors, humans have no influence or control on gravity. For more information on what causes landslides in Utah, click here.

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7.5: Types of Mass Wasting

A **rock fall** are the fastest of all landslide types and occurs when a rock falls through the air until it comes to rest on the ground—not too complicated. In Utah, they are common in the spring and fall because of freeze-thaw weathering. In the daytime, temperatures in the spring and fall tend to be above freezing, which allows liquid water to enter cracks within rocks.

At night, the temperatures cool below freezing and the water within the rocks freezes and expands which causes the rock to break more. The following morning, the ice will melt and go deeper within the crack to refreeze later that night. This freeze-thaw action over time can cause rocks to break off and fall to the ground. The debris the accumulates at the base of these steep slopes is called **talus**.

But rock falls can also occur when heavy precipitation is falling on a steep slope, causing the rocks to lose friction and fall. The YouTube video below is a rock fall captured in Taiwan in late August 2013, following heavy precipitation in the region.



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Rotational Slides

Rotational slides occur when the a landslide occurs in a curved manner concave to the sky. When this type of slide occurs, the upper surface of the slide tilts backwards toward the original slope and the lower surface moves away from the slope. They are common when the soil tends to be deep in clay or soft sediment deposits. The video on the right is a large landslide again in Taiwan in early September 2013 following every rainfall. Needless to say, they were having a bad few days in the region.

Transitional Slides

Rather than rotating, a **translational slide** occurs when slope failure occurs parallel to the slope. Often times the slope failure occurs on soil composed of clay or shale, or along old fault lines, or previous slide areas. What makes translational slides dangerous is that they tend to flow faster and travel farther than rotational slides. The most expensive translational slide in U.S. history actually occurred in Thistle, Utah in 1983.

Debris Flows



Debris flows are one of the most common, but most dangerous of the various types of landslides because of their speed and consistency. Debris flows tend to be a mixture of rock and water with two to three times the density of flooding streams. That density allows debris flows strip away the land and pick up objects as large as school buses.

Debris flows are most common at the mouth of canyons along alluvial fans. Lets first explain an alluvial fan. When floods occur within the mouth of a canyon, either because of intense thunderstorms or snow melt, the erosive power of the water can pick up sediment and boulders – a debris flow. Now once the debris flow reaches the mouth of a canyon, the sediment gets deposited in a fan-shaped delta called an alluvial fan. The problem is that people like to live along alluvial fans because of their scenic view on the canyon. Another influence of debris flows is wildfires. When a wildfire strips an area of its vegetation, the bare soil is easily eroded away in either a thunderstorm or snow melt creating these debris flows. Because of Utah's topography and tendency to wildfires, debris flows are quite common.

Volcanic Mass Wasting



Lahars were mentioned in the module on volcanoes, but in essence they are volcanic landslides. Recall that volcanoes eject pyroclastic material ranging is size from ash to boulders. Now there tends to be two ways lahars occur. One is if a thunderstorm precipitates large amounts of moisture on the pyroclastic material and the pyroclastics flow down slope. The other option is if a volcano is snow-capped and the heat from the volcano causes some of the snow to melt and mix with the pyroclastic material. What makes lahars so dangerous is that they have the consistency of concrete and can travel hundreds of miles. For a breakdown of potential landslide types in the State of Utah, check out the Utah Geologic Survey.

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7.6: Limiting Mass Wasting Potential

Drainage Controls

Ultimately preventing mass wasting is impossible because gravity will always exist, but smarter development can help minimize the risk and hazards. One component in landslide mitigation is basic drainage control of water. Recall that water can cause slopes to lose their friction as water lubricates individual grains of soil. And if you cut a slope and put a retaining wall for support, you may be preventing the water from filtering through. Thus you will often find drains at the base of retaining walls that allow underground water to within the slopes to drain out.

Slope Grade and Support

If people dig into the base of a slope to create a road or a home site, the slope may become unstable and move downhill. This is particularly dangerous when the underlying rock layers slope towards the area. Ultimately preventing landslides is impossible because gravity will always exist. But smarter development can help minimize the risk and hazards created by landslides. One component in landslide mitigation is basic drainage control of water. Recall that water can cause slopes to lose their friction as water lubricates individual grains of soil. And if you cut a slope and put a retaining wall for support, you may be preventing the water from filtering through. Thus you will often find drains at the base of retaining walls that allow underground water to within the slopes to drain out.Slope support is one of most common types of mitigation for potential mass wasting. As mentioned above, a retaining wall can be built to support a steep slope. Next, the retaining wall must be anchored to the bedrock within the slope to hold the wall to the slope. Another type of slope support is simply planting vegetation. The roots of vegetation tend to grab and hold soil in place, so by planting various types of plants and trees can be a simple and cheap way to stabilize a slope. For more on what homeowners can do to minimize your risk to landslides in Utah, click here.

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7.7: Subsidence

Subsidence occurs when loose, water saturated sediment begins to compact causing the ground surface to collapse. Now there are two types of subsidence.

Slow Subsidence



Slow subsidence occurs when the water within the sediment is slowly squeezed out because of overlying weight. There are several examples of slow subsidence, but the best one is Venice, Italy. Venice (image on the right) was built at sea level on the now submerged delta of the Brenta River. The city is sinking because of the overlying weight of the city and pumping of ground water. The problem now is that sea levels are rising as glaciers melt and water expands due to global warming. An example of slow subsidence in the U.S. includes New Orleans, Louisiana. As we all know from Hurricane Katrina, the Mississippi River has a vast network of levees that prevent the massive river from flooding – most of the time. But by preventing the spring-time flooding, we are preventing the river from depositing sediment onto the land. Instead, the sediment is being transported to the Gulf of Mexico creating the massive Mississippi delta.

Fast Subsidence



Fast subsidence occurs when naturally acidic water begins to dissolve limestone rock to forma a network of water-filled underground caverns. But if droughts or pumping of ground water reduces the water table below the level of the caves, they caverns collapse creating surface sinkholes.A dramatic example of fast subsidence occurred in Guatemala City in 2007 when a massive sinkhole formed 300 feet deep. As noted above, the underground region surrounding Guatemala is composed of limestone that and a vast underground network of caverns. It is believed that the water table has been dropping in the region and thus draining the caves. Afterward the caves can not support the overlying weight and collapse in.

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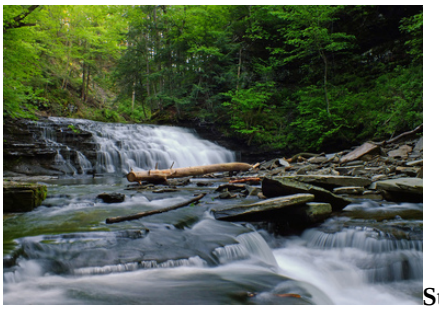
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7.8: Erosion and Deposition by Streams

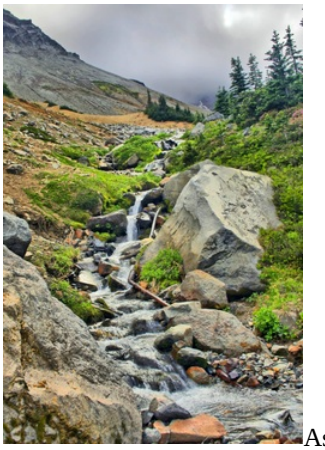


Streams, any running water from a rivulet to a raging river, complete the hydrologic cycle by returning precipitation that falls on land to the oceans. Some of this water moves over the surface and some moves through the ground as groundwater. Flowing water does the work of both erosion and deposition.

Erosion by Streams

Flowing streams pick up and transport weathered materials by eroding sediments from their banks. Streams also carry ions and ionic compounds that dissolve easily in the water. Sediments are carried as the following loads: *dissolved*, *suspended*, and *bed*. A **dissolved load** is composed of ions in solution. These ions are usually carried in the water all the way to the ocean.Sediments carried as solids as the stream flows are called a **suspended load**. The size of particles that can be carried within a load is determined by the stream's velocity. 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.Particles that are too large to be carried as suspended loads are bumped and pushed along the stream bed, called **bed load**. Bed load sediments do not move continuously, but rather in intermittent movements, 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.

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. The stream moves fast and does lots of work eroding the stream bed.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**. As streams move 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. **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.



Headwater

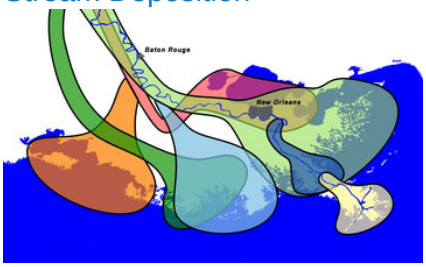


Base level



Meandering

Stream Deposition



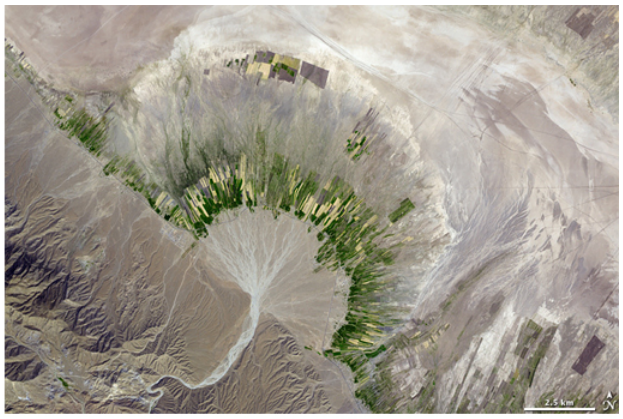
Movement of the Mississippi delta.

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. 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.A stream at flood stage carries lots of sediments. When its gradient decreases, the stream overflows its banks and broadens its channel. The decrease in gradient causes the stream to deposit its sediments, the largest first. These large sediments build a higher area around the edges of the stream channel, creating natural levees.

When a river enters standing water, its velocity slows to a stop. The stream moves back and forth across the region and drops its sediments in a wide triangular-shaped deposit called a **delta**. If a stream falls down a steep slope onto a broad flat valley, an **alluvial fan** develops. Alluvial fans generally form in arid regions.



Mississippi delta



Alluvial fan

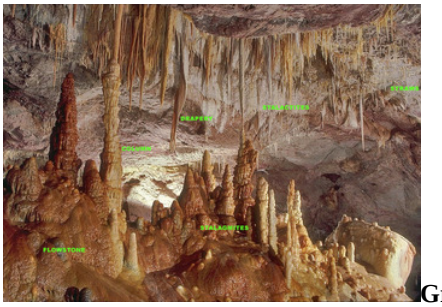
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7.9: Ground Water Erosion and Deposition

Cave Formation



Ground water is a strong erosional force, as it works to dissolve away solid rock. Carbonic acid is especially good at dissolving the rock limestone. 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 forming a cave.Ground water carries the dissolved minerals in solution. The minerals may then be deposited, for example, as **stalagmites** or **stalactites**.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.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.



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7.10: Wave Action and Erosion



Waves are important for building up and breaking down shorelines. Waves transport sand onto and off of beaches, transport sand along beaches, carves structures along the shore. The largest waves form when the wind is very strong, blows steadily for a long time, and blows over a long distance.

The wind could be strong, but if it gusts for just a short time, large waves won't form. Wave energy does the work of erosion at the shore. Waves approach the shore at some angle so the inshore part of the wave reaches shallow water sooner than the part that is further out. The shallow part of the wave 'feels' the bottom first. This slows down the inshore part of the wave and makes the wave "bend." This bending is called **refraction**.

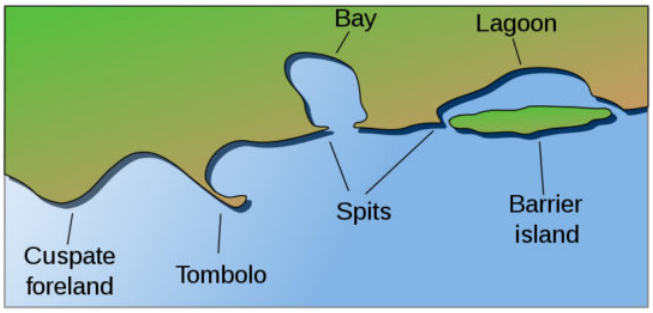
Wave refraction either concentrates wave energy or disperses it. In quiet water areas, such as bays, wave energy is dispersed, so sand is deposited. Areas that stick out into the water are eroded by the strong wave energy that concentrates its power on the wave-cut cliff.

A wave-cut platform is the level area formed by wave erosion as the waves undercut a cliff. An arch is produced when waves erode through a cliff. When a sea arch collapses, the isolated towers of rocks that remain are known as sea stacks.

Wave Deposition



Rivers carry sediments from the land to the sea. If wave action is high, a delta will not form. Waves will spread the sediments along the coastline to create a beach. Waves also erode sediments from cliffs and shorelines and transport them onto beaches.Beaches can be made of mineral grains, like quartz, rock fragments, and also pieces of shell or coral. Waves continually move sand along the shore and move sand from the beaches on shore to bars of sand offshore as the seasons change. In the summer, waves have lower energy so they bring sand up onto the beach. In the winter, higher energy waves bring the sand back offshore.Some features form by wave-deposited sand. These features include barrier islands and spits. A spit is sand connected to land and extending into the water. A spit may hook to form a **tombolo**. Shores that are relatively flat and gently sloping may be lined with long narrow barrier islands. Most barrier islands are a few kilometers wide and tens of kilometers long.In its natural state, a barrier island acts as the first line of defense against storms such as hurricanes. When barrier islands are urbanized, hurricanes damage houses and businesses rather than vegetated sandy areas in which sand can move. A large hurricane brings massive problems to the urbanized area.




Long Island, New York

Protecting Shorelines


Intact shore areas protect inland areas from storms that come off the ocean. Where the natural landscape is altered or the amount of development make damage from a storm too costly to consider, people use several types of structures to attempt to slow down wave erosion. A groin is a long narrow pile of rocks built perpendicular to the shoreline to keep sand at that beach. A breakwater is a structure built in the water parallel to the shore in order to protect the shore from strong incoming waves. A seawall is also parallel to the shore, but it is built onshore.People do not always want to choose safe building practices, and instead choose to build a beach house right on the beach. Protecting development from wave erosion is difficult and expensive and it doesn't always work. The northeastern coast of Japan was protected by anti-tsunami seawalls, yet waves from the 2011 tsunami that resulted from the Tohoku earthquake washed over the top of some seawalls and caused others to collapse. Japan is now planning to build even higher seawalls to prepare for any future (and inevitable) tsunami.

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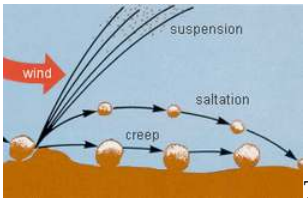
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7.11: Transport of Particles by Wind



The power of wind to erode depends on particle size, wind strength, and whether the particles are able to be picked up. Wind is a more important erosional force in arid than humid regions.Wind transports small particles, such as silt and clay, over great distances, even halfway across a continent or an entire ocean basin. Particles may be suspended for days. Wind more easily picks up particles on ground that has been disturbed, such as a construction site or a sand dune. Just like flowing water, wind transports particles as both bed load and suspended load. For wind, bed load is made of sand-sized particles, many of which move by **saltation**. The suspended load is very small particles of silt and clay.

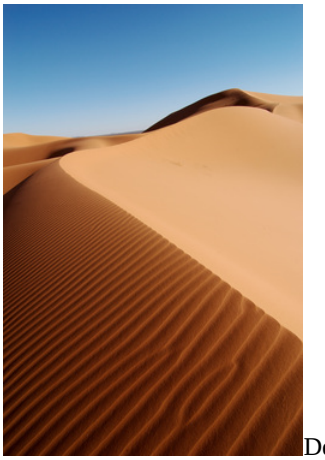
Wind Erosion



Desert varnish in Arches NP.

Wind is a stronger erosional force in arid regions than it is in humid regions because winds are stronger. In humid areas, water and vegetation bind the soil so it is harder to pick up. In arid regions, small particles are selectively picked up and transported. As they are removed, the ground surface gets lower and rockier, causing deflation. What is left is desert pavement, a surface covered by gravel sized particles that are not easily moved by wind.Particles moved by wind do the work of **abrasion**. As a grain strikes another grain or surface it erodes that surface. Abrasion by wind may polish natural or human-made surfaces, such as buildings. Stones that have become polished and faceted due to abrasion by sand particles are called **ventifacts**.Exposed rocks in desert areas often develop a dark brown to black coating called **desertvarnish**. Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron and manganese oxides. Often times petroglyphs are carved into the desert varnish by earlier civilizations in arid regions.

Wind Deposition



Deserts and seashores sometimes have sand dunes. **Beach dunes** have different compositions depending on their location. Beach dunes are usually quartz because in humid areas other minerals weather into clays. In the

tropics, sand dunes may be composed of calcium carbonate, which is common. In deserts, sand dunes may be composed of a variety of minerals. There is little weathering and so less stable minerals are left behind.**Dune sands** are usually very uniform in size and shape. Particles are sand-sized, because larger particles are too heavy for the wind to transport by suspension. They are rounded, since rounded grains roll more easily than angular grains.For sand dunes to form there must be an abundant supply of sand and steady winds. A strong wind slows down, often over some type of obstacle, such as a rock or some vegetation and drops its sand. As the wind moves up and over the obstacle, it increases in speed. It carries the sand grains up the gently sloping, upwind side of the dune by saltation. As the wind passes over the dune, its speed decreases. Sand cascades down the crest, forming the slip face of the dune. The slip face is steep because it is at the angle of repose for dry sand, about 34 degrees.Wind deposits dune sands layer by layer. If the wind changes directions, cross beds form. Cross beds are named for the way each layer is formed at an angle to the ground. The types of sand dune that forms depends on the amount of sand available, the character and direction of the wind, and the type of ground the sand is moving over.

Loess



Windblown silt and clay deposited layer on layer over a large area are **loess**, which comes from the German word loose. Loess deposits form downwind of glacial outwash or desert, where fine particles are available. Loess deposits make very fertile soils in many regions of the world.Fine-grained mud in the deep ocean is formed from silts and clays brought from the land by wind. The particles are deposited on the sea surface, then slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

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7.12: Formation and Movement of Glaciers

Glaciers cover about 10 percent 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 percent of Earth. Around 600 to 800 million years ago, geologists think that almost all of the Earth was covered in snow and ice, called the **Snowball Theory**. 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 and where it came from.



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Glaciers are solid ice that move extremely slowly along the land surface. They erode and shape the underlying rocks. Glaciers also deposit sediments in characteristic landforms. The two types of glaciers are: *continental* and *alpine*. **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.

