

PHYSICAL GEOGRAPHY



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Physical Geography

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1: MEASURING, MONITORING AND DESCRIBING THE EARTH

Learning Objectives

By the end of this chapter you should be able to

- List the ways in which Geographers use maps
- Demonstrate how longitude relates to time on earth
- Describe how scale and map projection can be used to distort ideas
- Relate electromagnetic radiation to remote sensing
- Define a Geographic Information System

1.1: Cartography

1.2: Location and Time on Earth

1.3: Map Scale and Projection

1.4: Remote Sensing

1.5: Geographic Information Systems (GIS)

1.1: Cartography

How do we know exactly where we are? How do we represent our world? Cartography is the science of map making. Maps are representations of the world, usually two-dimensional, graphic relationships that use lines, symbols and colors to convey information or ideas about spatial relationships. Geographers use maps for four reasons:

1. *To locate phenomena*- such as places, disease, peoples, etc.
2. *To show relationships* - using maps to prove that some traits are correlated, such as population growth and infant mortality rates, or air pollution and auto usage.
3. *To prove ideas* - maps illustrate relationships (as mentioned above) and statistics which allow us to support our ideas with location examples
4. *To ask questions* - at times maps may reflect areas of contradiction from basic relationships. Such anomalies enable us to question the causal factors we are addressing.

These are four thematic maps of the United States. Each communicates different information, each could be used for different purposes. The most familiar maps are a combination choropleth (where colors have values) and vector (line) maps. Your standard road atlas is also usually a combination choropleth and vector map, where colors represent land cover (green for forested areas, blue for water, and sometimes yellow for urban areas), and roads are represented by lines. A third type of map is an isopleth map, where lines represent changes of a continuous value. A USGS topographic map is an example of an isopleth map.

In a standard choropleth map, the colors represent value added by manufacture. This is a graduated color scheme, commonly used to convey a range of values. Without even looking at the legend in this graduated color scheme choropleth map, you can probably figure out that the darker colors (reds and dark oranges) represent high values, and the lighter colors represented lower values.

Another type of map uses pie charts to convey labor structures. While the divisions of the pie chart represent the types of labor in each city, the *size* of the pie chart represents the total size of the labor force. In this way, the map is conveying both the distribution of the labor force by *type* and also by *size*. Such a map would answer questions like: Where is the majority of the labor force in the US located? Where is the labor force not located? What reasons can you think of for this distribution? These are the types of questions that a good map should prompt you to contemplate.

Browse through more examples of maps.

1.2: Location and Time on Earth

We define where we are on earth by several grid systems. The most common of these is **latitude and longitude**. Latitude and longitude divide the earth up into a series of parallel lines (latitude) and vertical lines running from the north pole to the south pole (longitude). Your book has a very good description of latitude and longitude, so read it carefully.

The base lines for measuring latitude and longitude are the **equator** and the **prime meridian** (see the graphic below). The equator goes around the middle of the earth, or it is the longest circumference. The prime meridian is an arbitrary line of longitude, but it was picked to go through Greenwich, England, the location of the Royal Observatory. Latitude is measured from 0 to 90 degrees north of the equator (0 to 90N), and 0 to 90 degrees south of the equator (0 to 90S), with 0 being the equator. It is easy to remember this by thinking about 180 degrees in a hemisphere, or half circle. Longitude is measured from 0 to 180 degrees east of the Prime Meridian (0 to 180E) and 0 to 180 west of the Prime Meridian (0 to 180W). Therefore, everything in the United States has a northerly latitude (*it is in the northern hemisphere*), and a westerly longitude (*it is in the western hemisphere*).

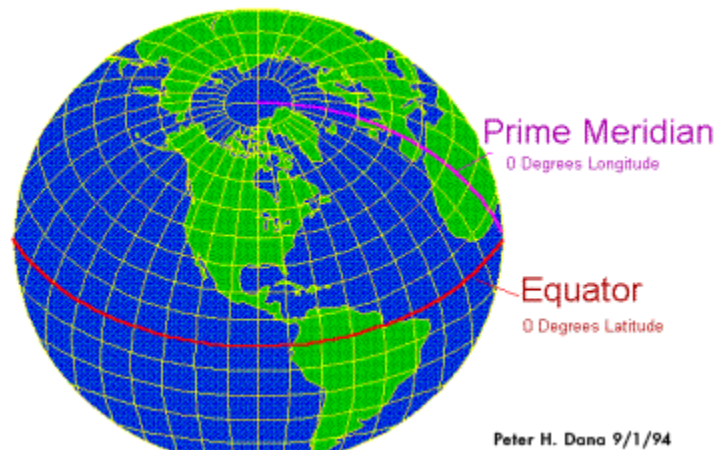


Figure 2.3.1 Latitudes and Longitudes

Increments of latitude and longitude are called 'degrees'. One degree is divided into 60 minutes ('). One minute is divided into 60 seconds ("). So a location might look something like this: 37°15' 23"N, 122°14'8"W (where is this?).

Conduct some research about the relationship between time and longitude. Each 15° increment in longitude equals one hour of time on earth. We have roughly divide the earth up in this manner by time zones. You can therefore roughly estimate (ignoring daylight savings time and the peculiarities of political gerrymandering of time zones) how many hours earlier or later one location is from another. For example, if you were in a ship at 20°W and you sailed to 80° W, what time would it be in your new location if it was 6pm in your old location? You would have traveled 60° to the west, so $60/15 = 4$, and west equals earlier, so it would be 2pm in your new location.

Check out the web site [World Clock](#) for time by location on earth.

1.3: Map Scale and Projection

Map scale is defined as: *The ratio of distance on a map to distance on the ground* Map scale is generally expressed as a ratio, such as 1:100,000. This means that one unit on the map is equal to 100,000 units on the ground, or the map representation of a widget is 1/100,000th of the actual size of the widget.