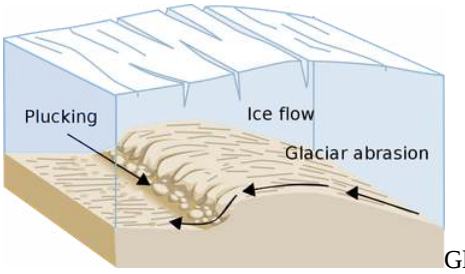


Alpine glacier



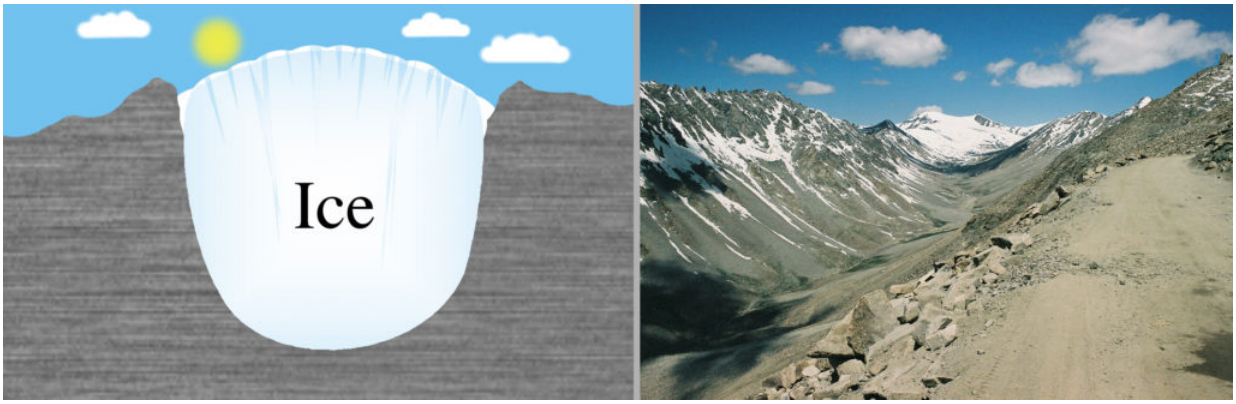
Continental glacier

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. With the weight of the ice over them, these rocks can scratch deeply into the

underlying bedrock making long, parallel grooves in the bedrock, called **glacial striations**. Mountain glaciers leave behind unique erosional features. When a glacier cuts through a 'V' shaped river valley, the glacier pucks rocks from the sides and bottom. This widens the valley and steepens the walls, making a 'U' shaped valley.For example, Utah's landscape has been greatly influenced by glacial activity of the last ice age. Using Google Maps for our map, first look at Little Cottonwood Canyon and notice how linear the canyon is. That is a direct result of an alpine glacier carving down creating a U-shaped canyon that ultimately ended in Lake Bonneville. Now using the same map, compare Little Cottonwood Canyon with Big Cottonwood Canyon. If you were to drive from the Salt Lake Valley up the canyon, you would notice the canyon to be more V-shaped since because it was carved out by the stream and spring runoff instead of a glacier. The canyon is also more jagged in shape rather than linear like U-shaped canyons. But notice about half way up the canyon, the direction of the canyon changes from the northeast to running southeast. At that pivot point is where the canyon stopped being carved by a river and was carved by another alpine glacier. From that pivot point to the end of the canyon, the canyon because linear and more U-shaped. The **cirque**, where the glacier originated, is at the head of the canyon is now home to Solitude Sky Resort and a portion of the melted cirque is now called Silver Lake.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. Up high on a mountain, where a glacier originates, rocks are pulled away from valley walls.



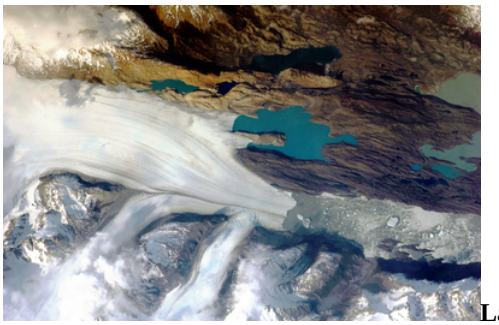
Depositional Features of Glaciers



Glacial erratic

As glaciers flow, mechanical weathering loosens rock on the valley walls, which falls as debris on the glacier. Glaciers can carry rocks of any size, from giant boulders to silt. These rocks can be carried for many miles over many years and decades. These rocks that are different in 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. **Glacial till** is found in different types of deposits. Linear rock deposits are called **moraines** and are named by their location relative to the glacier. Geologists study moraines to figure out how far glaciers extended and how long it took them to melt away.

Medial Moraine



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. 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.

While glaciers dump unsorted sediments, glacial melt water can sort and re-transport the sediments. As water moves through unsorted glacial till, it leaves behind the larger particles and takes away the smaller bits of sand and silt.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.



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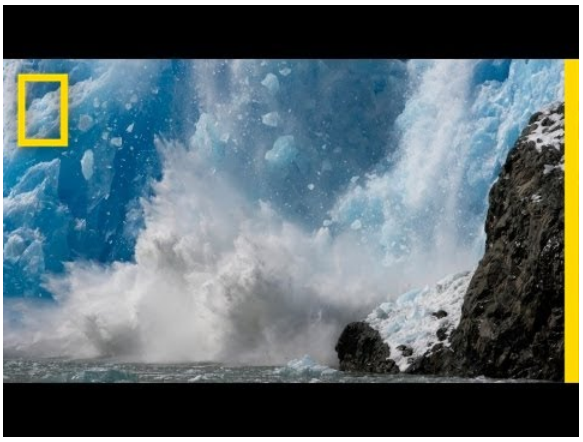
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7.13: Climate Change and Glacial Loss

There has been a lot of conversations and research in the scientific community about the dramatic amount of glacial melt that has been occurring around the planet as of late. Glaciers flow incredibly slowly down slope under the influence of gravity. But satellite imagery and on the ground data have shown that these glaciers are melting back and receding at an incredible rate. Because glaciers take so long to form and flow, they are excellent indicators of the temperature of the planet. As the planet has continued to warm over the last 100 years, glaciers from all around the world are retreating back. This is important to humanity because glaciers make up a large portion of the usable fresh water on the planet. As these glaciers melt away, so do huge amounts of fresh drinking water, just at a time when the human population continues to grow at an exponential rate.



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CHAPTER OVERVIEW

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8.1: Introduction to Earth's Fresh Water

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.

Learning Objectives

This chapter has several goals and objectives:

- Understand the distribution of Earth's water around the world.
- Describe the anatomy of a stream and it's components.
- Explain what a divide is and how it influences streams.
- Analyze and describe the importance and functions of wetlands.
- Describe the impacts of floods.
- Determine the influence groundwater has on fresh water around the planet.

Essential Questions

- How does precipitation affect the topology of the earth?
- What natural disasters are caused by the water cycle?
- 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?

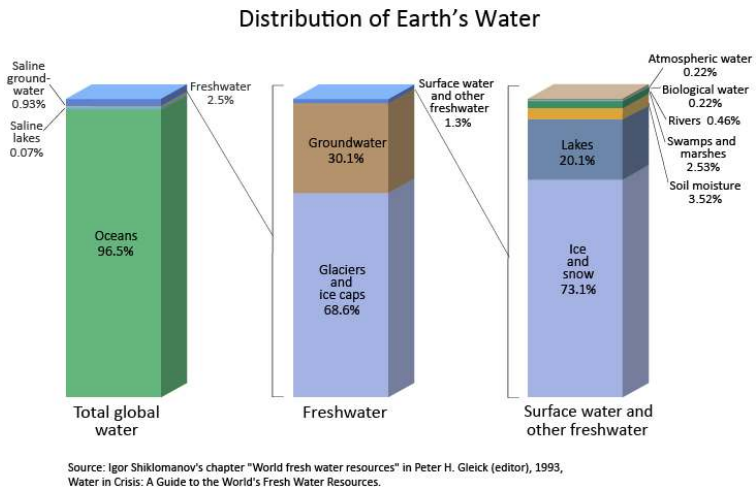
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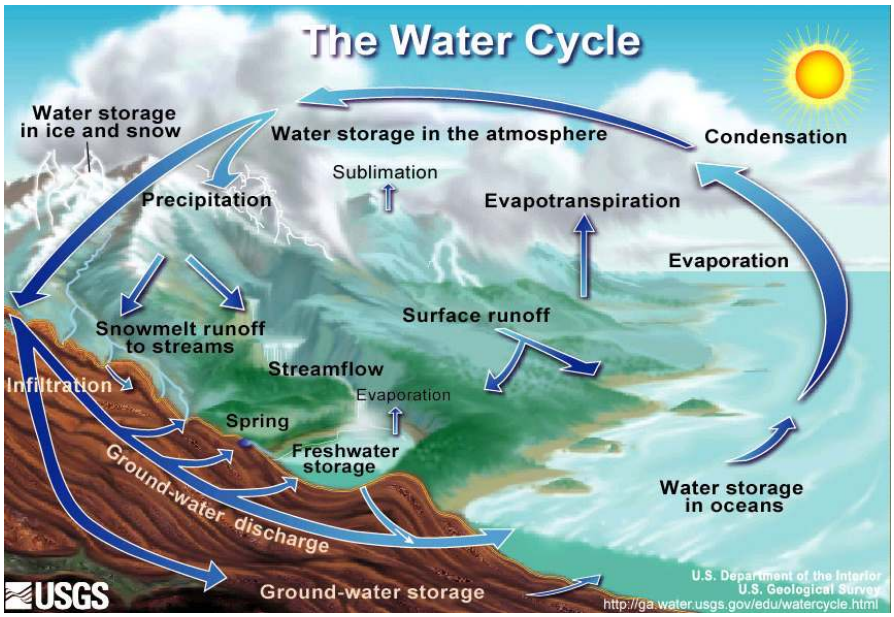
8.2: Distribution of Earth's Water

Earth's oceans contain 97% of the planet's water, so just 3% is fresh water, water with low concentrations of salts. 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.Earth's oceans contain 97% of the planet's water, so just 3% is fresh water, water with low concentrations of salts. 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.



Three States of Water

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?Water is the only substance on Earth that is present in all three states of matter – as a solid, liquid or gas. Along with that, 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).

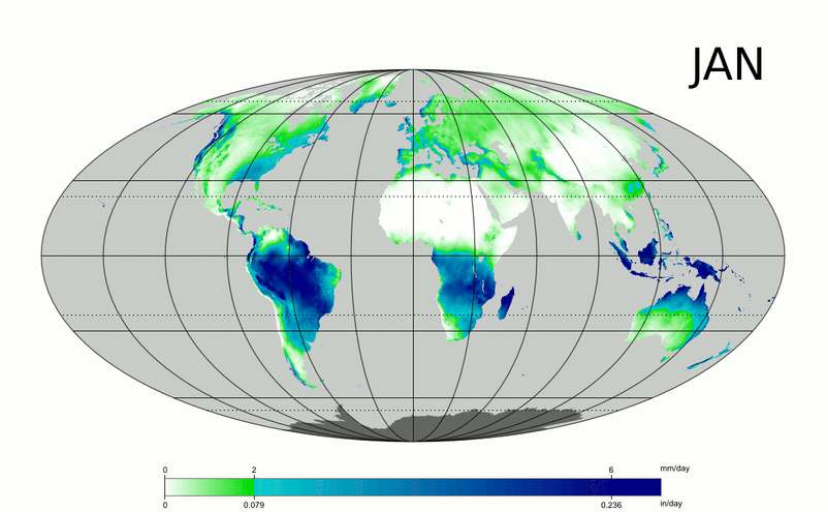


The Water Cycle

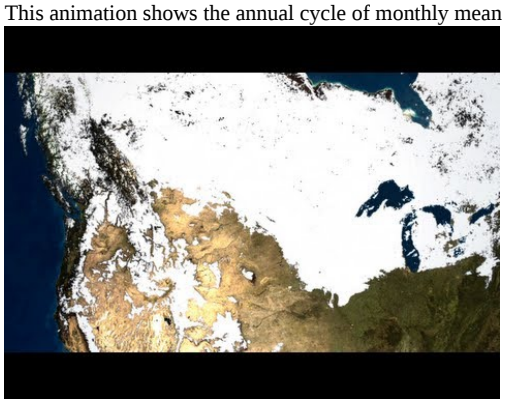
Because Earth's water is present in all three states, it can get into a variety of environments around the planet. The movement of water around Earth's surface is the **hydrologic (water) cycle**.The Sun, many millions of kilometers away, provides the energy that drives the water cycle. Our nearest star

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 freshwater 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.



This animation shows the annual cycle of monthly mean precipitation around the world.

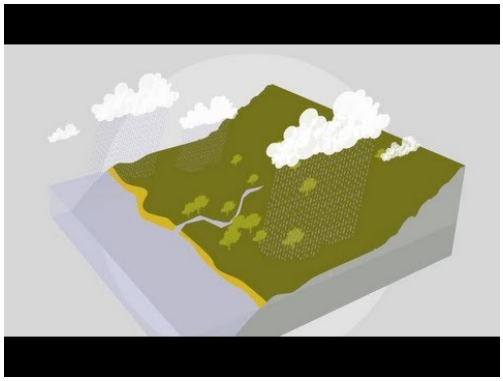


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When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds 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.



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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. Water trapped in soil is important for plants to grow. 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, a process known as transpiration. NASA has an excellent online guide of the hydrologic cycle.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.

Use	United States	Global
Agriculture	34 percent	70 percent
Domestic (drinking, bathing)	12 percent	10 percent
Industry	5 percent	20 percent
Power plant cooling	49 percent	small

The table 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.

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8.3: Streams and Rivers

 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** 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

 Oddly enough, there are a variety of different types streams. 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 sources and when two streams come together it's called a **confluence**. The smaller of the two streams is a **tributary** of the larger stream. A stream may create a pool where water slows and becomes deeper.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**. 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.

Rivers

Rivers are the largest types of stream, moving large amounts of water from higher to lower elevations. The Amazon River, the world's river with the greatest flow, has a flow rate of nearly 220,000 cubic meters per second! People have used rivers since the beginning of civilization as a source of water, food, transportation, defense, power, recreation, and waste disposal.



Confluence Tributary Estuary

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8.4: Divides

A **divide** is a topographically high area that separates a landscape into different water basins. 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.



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; ponds are often are fed by underground springs. **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. 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, and along tectonic faults, to name a few. Subglacial lakes are even found below a frozen ice cap.

As a result of geologic history and the arrangement of land masses, most lakes are in the Northern Hemisphere. In fact, more than 60% of all the world's lakes are in Canada—most of these lakes were formed by the glaciers that covered most of Canada in the last Ice Age.

Limnology is the study of bodies of freshwater and the organisms that live there. The ecosystem of a lake is divided into three distinct sections:

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 **limneticzone**) has abundant sunlight.
3. The **deep-water zone** (also the **aphotic** or **profundalzone**) 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.

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. Lakes may disappear if precipitation significantly diminishes.

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8.5: 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

There are a variety of different types of wetlands. **Marshes** are shallow wetlands around lakes, streams, or the ocean where grasses and reeds are common, but trees are not. Frogs, turtles, muskrats, and many varieties of birds are at home in marshes.

A **swamp** is a wetland with lush trees and vines found in a low-lying area beside slow-moving rivers. 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.

In an **estuary**, salt water from the sea mixes with fresh water from a stream or river. 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 seawater. Because of the rapid changes in salt content, estuaries have many different habitats for plants and animals and extremely high biodiversity.



Marshes



Swamps

Ecological Role of Wetlands

 As mentioned above, wetlands are home to many different species of organisms. Although they make up only 5 percent of the area of the United States, wetlands contain more than 30 percent of the plant types. Many endangered species live in wetlands, so wetlands are protected from human use. Wetlands also offer protection from storm surges from tropical storm systems like hurricanes and provide safe, hidden protection for hatchlings.

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.

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8.6: 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 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 snow-melt fills the ground with water and raises stream levels.

Flash floods are sudden and unexpected, taking place when very intense rains fall over a very brief period. 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.

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.



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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.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.

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8.7: Groundwater

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** 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.

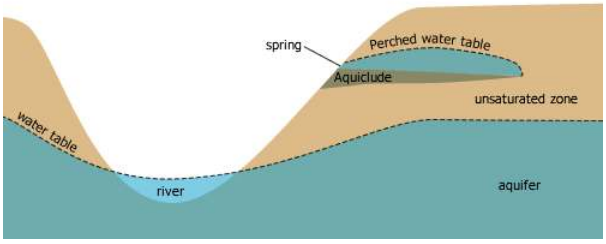
The amount of water that is available to enter groundwater in a region is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water 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.
Features of an Aquifer

To be a good aquifer, it must have good:

- porosity: small spaces between grains
- permeability: connections between pores
- natural recharge by precipitation

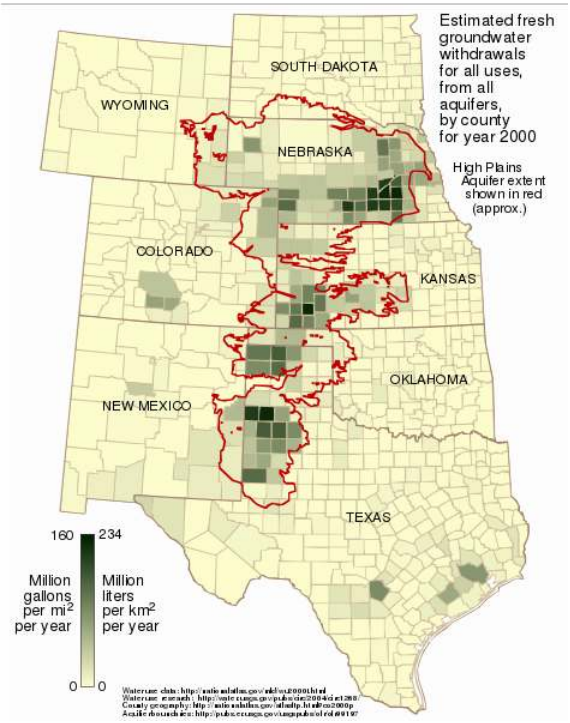
Th Environmental Protection Agency (EPA) has an animation to help people better understand aquifers. The water droplets are found in the pores between the sediment grains, which is **porosity**. When the water can travel between ores, that’s **permeability**. To reach an aquifer, surface water infiltrates 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. This impermeable rock layer forms the base of the aquifer. The upper surface where the groundwater reaches is 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. 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.

Click here to view another animation EPA on the water table.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 aboveground.



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. 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. About eight times more water is taken from the Ogallala Aquifer each year than is replenished. Much of the water is used for irrigation of crops in the Bread Basket of the central plains. Currently there is great concern about the longterm health of this vast aquifer because it is being tapped into and used at a greater rate than being replenished by natural processes. This could have huge implications in regards to food production in the country if this critical water source is depleted. At current rates of use, 70 percent of the aquifer could be gone by 2050.

Click here to learn more.Overuse and lowering of the water tables of aquifers could have other impacts as well. Lowering the water table may cause the ground surface to sink. Subsidence may occur beneath houses and other structures. 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 below, or a **spring**. A spring may be constant, or may only flow at certain times of year. Towns in many locations depend on water from springs. Springs can be an extremely important source of water in locations where surface water is scarce.

Wells

A **well** is created by digging or drilling to reach groundwater. 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.



Spring



Well

Finally, it's also important to understand how water is cleaned, filtered, and delivered to our homes and work. To many of us do not know where our water comes from and we take it for granted. This often times leads to wasteful water use of our lawns, showers, and other appliances. Again, click here to learn more from the EPA about water is treated before reaching us.

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CHAPTER OVERVIEW

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9.1: Introduction to Oceans and Coastal Environments

Learning Objectives

This chapter has several goals and objectives:

- Describe the significance of the ocean and how it influences weather and climate.
- Explain the different layers of the ocean.
- Understand the basic physics of ocean waves.
- Compare and contrast the differences between surface and deep ocean currents.

Essential Questions

- Based on scientific data, some scientists have hypothesized that if enough ice from Greenland melts, the Gulf Stream might be shut down. The logic is that too much fresh water could flow into the ocean, changing the salt water it would disrupt the salt and fresh water distribution. Why might this happen and how could it influence places like Europe?
- Are humans overfishing the world's oceans? What environmental and ecological concerns should be considered? How could this be a *tragedy of the commons*?

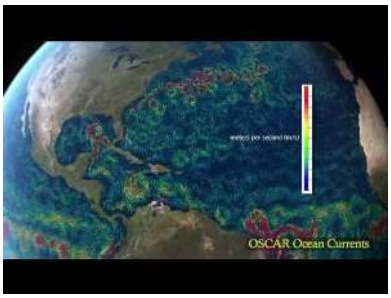
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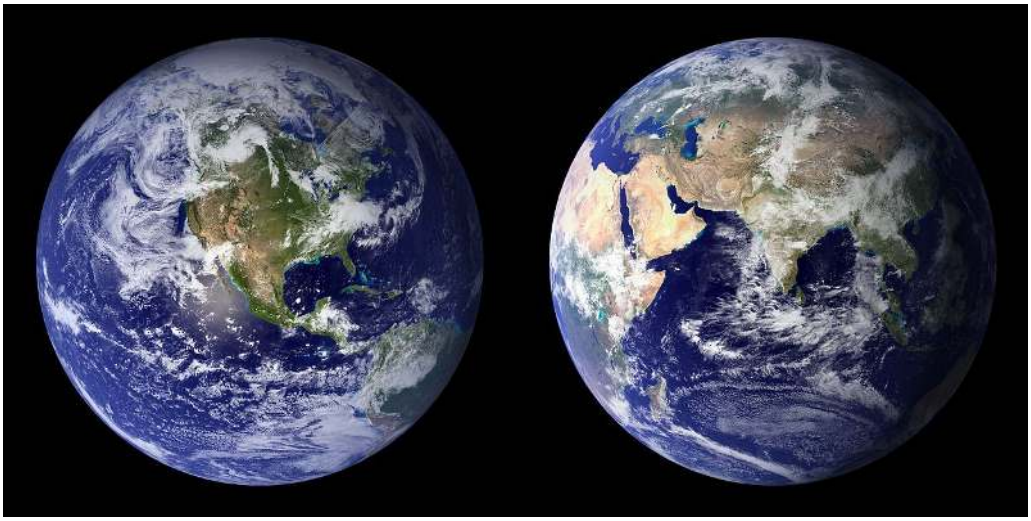
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9.2: Significance of the Oceans

The oceans make up 70 percent of the planet and contains 97 percent of all the water on Earth. It also makes up the vast majority of water stores the majority of the planet's moisture, terrestrial energy, and heat from the Sun. This energy is transferred between the equator and the two poles by larger surface currents by winds and deep ocean currents driven by differences in ocean density. It also provides the moisture and energy for storm systems and ultimately global climates. **Phytoplankton**, microscopic plants and animals in the oceans provide the foundation of the global **food web** of species. The earth's oceans are so vital for life that over 40 percent of the world's population live near coastal areas.

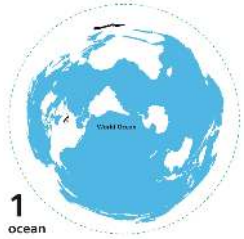


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The Blue Marble, captured by NASA in 2001.

Moderate Climates



70 percent of the planet is water.

As terrestrial creatures, humans think of the importance of the planet's land surfaces, yet Earth is a planet consisting of 70 percent water. From space, the dominance of water is obvious because most of it is stored in Earth's oceans.Earth would not be the same planet without its oceans. The oceans, along with the atmosphere, keep Earth's surface temperatures fairly constant worldwide. Some places on Earth reach as cold as −7 degrees Celsius, whereas other places reach as hot as 55 degrees Celsius. Yet on other planets like Mercury, temperatures range from −180 degrees Celsius to 430 degrees Celsius.The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the equator and then transport that solar energy to polar regions. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller along coastal areas compared to areas farther inland. Along coastal areas, 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.

Biologically Rich



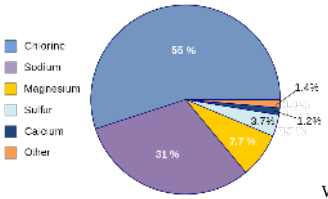
The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from the ocean and most precipitation falls on the oceans.The oceans are also home to an enormous amount of life. That is, they have tremendous biodiversity. Tiny ocean plants create 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.

Continental Margin

Recall from the chapter on Plate Tectonics 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.) 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 mapping of the ocean floor and coastal margins is called **bathymetry**.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.

Composition of Ocean Water



Water is a polar molecule so it can dissolve many substances such as salts, sugars, acids, bases, and organic molecules. 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 percent of the mass of ocean water, but the salt content or **salinity** is different in different locations.In places like estuaries, seawater mixes with fresh water, causing salinity to be much lower than average. Where there is lots of evaporation but little circulation of water, salinity can be much higher. The Dead Sea has 30 percent salinity—nearly nine times the average salinity of ocean water. It is called the Dead Sea because nearly nothing can survive within it because of its salinity. Earthquide has an interactive ocean maps, which can show salinity, temperature, nutrients, and other characteristics.Differences in water density are responsible for deep ocean currents. 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.

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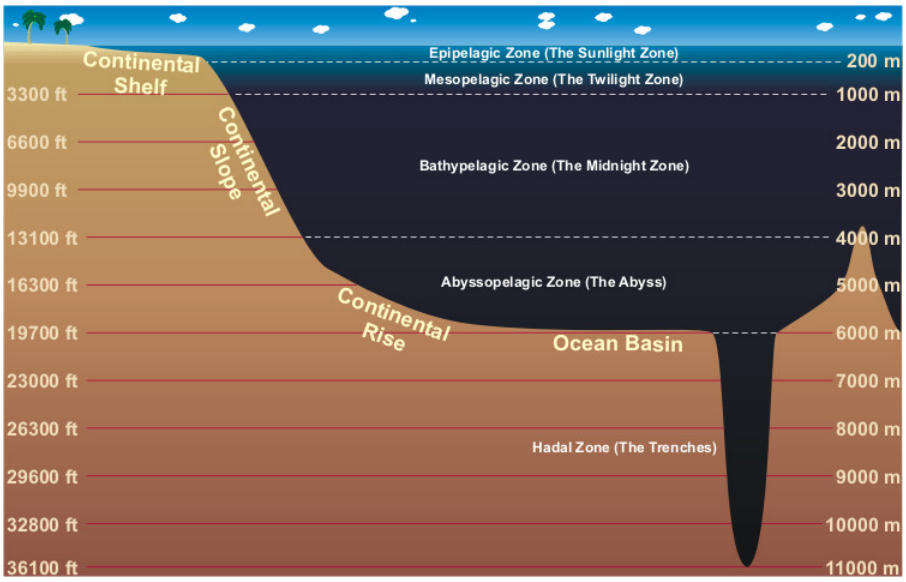
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9.3: Layers of the Ocean

In 1960, two men in a specially designed submarine called the **Trieste** descended into a submarine trench called the Challenger Deep (10,910 meters). The 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. There are three major factors that make the deep ocean hard to inhabit: *the absence of light*, *lowtemperature*, 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** (consisting of the Sunlight Zone and Twilight Zone). 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** (consisting of the Midnight Zone and the Abyss) 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.

Horizontal Divisions

The seabed is also divided into the zones described above, but the ocean itself is also divided horizontally by distance from the shore. Nearest to the shore lies the **intertidal zone**, the region between the high and low tidal marks. This hallmark of the intertidal is change, where water is in constant motions from ocean 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.

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9.4: Waves



Ocean water is constantly in motion: north-south, east-west, alongshore, and vertically. Seawater motions are the result of waves, tides, and currents. Ocean movements are the consequence of many separate factors: *wind*, *tides*, *Coriolis effect*, *water density differences*, and the *shape of the ocean basins*. **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

Ocean waves originate from steady winds or high storm winds over the water. Sometimes these winds are far from where the ocean waves are seen. The largest wind waves form when the wind is very strong, blows steadily for a long time, and 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. Water molecules in waves make circles or ellipses. Energy transfers between molecules but the molecules themselves mostly bob up and down in place. The Internet has a variety of animations to help explain the concept of wave action. In this animation, a water bottle bobs in place like a water molecule. An animation of motion in wind waves from the Scripps Institution of Oceanography. Here is an animation of a deep water wave is seen here. Notice the circular motion of water as wave energy transfers through it. Compare that to the wave action in shallow waters using this animation.



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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 surges**. 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.

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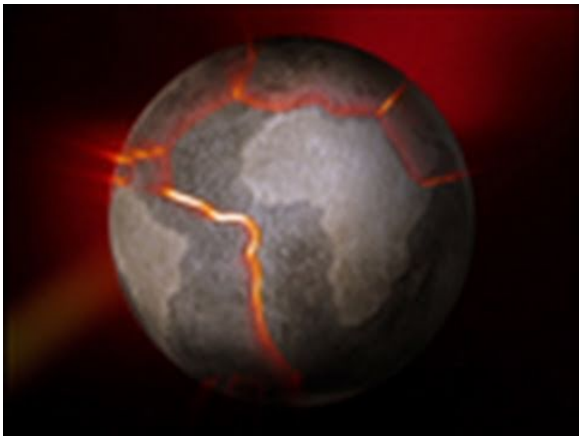


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Tsunamis

Tsunami are described in the Tectonic Forces chapter as damaging waves that result from the sharp jolt to the water from a powerful geologic event such as undersea earthquakes or volcanic eruptions. Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami. Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour). 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.

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 called a **run-up**. 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.



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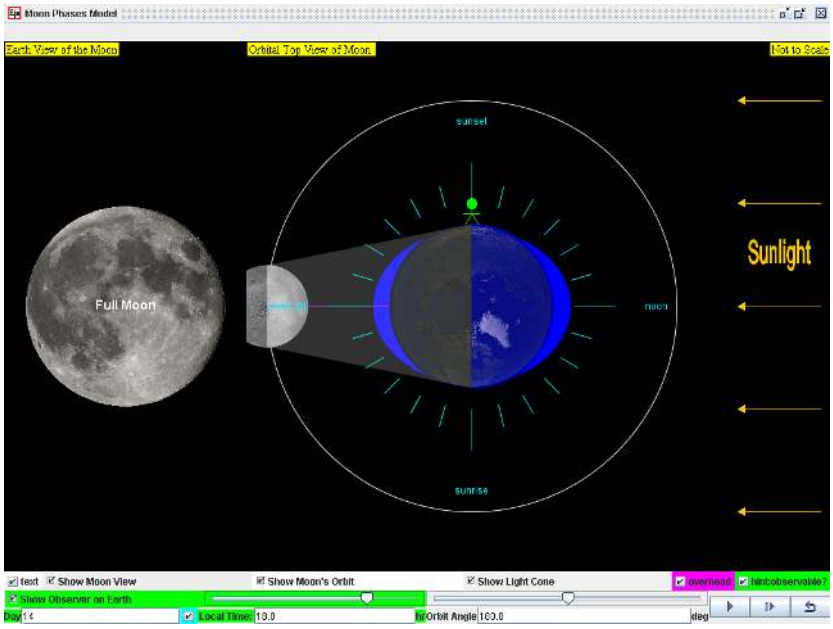
9.5: Tidal Waves



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. 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.

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 above it 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**. Click here to learn more.Since so much water is pulled into the two high tides, **low tides** form between the two high tides. As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides every day.The **tidal range** is the difference between the ocean level at high tide and the ocean at low tide. 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.

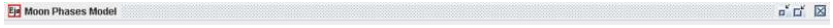


Spring tide

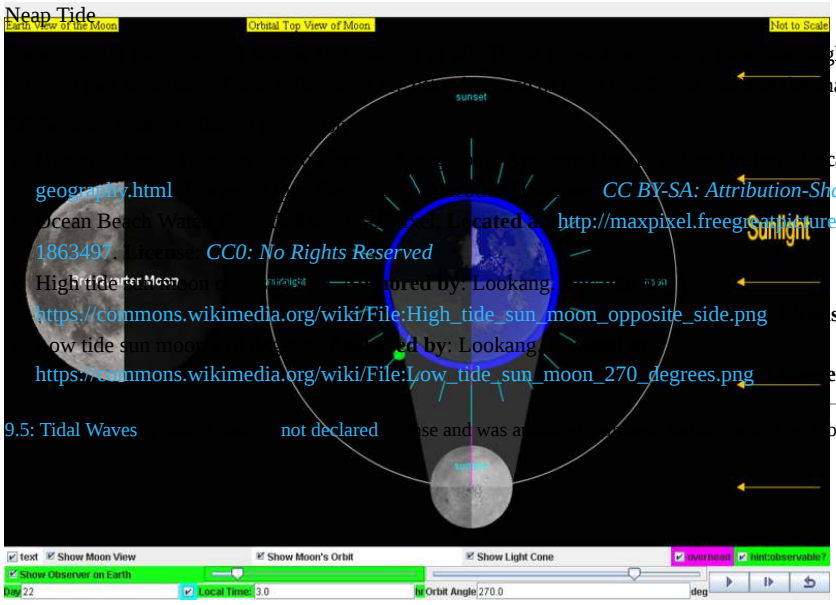
Monthly Tidal Patterns

Waves are additive so when the gravitational pull of the Sun and Moon are in the same direction, the high tides add and the low tides add. 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. The National Oceanic and Atmospheric Administration (NOAA) has a simple diagram of this process.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90 degree angle. 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. Here is another simple animation of spring and neap tides from NOAA.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.



Neap Tide



gh and one low tide per day or a different amount of time
hape of the coastline that the tide is entering.

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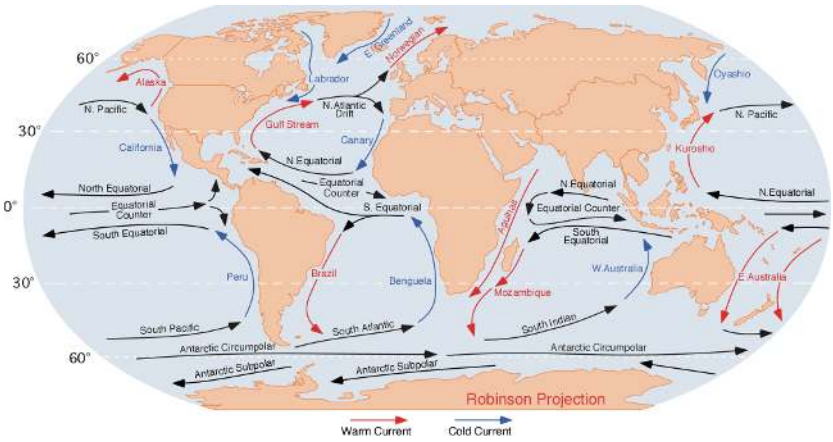
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9.6: Surface Currents

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*, and the *shape of the ocean basins*.



Surface ocean currents

Surface currents are extremely important because they distribute heat around the planet and are a major factor influencing climate around the globe.

Global Wind Currents

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 that more solar radiation strikes the equator than the polar regions, and the rotation of the Earth called the **Coriolis effect**. The causes of the global wind patterns will be described in detail later when we look at the atmosphere. Water in the surface currents is pushed in the direction of the major wind belts:

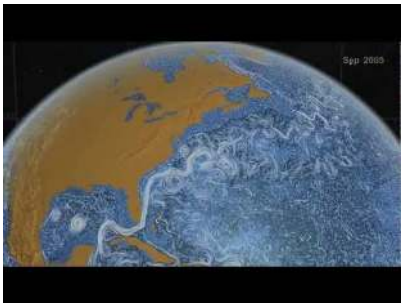
- **trade winds**: east to west between the equator and 30 degrees North and 30 degrees South
- **westerlies**: west to east in the middle latitudes
- **polar easterlies**: east to west between 50 degrees and 60 degrees north and south of the equator and the north and south pole

Rotation of the Earth

Wind is not the only factor that affects ocean currents. The Coriolis effect describes how Earth's rotation steers winds and surface ocean currents. The Coriolis effect 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.



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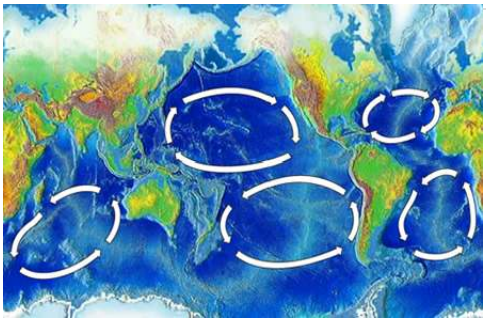
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9.7: Shape of the Ocean Basin



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. Near 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.You can see on the map below the major surface ocean currents that the surface ocean currents create loops called **gyres**.

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?



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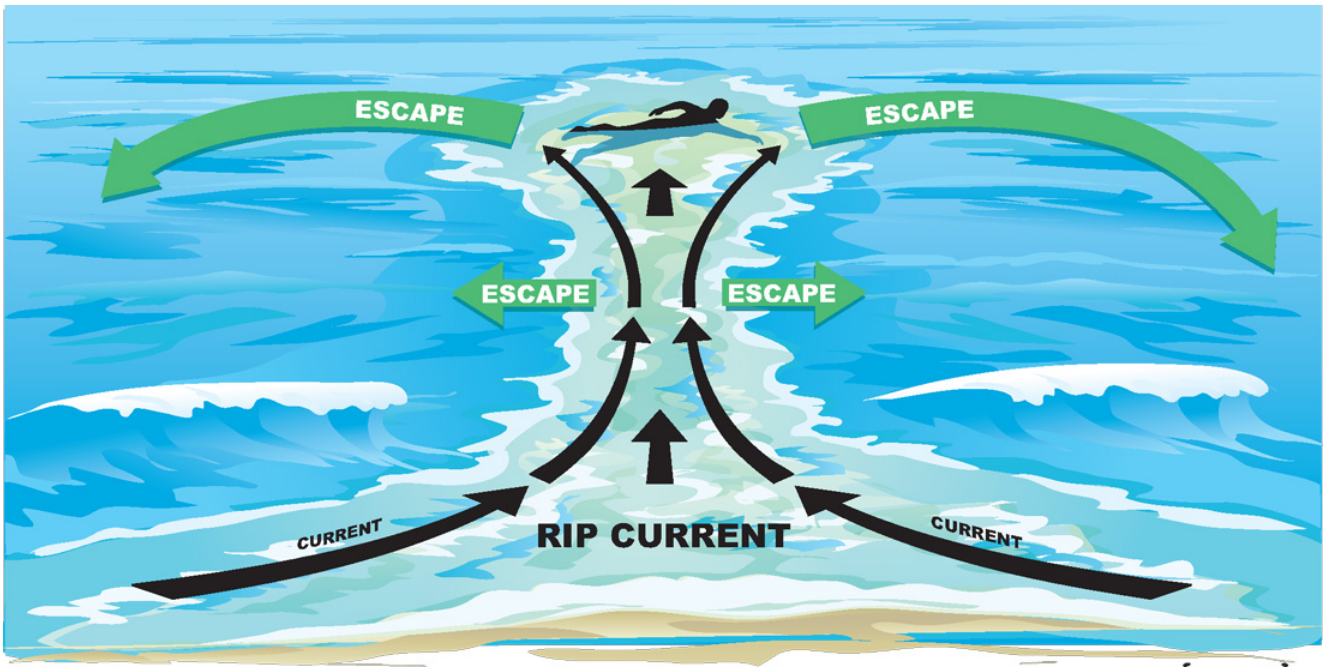
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9.8: Local and Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines. Two are *long shore currents* and *rip currents*. **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. Each summer in the United States at least a few people die when they are caught in rip currents.**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. 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 degrees C (5 to 11 degrees F). London, U.K., for example, is at the same latitude as Quebec, Canada. However, London's average January temperature is 3.8 degrees C (38 degrees F), while Quebec's is only -12 degrees C (10 degrees 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.

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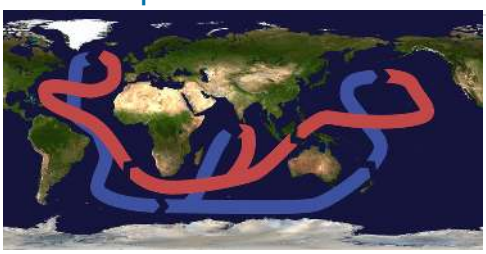
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9.9: Deep Currents



Red arrows indicate surface water currents and blue arrows indicate deep water 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**.

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. Water also sinks into the deep ocean 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**.

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.

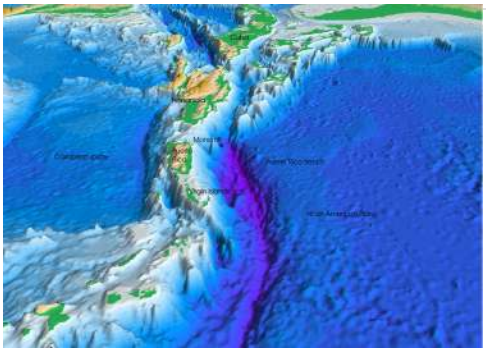
Upwelling also takes place along the equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the equator so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

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9.10: Studying the Seafloor



Bathymetric map of the Puerto Rico trench.

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. 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.

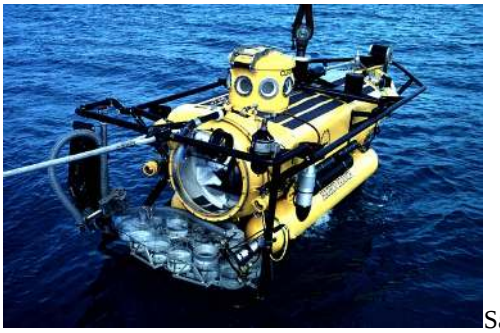
Mapping

In the Plate Tectonics chapter, you learned that echo sounders designed to locate enemy submarines allowed scientists to create bathymetric maps of the seafloor. 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.

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

Submersibles



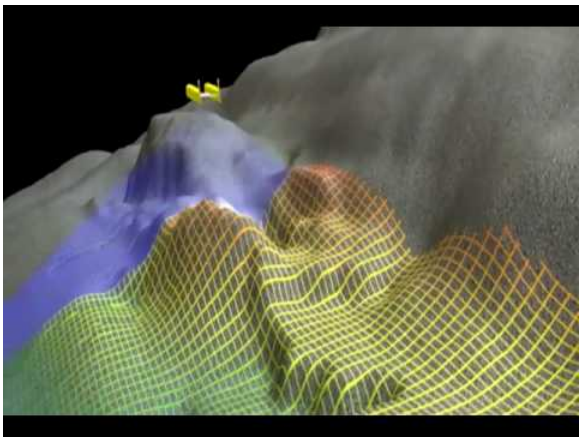
Samples of seawater and rocks can be collected directly by scientists in a **submersible**. These subs can take scientists down to make observations and the subs have arms for collecting samples. The submersible Alvin is an HOV, a human operated vehicle. Alvin can dive up to 4,500 m beneath the ocean surface and has made more than 4000 dives since 1964. Other submersibles can dive deeper.

View a slide show of DSV Alvin and its history from the Woods Hole Oceanographic Institution

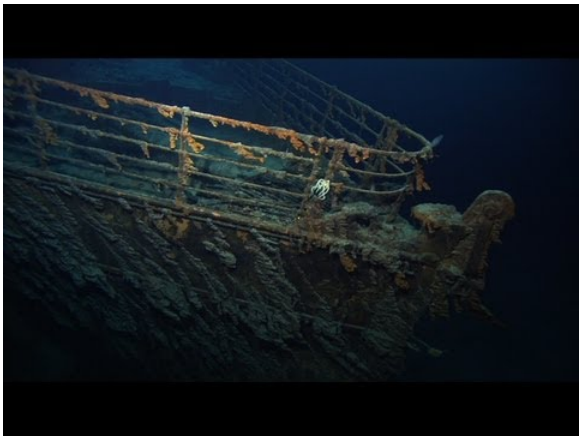
Remotely Operated Vehicles

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.



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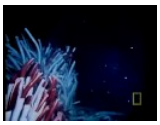
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9.11: Hydrothermal Vents

At mid-ocean ridges at **hydrothermal vents**, bacteria that use chemosynthesis for food energy are the base of a unique ecosystem. 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.



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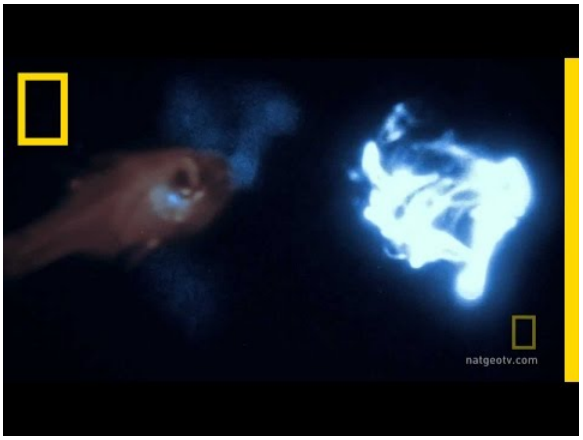
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9.12: Oceanic Zone

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.

The few species that live in the greatest depths are very specialized. 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.



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9.13: 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.

Intertidal

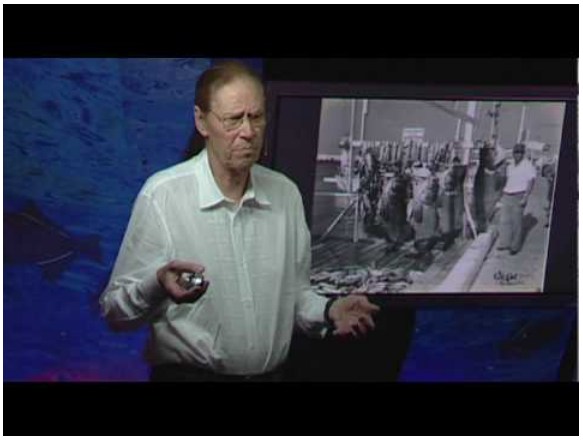


A great abundance of life is found in the intertidal zone. High energy waves pound the organisms that live in this zone and so they must be adapted to pounding waves and exposure to air during low tides. Hard shells protect from pounding waves and also protect against drying out when the animal is above water. Strong attachments keep the animals anchored to the rock.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.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. Eventually, all that is left is a reef island called an **atoll**. A **lagoon** is found inside the reef.

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.



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9.14: Types of Ocean Organisms

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. It's interesting to note that the smallest and largest animals on Earth live in the oceans.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. **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. **Zooplankton**, or animal plankton, eat phytoplankton as their source of food. 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.

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.

Marine Invertebrates



The variety and number of **invertebrates**, animals without a backbone, is truly remarkable. 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.

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).





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. Sea snakes bear live young in the ocean, but turtles, crocodiles, and marine iguanas all lay their eggs on land.

Seabirds and Marine Mammals



Many types of birds are adapted to living in the sea or on the shore. 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.

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9.15: Ocean Resources

Living Resources

 The ocean provides important living and nonliving resources. To be maintained for future use, these resources must be managed sustainably. Most fish are caught by lines or nets as they swim in the open waters of the ocean. Some species of fish are being over-harvested, 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.NONLIVING

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. A description of the Deepwater Horizon oil spill affecting the Gulf of Mexico is located in the Human Actions and Earth's Waters chapter.The seafloor has some valuable minerals. **Manganese nodules** containing manganese, iron, copper, nickel, phosphate, and cobalt 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?

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CHAPTER OVERVIEW

10: The Atmosphere

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10.2: Significance of the Atmosphere
10.3: Atmospheric Gasses
10.4: Layers of the Atmosphere
10.5: Atmospheric Energy, Temperature, and Heat
10.6: Energy from the Sun
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10.8: Atmospheric Movements and Flow
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10.10: The Polar Front and Jet Streams

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10.1: Introduction to the Atmosphere

Learning Objectives

The goals and objectives of this chapter are to:

- Understand the significance of the atmosphere.
- Describe the composition of the atmospheric gasses.
- Explain the major layers of the atmosphere and their importance.
- Analyze the relationships between energy, temperature, and heat.
- Describe how the Sun influences seasonality.
- Describe how heat is transferred around the planet.

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10.2: Significance of the Atmosphere



Earth's atmosphere is a thin blanket of gases and tiny particles: together called air. We are most aware of air when it moves and creates wind. All living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock. 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.

Indispensable for Life of 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?

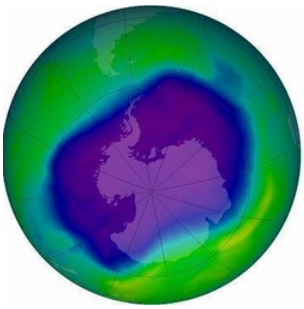
In **photosynthesis** plants use CO_2 and create O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere. By creating oxygen and food, plants have made an environment that is favorable for animals. In respiration, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

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 Layer Makes Life Possible



Ozone is a molecule composed of three oxygen atoms, (O3). 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.

Moderates Earth's Temperature

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. 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.

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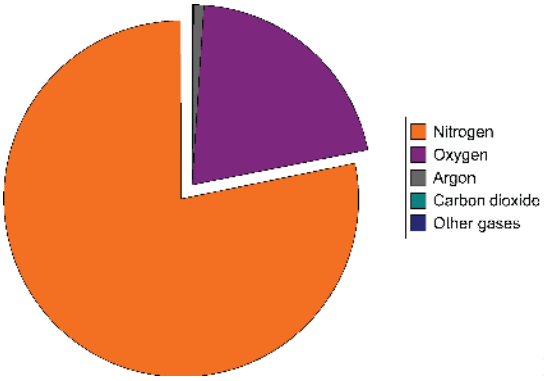
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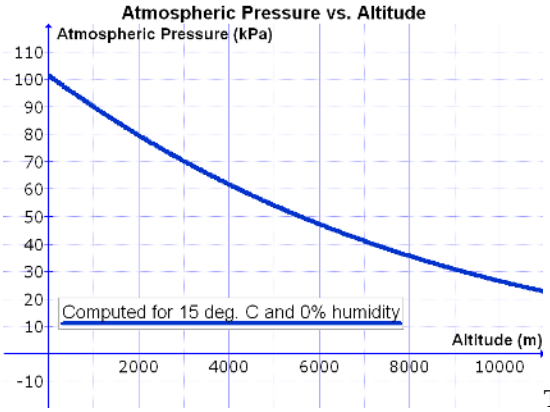
10.3: Atmospheric Gasses

Composition of the Atmosphere



Nitrogen and oxygen together make up 99 percent of the planet's atmosphere. The rest of the gases are minor components but sometimes are very important. **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? 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.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.

Atmospheric 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.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**. The reason why we are not crushed by this weight is because the molecules inside our bodies are pushing outward to compensate. Atmospheric pressure is felt from all directions, not just from above.

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.

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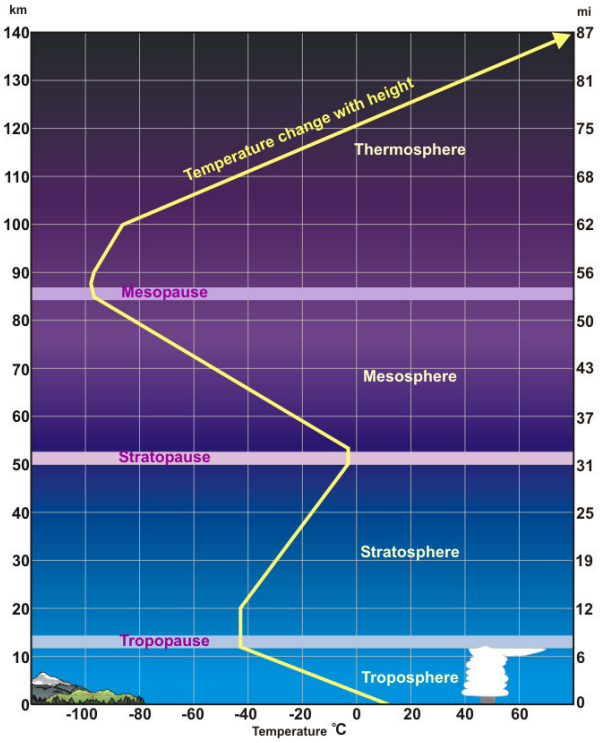
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10.4: Layers of the Atmosphere



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.Why does warm air rise? 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. 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. 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 6.5o ºC per 1,000 m (3.6o ºF per 1,000 ft.) of altitude. What is the source of heat for the troposphere?

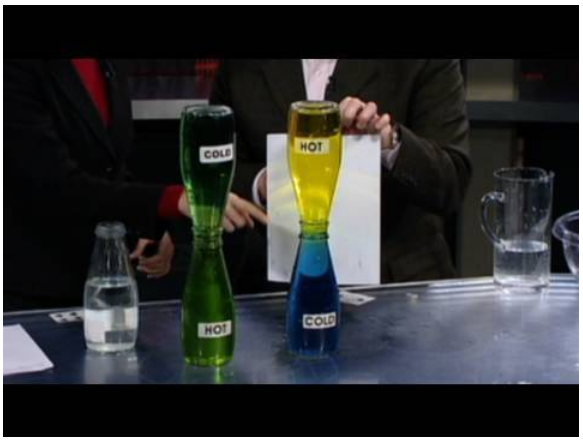
Earth's surface is a major source of heat for the troposphere, although nearly all of that heat comes from the Sun. Rock, soil, and water on Earth absorb the Sun's light and radiate it back into the atmosphere as heat. The temperature is also higher near the surface because of the greater density of 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. They 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. 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.



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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.

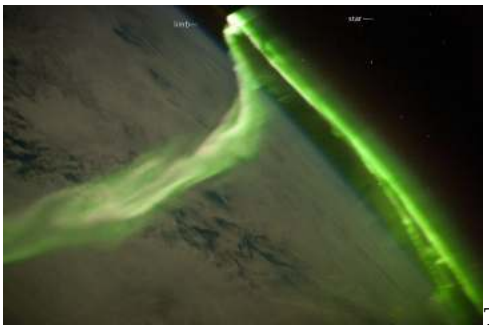
The **ozone layer** is found within the stratosphere between 15 to 30 km (9 to 19 miles) altitude. The thickness of the ozone layer varies by the season and also by latitude. The ozone layer is extremely important because ozone gas in the stratosphere absorbs most of the Sun's harmful ultraviolet (UV) 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.

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 degrees C (−130 degrees F).

The air in the mesosphere has extremely low density: 99.9 percent of the mass of the atmosphere is below the mesosphere. As a result, air pressure is very low. 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.

Thermosphere



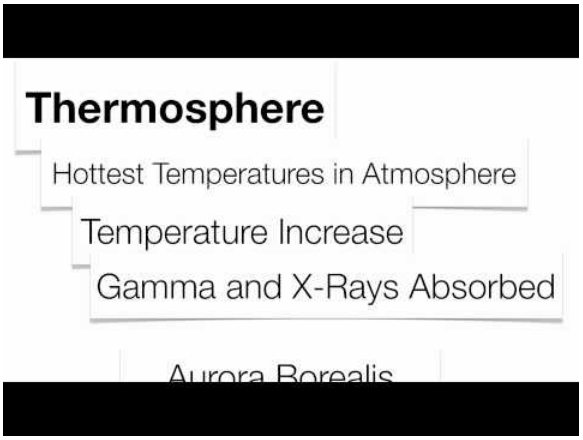
The density of molecules is so low in the **thermosphere** that one gas molecule can go about 1 km before it collides with another molecule. Since so little energy is transferred, the air feels very cold. Within the thermosphere is the **ionosphere**. The ionosphere gets its name from the solar radiation 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**. 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.

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.

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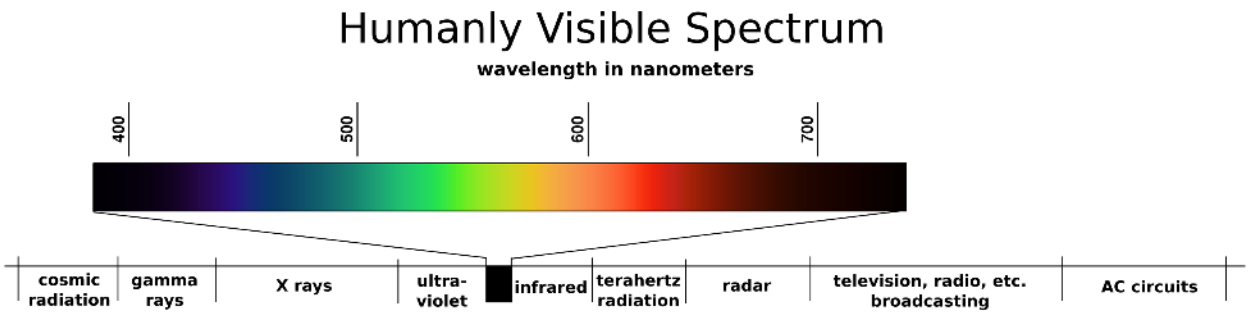
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10.5: Atmospheric Energy, Temperature, and Heat

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.

- 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.



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 degrees C (212 degrees 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 degrees C (1.8 degrees 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.

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10.6: Energy from the Sun

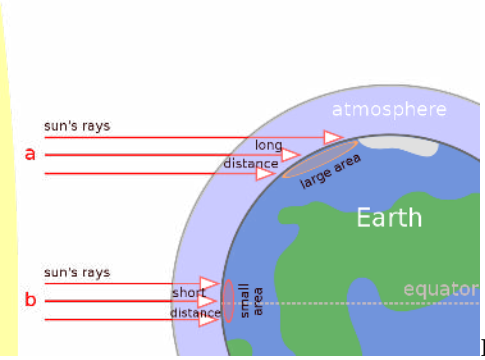
The earth constantly tries to maintain an energy balance with the atmosphere. Most of the energy that reaches the Earth's surface comes from the Sun. About 44 percent of solar radiation is in the visible light wavelengths, but the Sun also emits infrared, ultraviolet, and other wavelengths. When viewed 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.

Of the solar energy that reaches the outer atmosphere, UV wavelengths have the greatest energy. Only about 7 percent 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. Some of the wavelengths of solar radiation traveling through the atmosphere may be lost because they are absorbed by various gases. Ozone completely removes UVC, most UVB and some UVA from incoming sunlight. Oxygen, carbon dioxide, and water vapor also filter out some wavelengths.

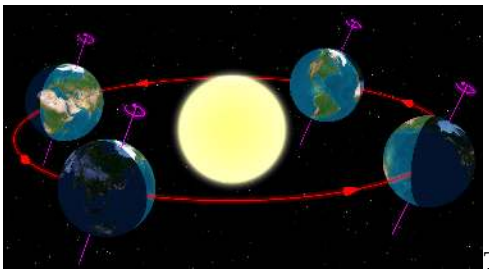
Solar Radiation on Earth



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 degrees 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. At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5 degrees 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.

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. 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.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an *equinox*. 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.

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10.7: 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 and is transferred, 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.

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 percent 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.
Because solar energy continually enters Earth's atmosphere and ground surface, is the planet getting hotter? The answer is no (although the next section contains an exception) because energy from Earth escapes into space through the top of the atmosphere. If the amount that exits is equal to the amount that comes in, then average global temperature stays the same. This means that the planet's heat budget is in balance. What happens if more energy comes in than goes out? If more energy goes out than comes in?

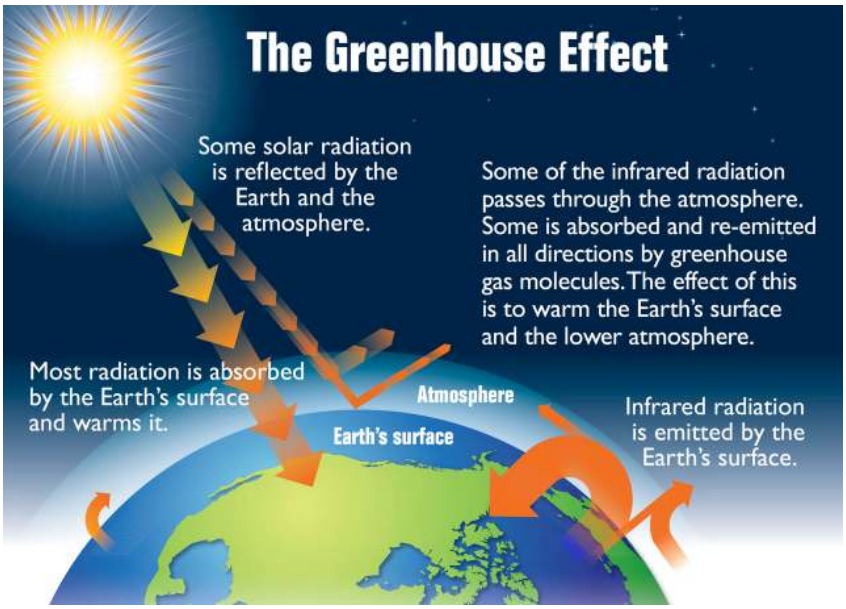
To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes). Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why?

The difference in solar energy received at different latitudes drives atmospheric circulation.

	Day Length	Sun Angle	Solar Radiation	Albedo
Equatorial Region	Nearly same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

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**. Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.



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. The 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 percent. 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.

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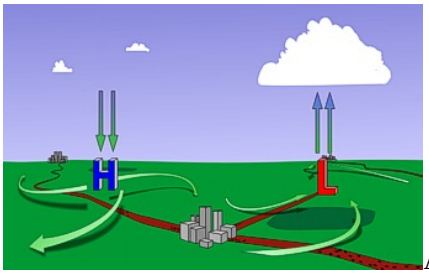
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10.8: Atmospheric Movements and Flow

Atmospheric Pressure and Winds



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.

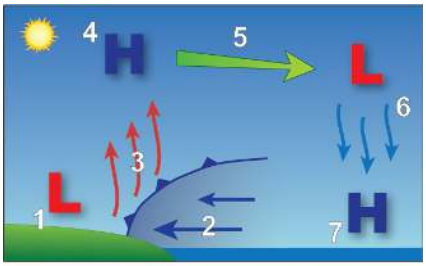
Within the troposphere are convection cells. Air that moves horizontally between high and low pressure zones makes **wind**. The greater the pressure difference between the pressure zones the faster the wind flow.

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.

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



Formation of the sea breeze

Since water has a very high specific heat, it maintains its temperature well. So water heats and cools more slowly than land. If there is a large temperature difference between the surface of the sea (or a large lake) and the land next to it, high and low pressure regions form. This creates local winds.

Sea breezes blow from the cooler ocean over the warmer land in summer. Where is the high pressure zone and where is the low pressure zone?

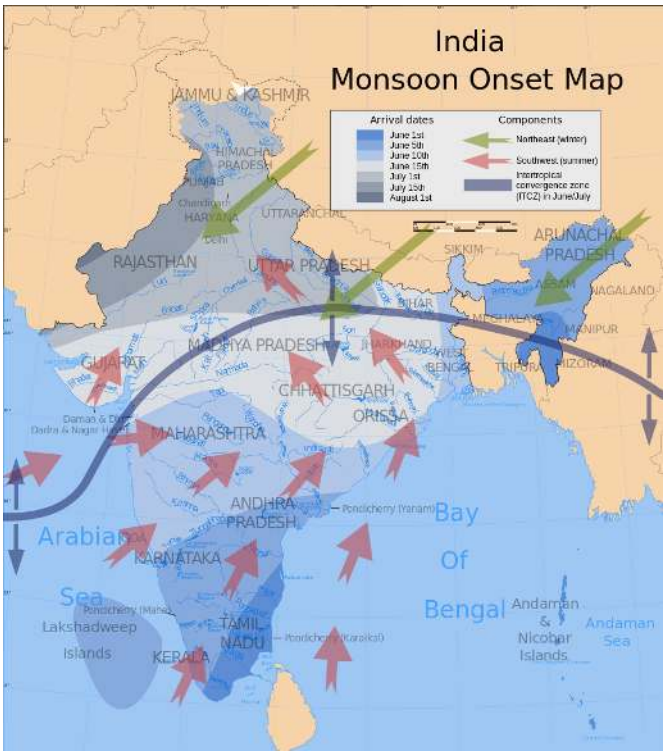
Sea breezes blow at about 10 to 20 km (6 to 12 miles) per hour and lower air temperature much as 5 to 10 degrees C (9 to 18 degrees F).

Land breezes blow from the land to the sea in winter. Where is the high pressure zone and where is the low pressure zone? Some warmer air from the ocean rises and then sinks on land, causing the temperature over the land to become warmer.

Land and sea breezes create the pleasant climate for which Southern California is known. The effect of land and sea breezes are felt only about 50 to 100 km (30 to 60 miles) inland. This same cooling and warming effect occurs to a smaller degree during day and night, because land warms and cools faster than the ocean.

Monsoonal 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.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.



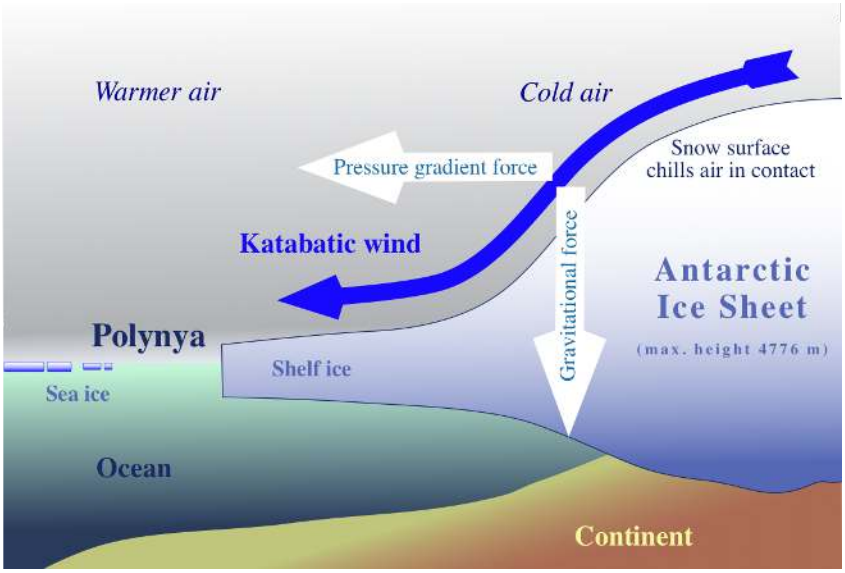
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Mountain and Valley Breezes

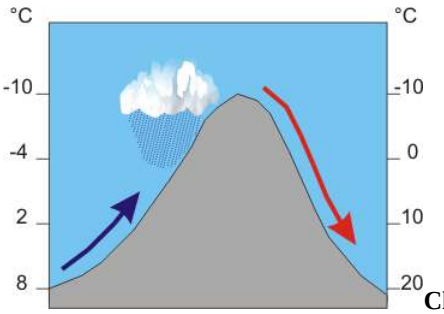
Temperature differences between mountains and valleys create mountain and valley breezes. During the day, air on mountain slopes is heated more than air at the same elevation over an adjacent valley. As the day progresses, warm air rises and draws the cool air up from the valley, creating a **valley 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

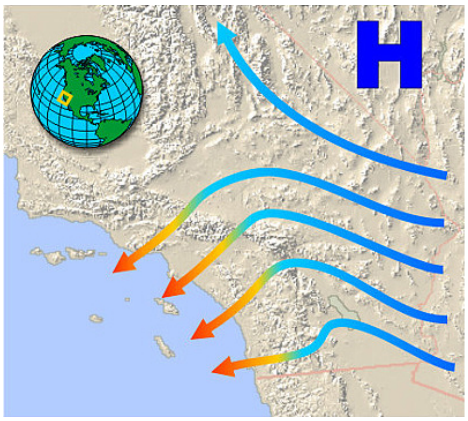


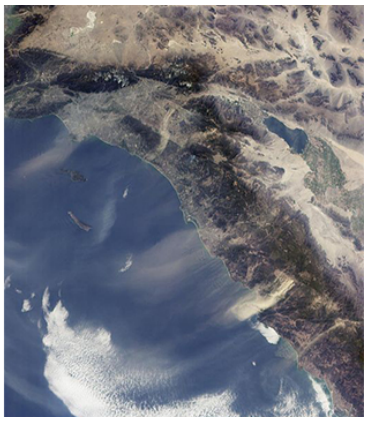
Chinook winds, also called **Foehn winds**, develop when air is forced up over a mountain range. This takes place, for example, when the westerly winds bring air from the Pacific Ocean over the Sierra Nevada Mountains in California. As the relatively warm, moist air rises over the windward side of the 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 20oC (36oF) 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**, which creates many of the world's deserts.

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.

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.





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. A **haboob** forms in the downdrafts on the front of a thunderstorm. The image on the left if of a nabob. **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.

On July 5, 2011 Phoenix Arizona experienced a large-scale haboob that was captured by many people using their smartphones and cameras. Watch this video of that event.

https://youtu.be/8vQMuwRjI6s

This video shows a giant duet devil:



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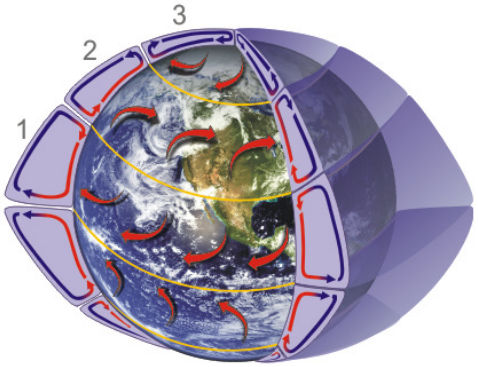
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10.9: Global Atmospheric Circulations

Global Atmospheric Pressure



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. 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 30oN 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 degrees and 30 degrees N.

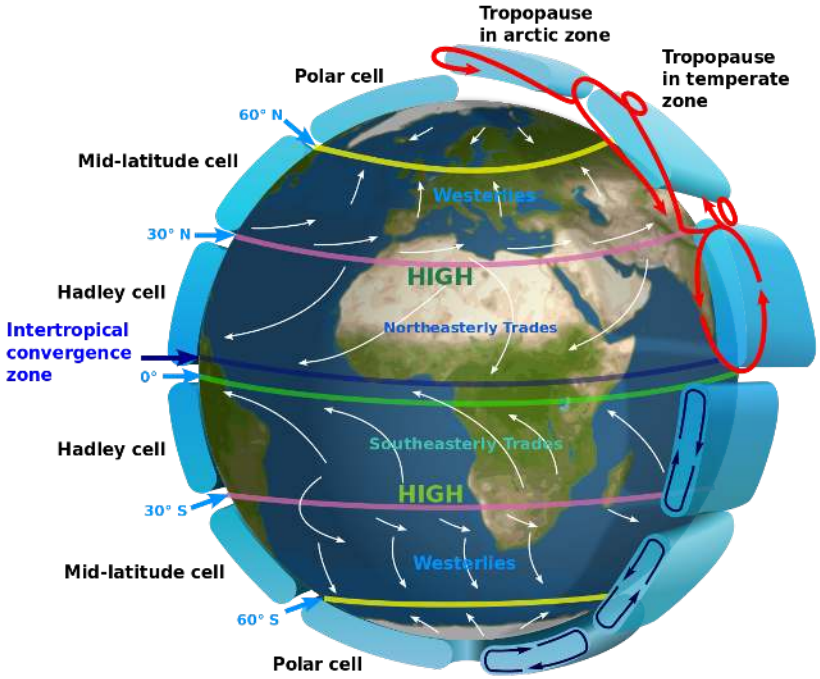
There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30oN and 50o to 60oN. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50 degrees N to 60 degrees N and the 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. Ultimately, because there are three large-scale convection cells in the Northern Hemisphere and are repeated in the Southern Hemisphere, the model to understand these patterns is called the **three-cell model**.

Global Wind Patterns

Global winds blow in belts encircling the planet. The global wind belts are enormous and the winds are relatively steady. 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. Technology today allows anyone to see global wind patterns in real-time, such as Earth Wind Map. Take a look at the Earth Wind Map and determine what patterns you can see occurring in the atmosphere in real-time. Are low pressure systems rotating counter-clockwise in the Northern Hemisphere? Are high pressure systems rotating clockwise in the Northern Hemisphere? Can you see the global wind patterns over the Atlantic and Pacific Oceans? Also notice how the winds flow faster over water than over continents because of land friction.

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?

Finally, 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.

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.





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10.10: The Polar Front and Jet Streams

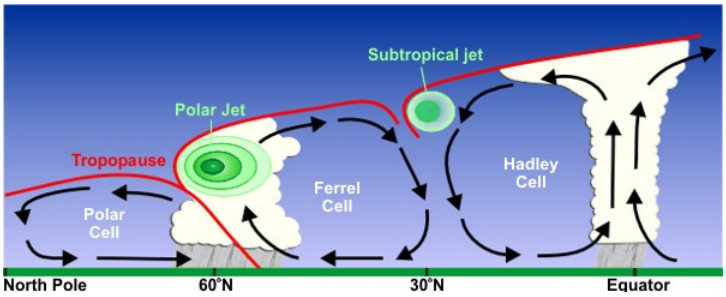
The **polar front** is the junction between the Ferrell and Polar cells. At this low pressure zone, relatively warm, moist air of the Ferrell Cell runs into relatively cold, dry air of the Polar cell. The weather where these two meet is extremely variable, typical of much of North America and Europe.

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.



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This explains why the polar jet stream is the world's most powerful. Jet streams move seasonally just as the angle of the Sun in the sky migrates north and south. The polar jet stream, known as "the jet stream," moves south in the winter and north in the summer.



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CHAPTER OVERVIEW

11: Weather Processes and Systems

11.1: Introduction to Weather Processes and Systems
11.2: Weather and Atmospheric Water
11.3: Air Masses
11.4: Weather Front
11.5: Thunderstorms
11.6: Tornadoes
11.7: Cyclones
11.8: Collecting Weather Data

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11.1: Introduction to Weather Processes and Systems

Learning Objectives

This chapter has several goals and objectives:

- Describe the various aspects and elements of weather and atmospheric water.
- Explain how air masses and weather fronts together form mid-latitude cyclones.
- Describe the three phases a thunderstorm goes through in it's life cycle.
- Determine the causes and geographic location of most tornadoes around the world.
- Describe the genesis of hurricanes formation
- Compare the difference between blizzards lake effects, and heat waves.

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11.2: Weather and Atmospheric Water

Elements of Weather

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.

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, and 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.



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Humidity



Humidity is the amount of water vapor in the air in a particular spot. We usually use the term to mean **relative humidity**, the percentage of water vapor a certain volume of air is holding relative to the maximum amount it can contain. If the humidity today is 80 percent, it means that the air contains 80 percent of the total amount of water it can hold at that temperature. What will happen if the humidity increases to more than 100 percent? The excess water condenses and forms precipitation.

Since warm air can hold more water vapor than cool air, raising or lowering temperature can change air's relative humidity. 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 percent humidity.

Clouds



Clouds have a big influence on weather by preventing solar radiation from reaching the ground; absorbing warmth that is re-emitted from the ground; and 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.

There are a variety of conditions needed for clouds to form. First, 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 percent 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.



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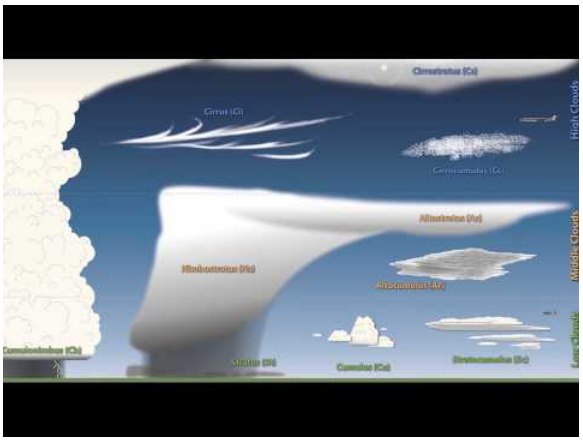


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Clouds are classified in several ways. The most common classification used today divides clouds into four separate cloud groups, which are determined by their altitude and if precipitation is occurring or not.

- *High-level clouds* form from ice crystals where the air is extremely cold and can hold little water vapor. **Cirrus**, **cirrostratus**, and **cirrocumulus** are all names of high clouds. Cirrocumulus clouds are small, white puffs that ripple across the sky, often in rows. Cirrus clouds may indicate that a storm is coming.
- *Middle-level clouds*, including **altocumulus** and **altostratus** clouds, may be made of water droplets, ice crystals or both, depending on the air temperatures. Thick and broad altostratus clouds are gray or blue-gray. They often cover the entire sky and usually mean a large storm, bearing a lot of precipitation, is coming.
- *Low-level clouds* are nearly all water droplets. **Stratus**, **stratocumulus** and **nimbostratus** clouds are common low clouds. Nimbostratus clouds are thick and dark that produce precipitation.
- Clouds with the prefix *cumulo–* grow vertically instead of horizontally and have their bases at low altitude and their tops at high or middle altitude. Clouds grow vertically when strong unstable air currents are rising upward. Common clouds include **cumulus humilis**, **cumulus mediocris**, **cumulus congestus**, and **cumulonimbus**.

To learn more about the various types of cloud formations from the National Oceanic and Atmospheric Administration (NOAA), click here.



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Fog



Fog 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**.

Precipitation



Precipitation is an extremely important part of weather. Some precipitation forms in place. The most common precipitation comes from clouds. Rain or snow droplets grow as they ride air currents in a cloud and collect other droplets. 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.



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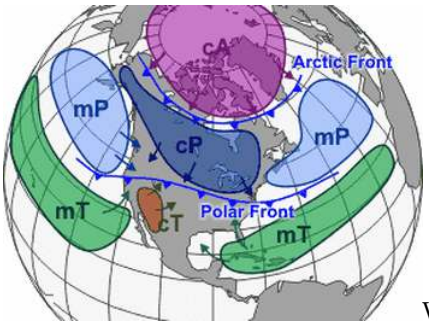
11.3: Air Masses

An **air mass** is a large mass of air that has similar characteristics of *temperature* and *humidity* within it. 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.



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Air Mass Formation



Where an air mass receives it's characteristics of temperature and humidity is called the **source region**. 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. 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. Air masses are classified based on their temperature and humidity characteristics. Below are examples of how air masses are classified over North America.

- **Maritime tropical (mT):** moist, warm air mass
- **Continental tropical (cT):** dry, warm air mass
- **Maritime polar (mP):** moist, cold air mass
- **Continental polar (cP):** dry, cold air mass

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

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11.4: Weather Front

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.

When two air masses meet together, the boundary between the two is called a **weather front**. At a front, the two air masses have different densities, based on temperature, 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.



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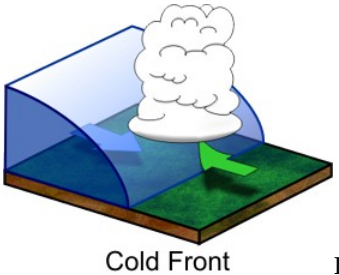
Stationary Fronts

At a **stationary front** the air masses do not move. 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. When a cold air mass takes the place of a warm air mass, there is a cold front.

Cold Fronts



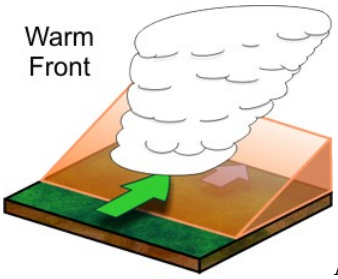
Cold Front

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. 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. A **squall line** is a line of severe thunderstorms that forms along a cold front. Behind the front is the cold air mass. This mass is drier so precipitation stops. The weather may be cold and clear or only partly cloudy. Winds may continue to blow into the low pressure zone at the front. The weather at a cold front varies with the season.

- spring and summer: The air is unstable so thunderstorms or tornadoes may form.
- spring: If the temperature gradient is high, strong winds blow.
- autumn: Strong rains fall over a large area.
- winter: The cold air mass is likely to have formed in the frigid arctic so there are frigid temperatures and heavy snows.

Warm Fronts



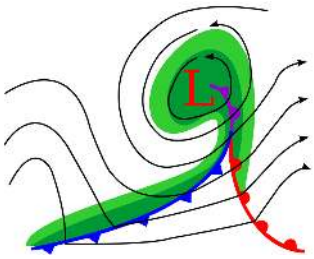
Along a **warm front**, a warm air mass slides over a cold air mass. When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable. Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition from cold air to warm air takes place over a long distance so the first signs of changing weather appear long before the front is actually over you.

Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. The clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog.

Occluded Fronts

An **occluded front** usually forms around a low pressure system. The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again.





Coriolis Effect curves the boundary where the two fronts meet towards the pole. If the air mass that arrives third is colder than either of the first two air masses, that air mass slip beneath them both. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass rides over the other air mass. This is called a warm occlusion.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.

Remember, a weather front is basically the boundary between two air masses of different densities. At the center of each air mass is typically a high pressure. This means that weather is typically sunny within air masses, but their temperatures could vary with the season and humidity could vary based on the source region of the air mass.

Now more often than not, these weather fronts are not isolated events. Often times, they are part of a larger rotating system called a mid-latitude cyclone. This type of cyclone will be discussed later in this chapter, but as an introduction it is a low pressure system that is usually mixing warmer air from the south (in the Northern Hemisphere) and colder air from the north.

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11.5: Thunderstorms



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.

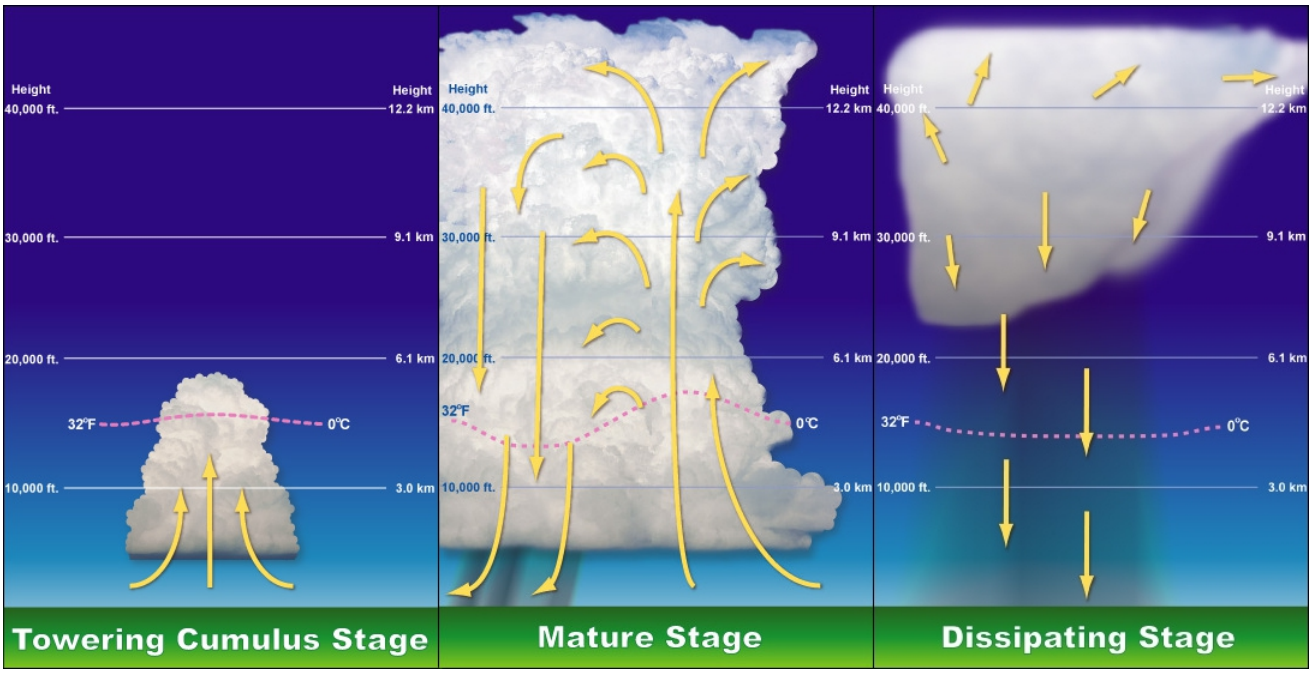
Thunderstorms are extremely common: Worldwide there are 14 million per year; that's 40,000 per day! Most drop a lot of rain on a small area quickly, but some are severe and highly damaging. They form when ground temperatures are high, ordinarily in the late afternoon or early evening in spring and summer. The two figures below show two stages of thunderstorm buildup.

Thunderstorm Genesis

All thunderstorms go through a three-stage life cycle. The first stage is called the **cumulus stage**, where an air parcel is forced to rise, cool, and condense, called the lower condensation level, to develop into a cumulus cloud. The process of water vapor condensing into liquid water releases large quantities of latent heat, which makes the air within the cloud warmer, and unstable causing the cloud continues to grow upward like a hot air balloon. These rising air parcels, called updrafts, prevent precipitation from falling from the cloud. But once the precipitation becomes too heavy for the updrafts to hold up, the moisture begins to fall creating downdrafts within the cloud. The downdrafts also begin to pull cold, dry air from outside the cloud toward the ground in a process called **entrainment**.

Once the precipitation begins to fall from the cloud, the storm has reached the **mature stage**. During this stage, updrafts and downdrafts exist side-by-side and the cumulonimbus is called a **cell**. If the updrafts reach the top of the troposphere, the cumulus cloud will begin to spread outward creating a defined **anvil**. At the same time, the downdrafts spread within the cloud and at first make the cloud become wider, but eventually overtaking the updrafts. Cool downdrafts form when precipitation and the cool air from entrainment are dragged down to the lower regions of a thunderstorm. It is also during the mature stage when the storm is most intense producing strong, gusting winds, heavy precipitation, lightning, and possibly small hail.

Once the downdrafts overtake the updrafts, which also prevents the release of latent heat energy, the thunderstorm will begin to weaken into the third and final stage, called the **dissipating stage**. During this stage, light precipitation and downdrafts become the dominate feature within the cloud as it weakens. In all, only twenty percent of the moisture within the cloud fell as precipitation whereas the other eighty percent evaporates back into the atmosphere.





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.

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result. The electrical discharge may be between one part of the cloud and another, two clouds, or a cloud and the ground.

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.



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11.6: Tornadoes

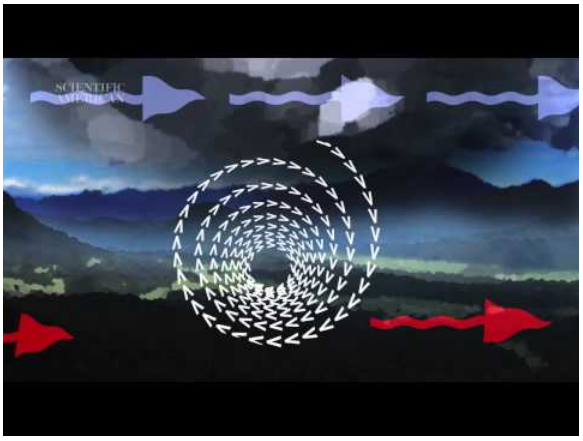


Tornadoes, also called twisters, are fierce products of severe thunderstorms. As air in a thunderstorm rises, the surrounding air races in to fill the gap, forming a funnel. A tornado lasts from a few seconds to several hours. The average wind speed is about 177 kph (110 mph), but some winds are much 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.

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. 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.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.



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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.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.

The intensity of tornadoes is measured on the Fujita Scale, which assigns a value based on wind speed and damage.

F-Scale	3 Second Gust (mph)	Damage
EF0 (Gale)	65–85	**Light:** tree branches fall and chimneys may collapse
EF1 (Weak)	86–110	**Moderate:** mobile homes, automobiles pushed aside
EF2 (Strong)	111–135	**Considerate:** roofs torn off houses, large trees uprooted
EF3 (Severe)	136–165	**Severe:** houses torn apart, trees uprooted, cars lifted
EF4 (Devastating)	166–200	**Devastating:** houses leveled, cars thrown
EF5 (Incredible)	Over 200	**Incredible:** structures fly, cars become missiles

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11.7: Cyclones

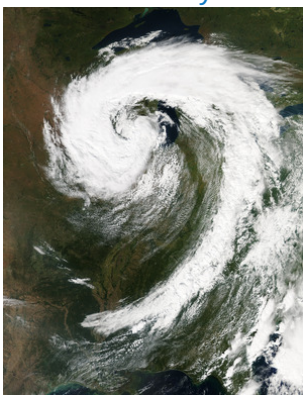


Cyclones can be the most intense storms on Earth. A **cyclone** is a system of winds rotating counterclockwise in the Northern Hemisphere around a low pressure center. The swirling air rises and cools, creating clouds and precipitation.

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.

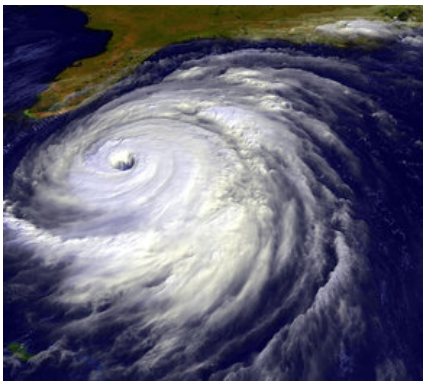
Mid-Latitude Cyclones



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.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.

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. By any name, they are the most damaging storms on Earth. Hurricanes arise in the tropical latitudes (between 10 degrees and 25 degrees N) in summer and autumn when sea surface temperature are 28 degrees C (82 degrees 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 degrees C (82 degrees 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.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.



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At the center or heart of the hurricane is called the **eye**. Within the eye of a hurricane, winds are light, precipitation is minimal, and occasionally the skies above are clear. It is the calm region of the tropical storm, but that is what makes it so dangerous. Many people tend to go outside as the eye moves overhead because they believe the storm is over. But what some don't realize is that "round two" is coming from behind.

Moving away from the eye wall are organized, intense thunderstorms, called **spiral rain bands**, that rotate around and toward the storm's eye wall. These rain bands are the first

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the **Saffir-Simpson Scale**.

Category	MPH	Estimated Damage
1 (Weak)	74–95	Above normal; no read damage to structures
2 (Moderate)	96–110	Some property damage; considerable damage to vegetation
3 (Strong)	111–130	Some buildings damaged; mobile homes destroyed
4 (Very strong)	131–156	Complete roof failure on small residences; major beach erosion of beach areas
5 (Devastating)	Over 156	Complete roof and some building failure on most residential and industrial buildings

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.

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.

For over a decade, the conversation in the United States over hurricanes was directed toward Hurricane Katrina. But in late October 2012, a Category 3 hurricane called Hurricane Sandy, sometimes called Superstorm Sandy, struck the eastern coast of the United States. It is estimaged that the storm system caused $68 billion in damage and killed nearly 300 people.

What made Hurricane Sandy different from most tropical storms was how powerful it was so late in the hurricane season. The concern is that as the planet warms from anthropogenic (human-enhanced) climate change, the oceans will likely warm up allow hurricanes to become stronger, travel farther toward the poles, and the hurricane season last longer.



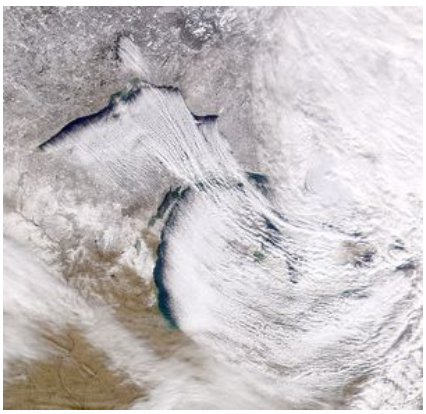
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To view an interactive map on hurricanes created by the National Oceanic and Atmospheric Administration, click here.

Blizzards and Lake Effects

A **blizzard** is distinguished by certain conditions:

- Temperatures below –7 degrees C (20 degrees F); –12oC (10 degrees 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.



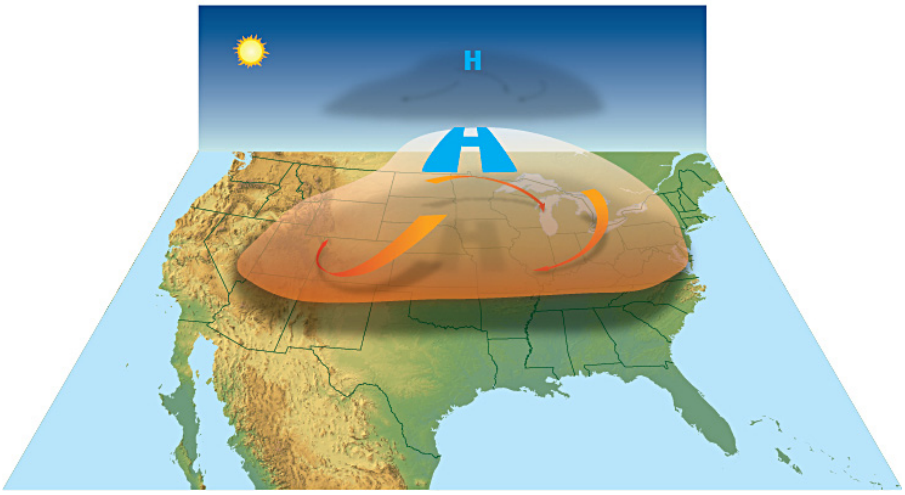
Lake-effect snow off the Great Lakes

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. 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**.

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.

Heat Waves

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 degrees F (30 degrees 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?



A high pressure zone kept the jet stream further north than normal for August.

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11.8: Collecting Weather Data

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.

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.

Thermometers



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.

Barometers

Meteorologists use **barometers** to measure air pressure. A barometer may contain water, air, or mercury, but like thermometers, barometers are now mostly digital. A change in barometric pressure indicates that a change in weather is coming. If air pressure rises, a high pressure cell is on the way and clear skies can be expected. If pressure falls, a low pressure cell is coming and will likely bring storm clouds. Barometric pressure data over a larger area can be used to identify pressure systems, fronts, and other weather systems.

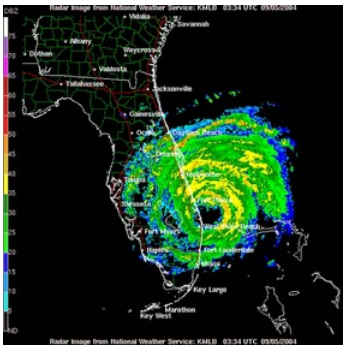
Weather Stations

Weather stations contain some type of thermometer and barometer. Other instruments measure different characteristics of the atmosphere such as wind speed, wind direction, humidity, and amount of precipitation. These instruments are placed in various locations so that they can check the atmospheric characteristics of that location. 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. The official weather stations used by the National Weather Service is called the Automated Surface Observing System (ASOS).

Radiosondes

Radiosondes is a balloon that measures atmospheric characteristics, such as temperature, pressure, and humidity as they move through the air. Radiosondes in flight can be tracked to obtain wind speed and direction. Radiosondes use a radio to communicate the data they collect to a computer. Radiosondes are launched from about 800 sites around the globe twice daily to provide a profile of the atmosphere. Radiosondes can be dropped from a balloon or airplane to make measurements as they fall. This is done to monitor storms, for example, since they are dangerous places for airplanes to fly.

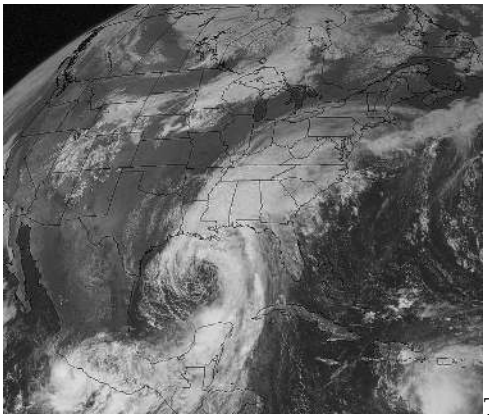
Radar



Radar stands for Radio Detection and Ranging. 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.

Satellites

Weather satellites have been increasingly important sources of weather data since the first one was launched in 1952 and 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.

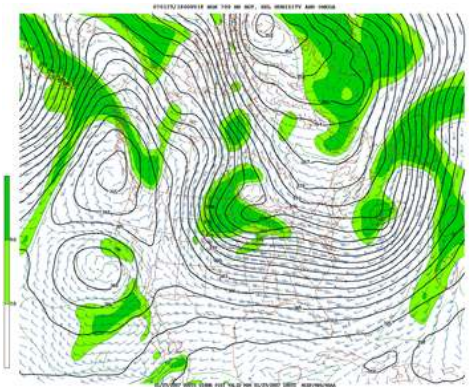


They also observe all energy from all wavelengths in the electromagnetic spectrum.The flagship of the National Weather Service is the Geostationary Operational Environmental Satellites (GOES). These satellites are the ones you see on the nightly news where it looks like the clouds are moving, but not the planet. That is because these satellites are “geo-fixed” on a particular location over Earth rotating around the planet as fast as Earth’s rotation at a distance of over 23,000 miles above the planet. There are basically three different types of GOES: visible, infrared, and water vapor. 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**.** The final type of GOES imagery is water vapor. This type of imagery looks at the moisture content in the upper-half of the atmosphere. This is important for determining if clouds can grow to great heights like cumulonimbus thunderstorms.

The other type of satellite commonly used in weather forecasting is called a Polar Orbiting Environmental Satellites (POES). These types of satellites fly much lower to the earth, only about 530 miles, and orbit the planet pole-to-pole. You’ve probably seen these satellites at night when you see one crossing the sky. Look for their direction and odds are they are moving northward or southward toward each pole.

Just like the weather satellites on the news, you’ve seen these images often when you are looking at natural disasters like hurricanes or volcanic eruptions, wars like have occurred in Afghanistan, Iraq, or recently in Syria. Even the Malaysian flight that “disappeared” in the Indian Ocean for weeks was ultimately discovered using polar orbiting satellites. Common types of these satellites include: Landsat, MODIS, and the Tropical Rainfall Measuring Mission (TRMM).

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. The models then calculate what will happen over time at various altitudes for a grid of evenly spaced locations. The grid points are usually between 10 and 200 kilometers apart. Using the results calculated by the model, the program projects weather further into the future. It then uses these results to project the weather still further into the future, as far as the meteorologists want to go. Once a forecast is made, it is broadcast by satellites to more than 1,000 sites around the world.

NWP produces the most accurate weather forecasts, but as anyone knows, even the best forecasts are not always right. Weather prediction is extremely valuable for reducing property damage and even fatalities. If the proposed track of a hurricane can be predicted, people can try to secure their property and then evacuate.

Weather maps

Weather maps, also called **synoptic maps**, simply and graphically depict meteorological conditions in the atmosphere from a spatial perspective. 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. Metorologists use many different symbols as a quick and easy way to display information on the map.



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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:

- **Isotherms**, likes connecting points of equal temperature. They spatially show temperature gradients and can indicate the location of a front. In terms of precipitation, what does the 0 ºC (32 ºF) isotherm show?
- **Isobars** are lines of equal average air pressure at sea level. Closed isobars represent the locations of high and low pressure cells.
- **Isotachs** are lines of constant wind speed. Where the minimum values occur high in the atmosphere, tropical cyclones may develop. The highest wind speeds can be used to locate the jet stream.

Surface weather analysis maps are weather maps that only show conditions on the ground**.**

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CHAPTER OVERVIEW

12: Climate Systems and Change

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12.2: Controls of Climate
12.3: Climate Zones and Biomes
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12.5: Dry Climates (Group B)
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12.1: Introduction to Climate Systems and Change

Learning Objectives

This chapter has several goals and objectives:

- Explain the controlling factors of global climates.
- Describe the various global climates and biomes classified using the Koppen Classification System.
- Analyze Earth's climatic past and how scientists measure and collect climate data.
- Describe the causes of short-term and long-term climate change.
- Determine why the overwhelming majority of scientists believe the current warming of the planet is because of
- human activity.

Essential Questions

- In what ways does climate influence regional culture?
- What impacts could a changing climate have on local, regional, and international social, economic, and geopolitical stability?
- Should global environmental issues like climate change be resolved by individuals, nations, or international institutions like the United Nations?
- What is your worldview on global environmental issues and how they should be addressed?

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12.2: Controls of Climate

 Although almost anything can happen with the weather, climate is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's. Climate then is the long-term average of weather. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good!

Climate is the average of weather in that location over a long period of time, usually for at least 30 years. A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation. Climate can change, but only over long periods of time. The climate of a region depends on its position relative to many things. These factors are described in the next sections.

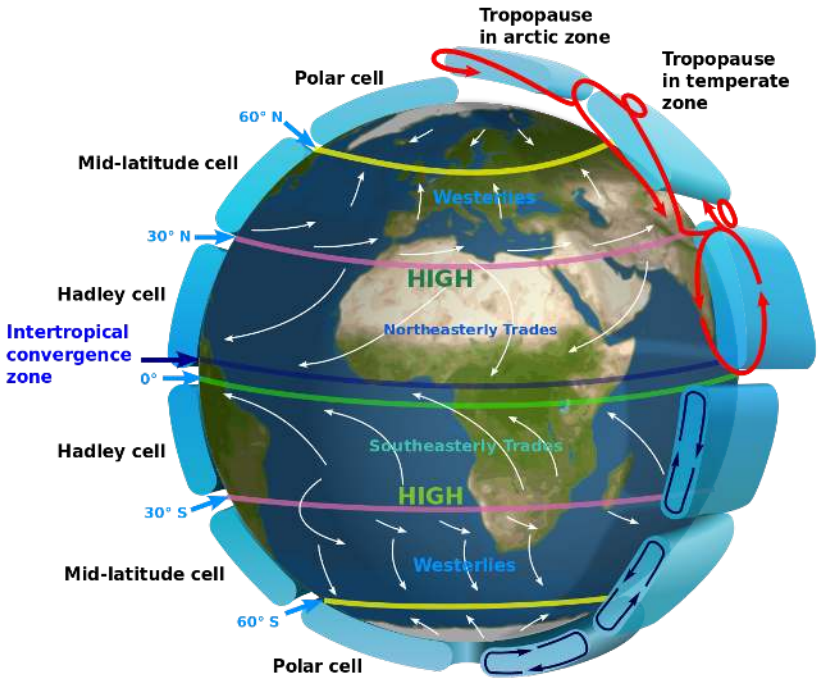
Latitude

The main factor influencing the climate of a region is latitude because different latitudes receive different amounts of solar radiation. To review from the Earth's Atmosphere chapter:

- The equator receives the most solar radiation. Days are equally long year-round and the sun is just about directly overhead at midday.
- The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the sun's light.

Atmospheric Circulation

Recall from the Earth's Atmosphere chapter the circulation cells and global wind belts. The position of a region relative to the circulation cells and wind belts has a great effect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.



Intertropical Convergence Zone

The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain. Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail because there were no steady winds.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5o north of the equator while in the winter it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area.

Hadley Cell and Ferrel Cell Boundaries

At about 30 degrees N and 30 degrees S, the air is fairly warm and dry because much of it came from the equator where it lost most of its moisture at the ITCZ. At this location the air is descending, and sinking air warms and causes evaporation.

Mariners named this region the horse latitudes. Sailing ships were sometimes delayed for so long by the lack of wind that they would run out of water and food for their livestock. Sailors tossed horses and other animals over the side after they died. Sailors sometimes didn't make it either.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and Polar Cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. For example, in California, the predominant winds are the westerlies blowing in from the Pacific Ocean, which bring in relatively cool air in summer and relatively warm air in winter. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

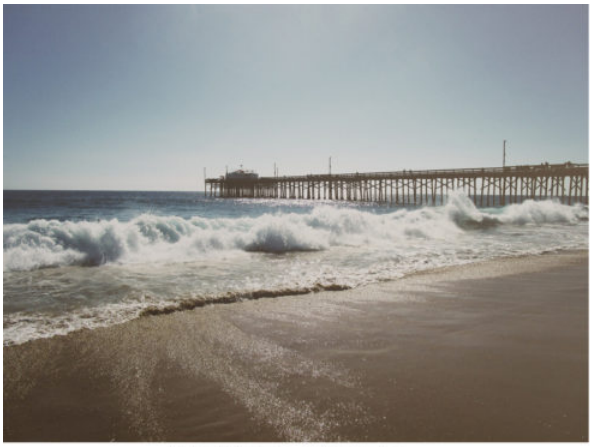
Continental Position

When a particular location is near an ocean or large lake, the body of water plays an extremely important role in affecting the region's climate.

- A **maritime climate** is strongly influenced by the nearby sea. Temperatures vary a relatively small amount seasonally and daily. For a location to have a true maritime climate, the winds must most frequently come off the sea.

- A **continental climate** is more extreme, with greater temperature differences between day and night and between summer and winter.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37 ºN latitude, within the westerly winds.

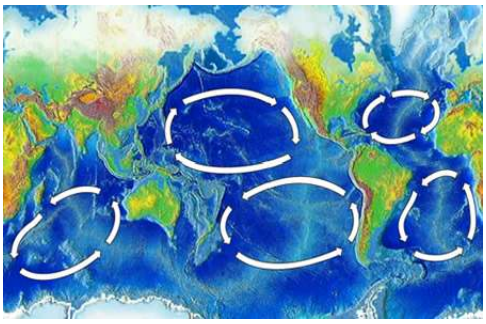


Maritime climate



Continental climate

Ocean Currents



The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of along the western United States is caused by a clockwise rotating ocean current that is bringing cold water from the arctic toward the equator. The climatic effect is that coastal regions of California, Oregon, and Washington are are cool. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. But that same ocean current brings warm, tropical water to eastern Japan.In the Atlantic Ocean, the northern ocean current, called the **Gulf Stream**, brings warm water from the tropics to the southern states. This is a major reason why the southern states experience humid conditions in the summer and tornadoes because of all this warm moisture. The Gulf Stream also impacts Europe by bringing warm water northward, making this region that is rather northward warmer than expected.

Altitude and Mountain Ranges



Air pressure and air temperature decreases with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher

altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood (5,640 feet) average annual temperature is 62 degrees F (17 degrees C), while Climax Lake (11,300 feet) is 42 degrees F (5.4 degrees C).

Mountain ranges have two effects on the climate of the surrounding region. The first is something called the **rainshadow effect**, which brings warm dry climate to the leeward size of a mountain range, was described in the Earth's Atmosphere chapter**.** The second effect mountains have on climate systems is the ability to separate coastal regions from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

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12.3: Climate Zones and Biomes

A **climate zone** results from the climate conditions of an area: its temperature, humidity, amount and type of precipitation, and the season. A climate zone is reflected in a region's natural vegetation. Perceptive travelers can figure out which climate zone they are in by looking at the vegetation, even if the weather is unusual for the climate on that day.

The major factors that influence climate determine the different climate zones. In general, the same type of climate zone will be found at similar latitudes and in similar positions on nearly all continents, both in the Northern and Southern Hemispheres. The one exception to this pattern is the climate zones called the continental climates, which are not found at higher latitudes in the Southern Hemisphere. This is because the Southern Hemisphere land masses are not wide enough to produce a continental climate.

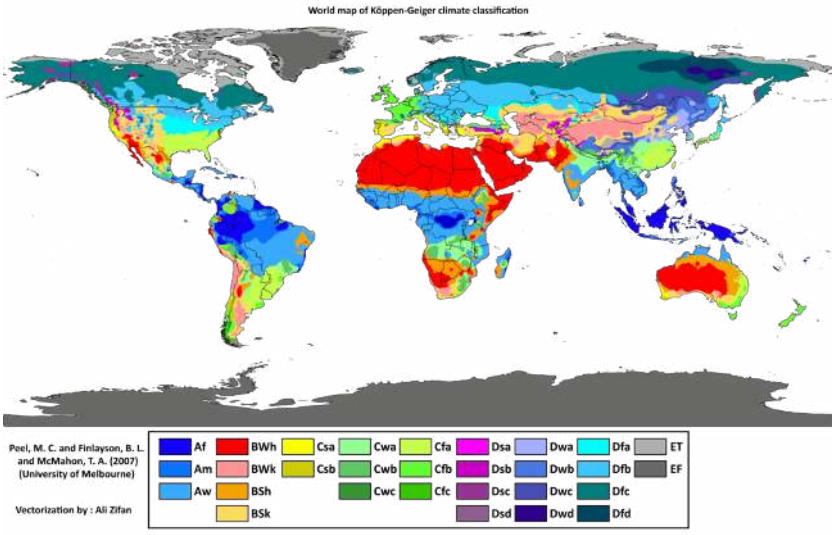


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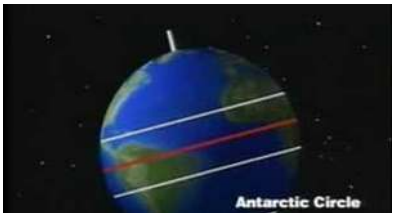
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The most common system used to classify climatic zones is the **Köppen classification system**. This system is based on the *temperature*, the amount of *precipitation*, and the times of year when precipitation occurs. Since climate determines the type of vegetation that grows in an area, vegetation is used as an indicator of climate type.



Click for a larger image

A climate type and its plants and animals make up a **biome**. The organisms of a biome share certain characteristics around the world, because their environment has similar advantages and challenges. The organisms have adapted to that environment in similar ways over time. For example, different species of cactus live on different continents, but they have adapted to the harsh desert in similar ways.



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The Köppen classification system recognizes five major climate groups, each with a distinct capital letter A through E. Each lettered group is divided into subcategories. Some of these subcategories are forest (f), monsoon (m), and wet/dry (w) types, based on the amount of precipitation and season when that precipitation occurs.

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12.4: Tropical Moist Climates (Group A)

Tropical Moist (Group A) climates are found in a band about 15º to 25º N and S of the equator. What climate characteristics is the tropical moist climate group likely to have?

- Temperature: Intense sunshine; each month has an average temperature of at least 18 ºC (64 ºF).
- Rainfall: Abundant, at least 150 cm (59 inches) per year.



The wet tropics have almost no annual temperature variation and tremendous amounts of rain fall year round, between 175 and 250 cm (65 and 100 inches). These conditions support the tropical rainforest biome. **Tropical rainforests** are dominated by densely packed, broadleaf evergreen trees. These rainforests have the highest number of species or **biodiversity** of any ecosystem.

Tropical Monsoon (Am)

The tropical monsoon climate has very low precipitation for one to two months each year. Rainforests grow here because the dry period is short, and the trees survive off of soil moisture. This climate is found where the monsoon winds blow, primarily in southern Asia, western Africa, and northeastern South America.

Tropical Wet and Dry

The tropical wet and dry climate lies between about 5o and 20o latitude, around the location of the ITCZ. In the summer, when the ITCZ drifts northward, the zone is wet. In the winter, when the ITCZ moves toward the equator, the region is dry. This climate exists where strong monsoon winds blow from land to sea, such as in India.

Rainforests cannot survive the months of low rainfall, so the typical vegetation is **savanna**. This biome consists mostly of grasses, with widely scattered deciduous trees and rare areas of denser forests.

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12.5: Dry Climates (Group B)

The Dry Climates (Group B) have less precipitation than evaporation. Dry climate zones cover about 26 percent of the world's land area. What climate characteristics is the dry climate group likely to have?

- Temperature: Abundant sunshine. Summer temperatures are high; winters are cooler and longer than Tropical Moist climates
- Rainfall: Irregular; several years of drought are often followed by a single year of abundant rainfall

Arid Desert (Bw)



Low-latitude, arid deserts are found between 15º to 30º N and S latitudes. This is where warm dry air sinks at high pressure zones. True deserts make up around 12 percent of the world's lands.

In the Sonoran Desert of the southwestern United States and northern Mexico, skies are clear. The typical weather is extremely hot summer days and cold winter nights. Although annual rainfall is less than 25 cm (10 inches), rain falls during two seasons. Pacific storms bring winter rains and monsoons bring summer rains. Since organisms do not have to go too many months without some rain, a unique group of plants and animals can survive in the Sonoran desert**.**

Semi-Arid or Steppe (Bs)



Higher latitude semi-arid deserts, also called **steppe**, are found in continental interiors or in rainshadows. Semi-arid deserts receive between 20 and 40 cm (8 to 16 inches) of rain annually. The annual temperature range is large.

In the United States, the Great Plains, portions of the southern California coast, and the Great Basin are semi-arid deserts**.**

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12.6: Moist Subtropical Mid-latitude (Group C)

What climate characteristics is the moist subtropical group likely to have?

- **Temperature:** The coldest month ranges from just below freezing to almost balmy, between −3 ºC and 18 ºC (27º to 64 ºF). Summers are mild with average temperatures above 10 ºC (50 ºF). Seasons are distinct.
- **Rainfall:** There is plentiful annual rainfall.

Dry Summer Subtropical or Mediterranean Climates (Cs)



The Dry Summer Subtropical climate is found on the western sides of continents between 30º and 45º latitude. Annual rainfall is 30 to 90 cm (14 to 35 inches), most of which comes in the winter**.**

The climate is typical of coastal California, which sits beneath a summertime high pressure for about five months each year. Land and sea breezes make winters moderate and summers cool. Vegetation must survive long summer droughts. The scrubby, woody vegetation that thrives in this climate is called **chaparral**.

Humid Subtropical (Cfa)



The Humid Subtropical climate zone is found mostly on the eastern sides of continents**.** Rain falls throughout the year with annual averages between 80 and 165 cm (31 and 65 inches). Summer days are humid and hot, from the lower 30s up to 40 ºC (mid-80s up to 104 ºF). Afternoon and evening thunderstorms are common. These conditions are caused by warm tropical air passing over the hot continent. Winters are mild, but middle-latitude storms called cyclones may bring snow and rain. The southeastern United States, with its hot humid summers and mild, but frosty winters, is typical of this climate zone.

Marine West Coast Climate (Cfb)

This climate lines western North America between 40º and 65º latitude, an area known as the Pacific Northwest**.** Ocean winds bring mild winters and cool summers. The temperature range, both daily and annually, is fairly small. Rain falls year round, although summers are drier as the jet stream moves northward. Low clouds, fog, and drizzle are typical. In Western Europe the climate covers a larger region since no high mountains are near the coast to block wind blowing off the Atlantic.

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12.7: Humid Continental (Group D)



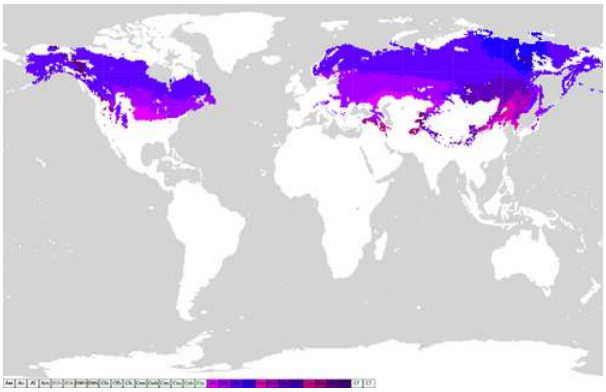
Continental (Group D) climates are found in most of the North American interior from about 40 °N to 70 °N. What climate characteristics is the continental group most likely to have?

- Temperature: The average temperature of the warmest month is higher than 10 °C (50 °F) and the coldest month is below −3 °C (−27 °F).
- Precipitation: Winters are cold and stormy (look at the latitude of this zone and see if you can figure out why). Snowfall is common and snow stays on the ground for long periods of time.

Trees grow in continental climates, even though winters are extremely cold, because the average annual temperature is fairly mild. Continental climates are not found in the Southern Hemisphere because of the absence of a continent large enough to generate this effect.

Humid Continental (Dfa, Dfb)

The humid continental climates are found around the polar front in North America and Europe.



In the winter, middle-latitude cyclones bring chilly temperatures and snow. In the summer, westerly winds bring continental weather and warm temperatures. The average July temperature is often above 20 ºC (70 ºF). The region is typified by deciduous trees, which protect themselves in winter by losing their leaves.

The two variations of this climate are based on summer temperatures.

- Dfa, long, hot summers: summer days may be over 38 ºC (100 ºF), nights are warm and the temperature range is large, perhaps as great as 31 ºC (56 ºF). The long summers and high humidity foster plant growth**.**
- Dfb, long, cool summers: summer temperatures and humidity are lower. Winter temperatures are below −18 ºC (0 ºF) for long periods.

Subpolar (Dfc)

 The subpolar climate is dominated by the continental polar air that masses over the frigid continent. Snowfall is light, but cold temperatures keep snow on the ground for months. Most of the approximately 50 cm (20 inches) of annual precipitation falls during summer cyclonic storms. The angle of the Sun's rays is low but the Sun is visible in the sky for most or all of the day during the summer, so temperatures may get warm, but are rarely hot. These continental regions have extreme annual temperature ranges.

The boreal, coniferous forests found in the subpolar climate are called **taiga** and have small, hardy, and widely spaced trees. Taiga vast forests stretch across Eurasia and North America.

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12.8: Polar Climates (Group E)

Polar climates are found across the continents that border the Arctic Ocean, Greenland, and Antarctica. What climate characteristics is the polar climate group most likely to have?

- Temperature: Winters are entirely dark and bitterly cold. Summer days are long, but the sun is low on the horizon so summers are cool. The average temperature of the warmest month at less than 10 ºC (50 ºF). The annual temperature range is large.
- Precipitation: The region is dry with less than 25 cm (10 inches) of precipitation annually; most precipitation occurs during the summer.

Polar Tundra (ET)



The polar tundra climate is continental, with severe winters. Temperatures are so cold that a layer of permanently frozen ground, called **permafrost** forms below the surface. This frozen layer can extend hundreds of meters deep. The average temperature of the warmest months is above freezing, so summer temperatures defrost the uppermost portion of the permafrost. In winter, the permafrost prevents water from draining downward. In summer, the ground is swampy. Although the precipitation is low enough in many places to qualify as a desert, evaporation rates are also low, so the landscape receives more usable water than a desert.

Because of the lack of ice-free land near the South Pole, there is very little tundra in the Southern Hemisphere. The only plants that can survive the harsh winters and soggy summers are small ground-hugging plants like mosses, lichens, small shrubs, and scattered small trees that make up the **tundra**.

Ice Cap

Ice caps are found mostly on Greenland and Antarctica, about 9 percent of the Earth's land area. Ice caps may be thousands of meters thick. Ice cap areas have extremely low average annual temperatures, e.g. −29 ºC (−20 ºF) at Eismitte, Greenland. Precipitation is low because the air is too cold to hold much moisture. Snow occasionally falls in the summer.



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12.9: Hightland Climates (Group H)



When climate conditions in a small area are different from those of the surroundings, the climate of the small area is called a **microclimate**. The microclimate of a valley may be cool relative to its surroundings since cold air sinks. The ground surface may be hotter or colder than the air a few feet above it, because rock and soil gain and lose heat readily. Different sides of a mountain will have different microclimates. In the Northern Hemisphere, a south-facing slope receives more solar energy than a north-facing slope, so each side supports different amounts and types of vegetation.

Altitude mimics latitude in climate zones. Climates and biomes typical of higher latitudes may be found in other areas of the world at high altitudes.

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12.10: Climate Change in Earth History

For the past two centuries, climate has been relatively stable. People placed their farms and cities in locations that were in a favorable climate without thinking that the climate could change. But climate has changed throughout Earth history, and a stable climate is not the norm. In recent years, Earth's climate has begun to change again. Most of this change is warming because of human activities that release greenhouse gases into the atmosphere. The effects of warming are already being seen and will become more extreme as temperature rise.



Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago. Glaciers advanced and retreated in cycles, known as glacial and interglacial periods. With so much of the world's water bound into the ice, sea level was about 125 meters (395 feet) lower than it is today. Many scientists think that we are now in a warm, interglacial period that has lasted about 10,000 years.

For the past 2,000 years, climate has been relatively mild and stable when compared with much of Earth's history. Why has climate stability been beneficial for human civilization? Stability has allowed the expansion of agriculture and the development of towns and cities.

Fairly small temperature changes can have major effects on global climate. The average global temperature during glacial periods was only about 5.5 degrees C (10 degrees F) less than Earth's current average temperature. Temperatures during the interglacial periods were about 1.1 degrees C (2.0 degrees F) higher than today.

Since the end of the Pleistocene, the global average temperature has risen about 4 degrees C (7 degrees F). Glaciers are retreating and sea level is rising. While climate is getting steadily warmer, there have been a few more extreme warm and cool times in the last 10,000 years. Changes in climate have had effects on human civilization.

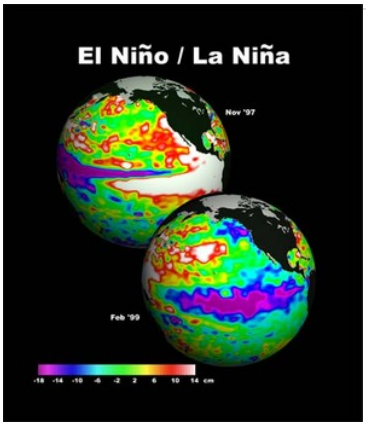
- The Medieval Warm Period from 900 to 1300 A.D. allowed Vikings to colonize Greenland and Great Britain to grow wine grapes.
- The Little Ice Age, from the 14th to 19th centuries, the Vikings were forced out of Greenland and humans had to plant crops further south.

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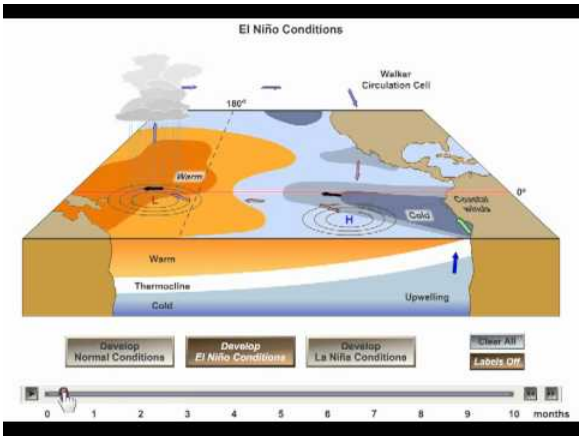
12.11: Short-term Climate Changes



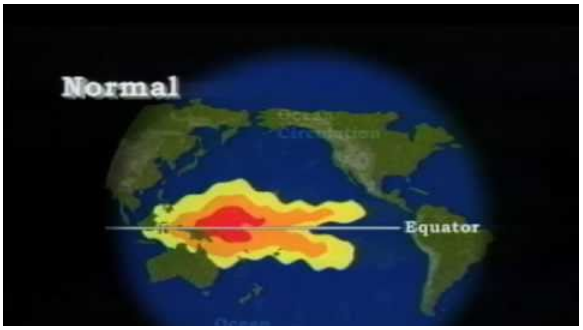
Short-term changes in climate are common. The largest and most important of these is the oscillation between El Niño and La Niña conditions. This cycle is called the ENSO (El Niño southern oscillation). The ENSO drives changes in climate that are felt around the world about every two to seven years.

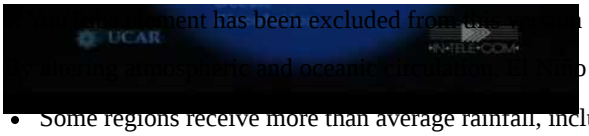
In a normal year, the trade winds blow across the Pacific Ocean near the equator from east to west (toward Asia). A low pressure cell rises above the western equatorial Pacific. Warm water in the western Pacific Ocean and raises sea levels by one-half meter. Along the western coast of South America, the Peru Current carries cold water northward, and then westward along the equator with the trade winds. Upwelling brings cold, nutrient-rich waters from the deep sea.

In an **El Niño** year, when water temperature reaches around 28 degrees C (82 degrees F), the trade winds weaken or reverse direction and blow east (toward South America)**.** Warm water is dragged back across the Pacific Ocean and piles up off the west coast of South America. With warm, low-density water at the surface, upwelling stops. Without upwelling, nutrients are scarce and plankton populations decline. Since plankton form the base of the food web, fish cannot find food, and fish numbers decrease as well. All the animals that eat fish, including birds and humans, are affected by the decline in fish.



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affecting atmospheric and oceanic circulation. El Niño events change global climate patterns.

- Some regions receive more than average rainfall, including the west coast of North and South America, the southern United States, and Western Europe.
- Drought occurs in other parts of South America, the western Pacific, southern and northern Africa, and southern Europe.

An El Niño cycle lasts one to two years. Often normal circulation patterns resume. Sometimes circulation patterns bounce back quickly and extremely, called **La Niña**.

In a La Niña year, as in a normal year, trade winds moves from east to west and warm water piles up in the western Pacific Ocean. Ocean temperatures along coastal South America are colder than normal (instead of warmer, as in El Niño). Cold water reaches farther into the western Pacific than normal.

Other important oscillations are smaller and have a local, rather than global, effect. The North Atlantic Oscillation mostly alters climate in Europe. The Mediterranean also goes through cycles, varying between being dry at some times, and warm and wet at others.

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12.12: Causes of Long-term Climate Change

Many processes can cause climate to change. These include changes in the amount of energy the Sun produces over years; the positions of the continents over millions of years; in the tilt of Earth's axis; orbit over thousands of years; that are sudden and dramatic because of random catastrophic events, such as a large asteroid impact; in greenhouse gases in the atmosphere, caused naturally or by human activities.

Plate Tectonics

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents are joined into one supercontinent (such as Pangaea), nearly all locations experience a continental climate. When the continents separate, heat is more evenly distributed.Plate tectonic movements may help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age.

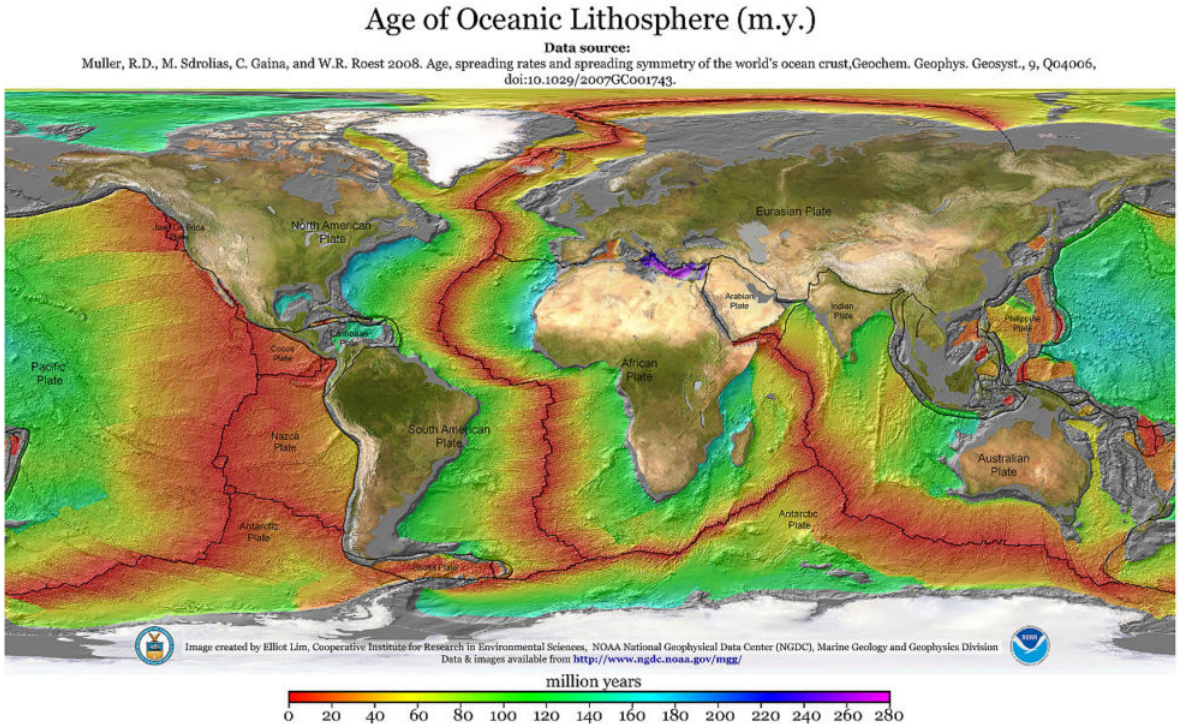
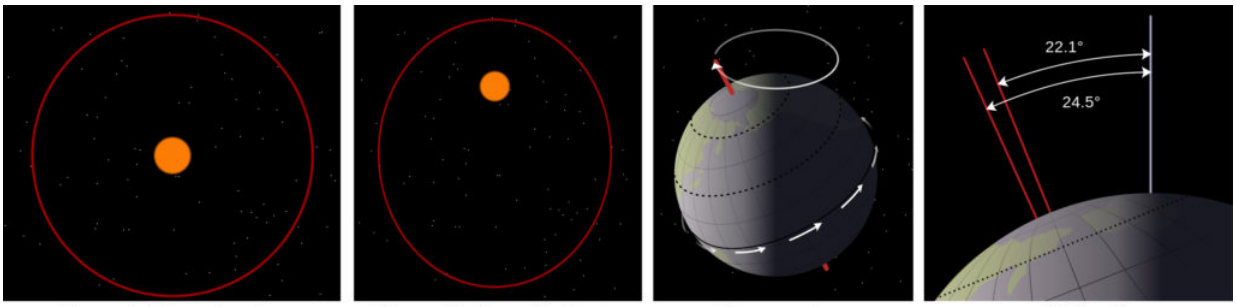


Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather. Massive eruptions of the fluid lavas that create lava plateaus release much more gas and dust, and can change climate for many years. This type of eruption is exceedingly rare; none has occurred since humans have lived on Earth.

Milankovitch Cycles

The most extreme climate of recent Earth history was the Pleistocene. Scientists attribute a series of ice ages to variation in the Earth's position relative to the Sun, known as **Milankovitch cycles**. The Earth goes through regular variations in its position relative to the Sun:

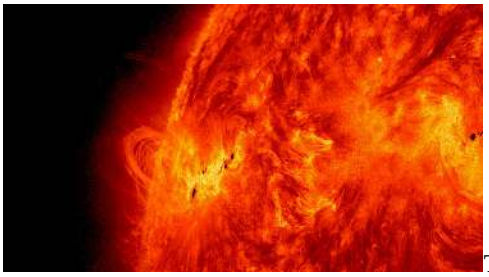


The shape of the Earth's orbit changes slightly as it goes around the Sun. The orbit varies from more circular to more elliptical in a cycle lasting between 90,000 and 100,000 years. When the orbit is more elliptical, there is a greater difference in solar radiation between winter and summer.

The planet wobbles on its axis of rotation. At one extreme of this 27,000 year cycle, the Northern Hemisphere points toward the Sun when the Earth is closest to the Sun. Summers are much warmer and winters are much colder than now. At the opposite extreme, the Northern Hemisphere points toward the Sun when it is farthest from the Sun. This results in chilly summers and warmer winters.The planet's tilt on its axis varies between 22.1 degrees and 24.5 degrees. Seasons are caused by the tilt of Earth's axis of rotation, which is at a 23.5o angle now. When the tilt angle is smaller, summers and winters differ less in temperature. This cycle lasts 41,000 years.

When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

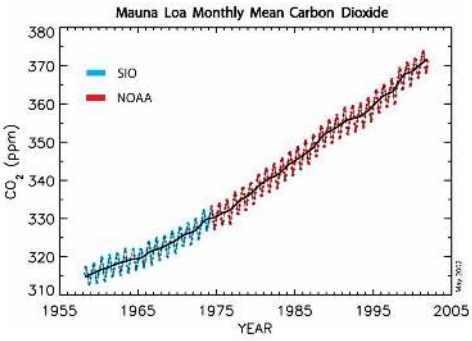
Sun Variation



The amount of energy the Sun radiates is variable. **Sunspots** are magnetic storms on the Sun's surface that increase and decrease over an eleven-year cycle. When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is and there is no known eleven-year cycle in climate variability.

The Little Ice Age corresponded to a time when there were no sunspots on the Sun.

Changes in Atmospheric Greenhouse Gas Levels



Since greenhouse gases trap the heat that radiates off the planet's surfaces what would happen to global temperatures if atmospheric greenhouse gas levels decreased? What if greenhouse gases increased? A decrease in greenhouse gas levels decreases global temperature and an increase raises air temperature.

Greenhouse gas levels have varied throughout Earth history. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods. Natural processes add (volcanic eruptions and the decay or burning of organic matter) and remove absorption by plants, animal tissue, and the ocean) CO_2 from the atmosphere. When plants are turned into fossil fuels the CO_2 in their tissue is stored with them. So CO_2 is removed from the atmosphere. What does this do to Earth's average temperature?

Fossil fuel use has skyrocketed in the past few decades more people want more cars and industrial products. This has released CO_2 into the atmosphere.

Burning tropical rainforests, to clear land for agriculture, a practice called **slash-and-burn agriculture**, also increases atmospheric CO_2. By cutting down trees, they can no longer remove CO_2 from the atmosphere. Burning the trees releases all the CO_2 stored in the trees into the atmosphere.

There is now nearly 40 percent more CO_2 in the atmosphere than there was 200 years ago, before the Industrial Revolution. About 65 percent of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958. CO_2 is the most important greenhouse gas that human activities affect because it is so abundant. But other greenhouse gases are increasing as well. A few are:

- Methane: released from raising livestock, rice production, and the incomplete burning of rainforest plants.
- Chlorofluorocarbons (CFCs): human-made chemicals that were invented and used widely in the twentieth century.
- Tropospheric ozone: from vehicle exhaust, it has more than doubled since 1976.

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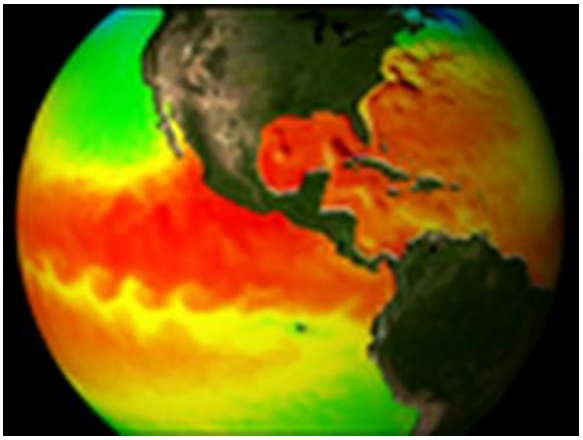
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12.13: Anthropogenic Climate Change

Temperatures are Rising

With more greenhouse gases trapping heat, average annual global temperatures are rising. This is known as **global warming**. While temperatures have risen since the end of the Pleistocene, 10,000 years ago, this rate of increase has been more rapid in the past century, and has risen even faster since 1990. The nine warmest years on record have all occurred since 1998, and the 10 of the 11 warmest years have occurred since 2001 (through 2012). The 2000s were the warmest decade yet. Annual variations aside, the average global temperature increased about 0.8 degrees C (1.5 degrees F) between 1880 and 2010, according to the Goddard Institute for Space Studies, NOAA.



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The United States has long been the largest emitter of greenhouse gases, with about 20 percent of total emissions in 2004. As a result of China's rapid economic growth, its emissions surpassed those of the United States in 2008. However, it's also important to keep in mind that the United States has only about one-fifth the population of China. What's the significance of this? The average United States citizen produces far more greenhouse gases than the average Chinese person.If nothing is done to decrease the rate of CO_2 emissions, by 2030, CO_2 emissions are projected to be 63 percent greater than they were in 2002.

Future Warming

The amount CO_2 levels will rise in the next decades is unknown. What will this number depend on in the developed nations? What will it depend on in the developing nations? In the developed nations it will depend on technological advances or lifestyle changes that decrease emissions. In the developing nations, it will depend on how much their lifestyles improve and how these improvements are made. Computer models are used to predict the effects of greenhouse gas increases on climate for the planet as a whole and also for specific regions.

If nothing is done to control greenhouse gas emissions and they continue to increase at current rates, the surface temperature of the Earth can be expected to increase between 0.5 degrees C and 2.0 degrees C (0.9 degrees F and 3.6 degrees F) by 2050 and between 2 degrees and 4.5 degrees C (3.5 degrees and 8 degrees F) by 2100, with CO_2 levels over 800 parts per million (ppm). On the other hand, if severe limits on CO_2 emissions begin soon, temperatures could rise less than 1.1 degrees C (2 degrees F) by 2100.

Whatever the temperature increase, it will not be uniform around the globe. A rise of 2.8 degrees C (5 degrees F) would result in 0.6 degrees to 1.2 degrees C (1 degree to 2 degrees F) at the equator, but up to 6.7 degrees C (12 degrees F) at the poles. So far, global warming has affected the North Pole more than the South Pole, but temperatures are still increasing at Antarctica**.**The timing of events for species is changing. Mating and migrations take place earlier in the spring months. Species that can are moving their ranges uphill. Some regions that were already marginal for agriculture are no longer farmable because they have become too warm or dry.



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Glaciers are melting and vegetation zones are moving uphill. If fossil fuel use exploded in the 1950s, why do these changes begin early in the animation? Does this mean that the climate change we are seeing is caused by natural processes and not by fossil fuel use?

As greenhouse gases increase, changes will be more extreme. Oceans will become slightly more acidic, making it more difficult for creatures with carbonate shells to grow, and that includes coral reefs. A study monitoring ocean acidity in the Pacific Northwest found ocean acidity increasing ten times faster than expected and 10 percent to 20 percent of shellfish (mussels) being replaced by acid tolerant algae.

Plant and animal species seeking cooler temperatures will need to move poleward 100 to 150 km (60 to 90 miles) or upward 150 m (500 feet) for each 1.0 degrees C (8 degrees F) rise in global temperature. There will be a tremendous loss of biodiversity because forest species can't migrate that rapidly. Biologists have already documented the extinction of high-altitude species that have nowhere higher to go.

Decreased snow packs, shrinking glaciers, and the earlier arrival of spring will all lessen the amount of water available in some regions of the world, including the western United States and much of Asia. Ice will continue to melt and sea level is predicted to rise 18 to 97 cm (7 to 38 inches) by 2100**.** An increase this large will gradually flood coastal regions where about one-third of the world's population lives, forcing billions of people to move inland.

Weather will become more extreme with heat waves and droughts. Some modelers predict that the Midwestern United States will become too dry to support agriculture and that Canada will become the new breadbasket. In all, about 10 percent to 50 percent of current cropland worldwide may become unusable if CO_2 doubles. There are global monitoring systems to help monitor potential droughts that could turn into famines if they occur in politically and socially unstable regions of the world and if appropriate action isn't taken in time. One example is FEWS NET, which is a network of social and environmental scientists using geospatial technology to monitor these situations. But even with proper monitoring, if nations don't act, catastrophes can occur like in Somalia from 2010–2012.

https://youtu.be/i-0fOP-nfU0

Although scientists do not all agree, hurricanes are likely to become more severe and possibly more frequent. Tropical and subtropical insects will expand their ranges, resulting in the spread of tropical diseases such as malaria, encephalitis, yellow fever, and dengue fever.

You may notice that the numerical predictions above contain wide ranges. Sea level, for example, is expected to rise somewhere between 18 and 97 cm—quite a wide range. What is the reason for this uncertainty? It is partly because scientists cannot predict exactly how the Earth will respond to increased levels of greenhouses gases. How quickly greenhouse gases continue to build up in the atmosphere depends in part on the choices we make.

An important question people ask is this: Are the increases in global temperature natural? In other words, can natural variations in temperature account for the increase in temperature that we see? The scientific data shows no, natural variations can not explain the dramatic increase in global temperatures. Changes in the Sun's irradiance, El Niño and La Niña cycles, natural changes in greenhouse gas, plate tectonics, and the Milankovitch Cycles cannot account for the increase in temperature that has already happened in the past decades.

In December 2013 and April 2014, the Intergovernmental Panel on Climate Change (IPCC) released a series of damaging reports on not only the current scientific knowledge of climate change, but also on the vulnerability and impacts to humans and ecosystems. Below are two videos detailing the physical science of climate change (Working Group I), and the risks and impacts to

the planet (Working Group II). But it is important to get a strong, data driven understanding of climate change. Along with the IPCC, other organizations like the United Nations Environmental Programme (UNEP), World Health Organizations, World Meteorological Organization (WMO), NASA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Environmental Protection Agency (EPA).



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