One way that I find useful to visualize map scale is to think about a map of the world. The length of the equator at different scales is a good way to think about the actual size of a map at that scale. The table below lists the distance on the map (as if you were to lay a ruler along the map and measure the equator) for each map scale. As you can see, a 1:400,000,000 scale map would probably fit across two pages of your textbook, while a 1:10,000,000 scale map would take up a wall of your classroom. At 1:1,000 scale, a map of the world would stretch across the county!

The Length of the Earth's Equator at Different Map Scales

Map Scale	Distance of the Equator on the Map (m)
1:400,000,000	0.10002
1:40,000,000	1.0002
1:10,000,000	4.0008
1:1,000,000	40.008
1:100,000	400.078
1:10,000	4000.78
1:1,000	40,007.8

Large Scale Maps vs. Small Scale Maps

"Large Scale"	"Small Scale"
<i>Small features are large</i> • A map of this room • A map of this campus • A map of this city	<i>Large features are small</i> • A map of this country • A map of this world

Resolution is defined as: *The smallest feature that is represented on the map*

- A city such as Los Altos Hills probably **would not** be represented on a map of the USA (at a scale 1:10,000,000). The **resolution** of this map is therefore too coarse to represent our city.
- A city such as Los Altos Hills probably **would** be represented on a map of the Bay Area (scale 1:500,000). The **resolution** of this map is therefore fine enough to represent our city.

Map projection is the way in which we represent the spherical earth on a flat map (see below). You may want to do some searches to find different types of map projections. The most important thing to remember about map projections, however, is that *there will always be some distortion*. Some map projections preserve relative areas, some projections preserve shape (such as the shape of coast lines), some try to do both and end up doing neither. But the result is that there will *always* be some error in a projected map.

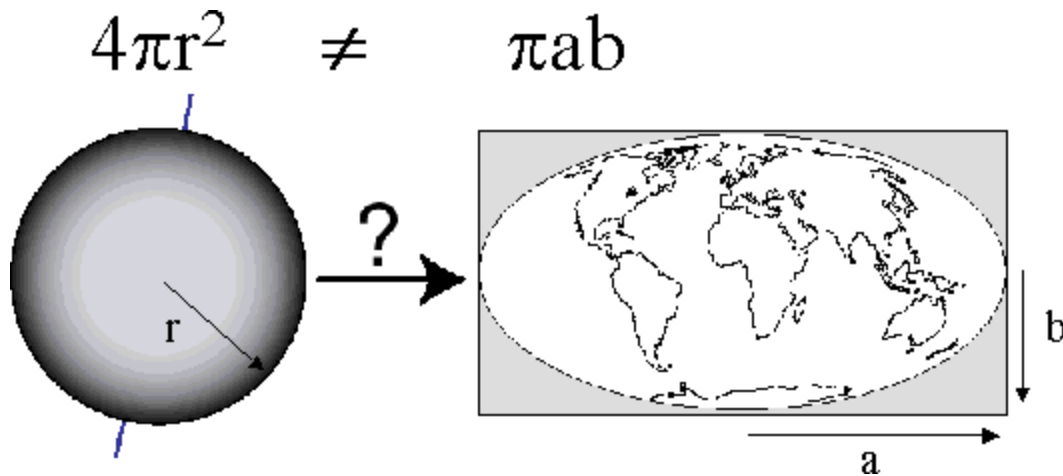


Figure 2.4.1 Map projection

One example of error in map projection can be seen in maps of the United States. The graphic below shows three different projections of the United States overlain. Note that the further you get from the center of the projection (the hot pink dot in the middle of the figure below) the bigger the distortion gets. Look in particular at Florida, Washington and Maine.

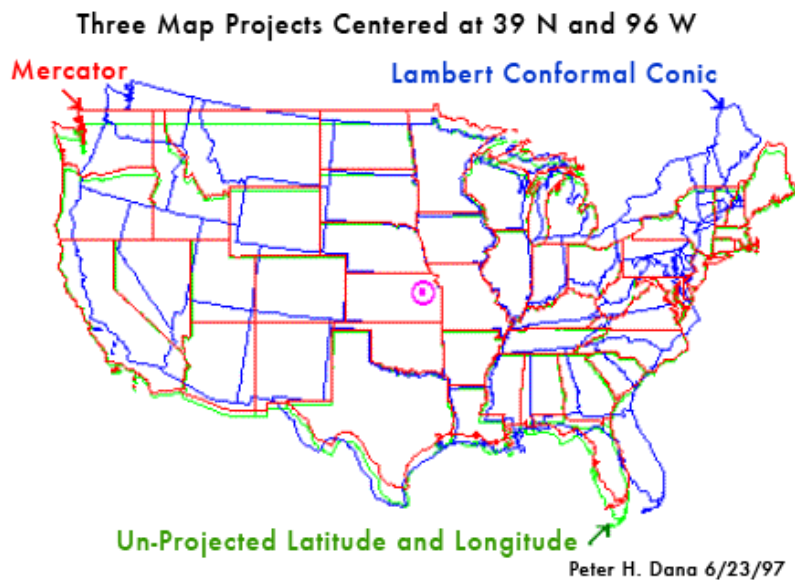


Figure 2.4.2 Map projection of the United States

Another example of distortion caused by map projection is the represented area of Australia and Greenland. The landmass of Greenland is 1/3 that of Australia. That is to say, Australia is three times as big as Greenland. The map on the left is a Mollweide Equal Area projection which preserves the relative area of landforms. The projection on the right is a Gall projection (very similar to a Mercator projection), and it preserves the shape of landforms but not the area.

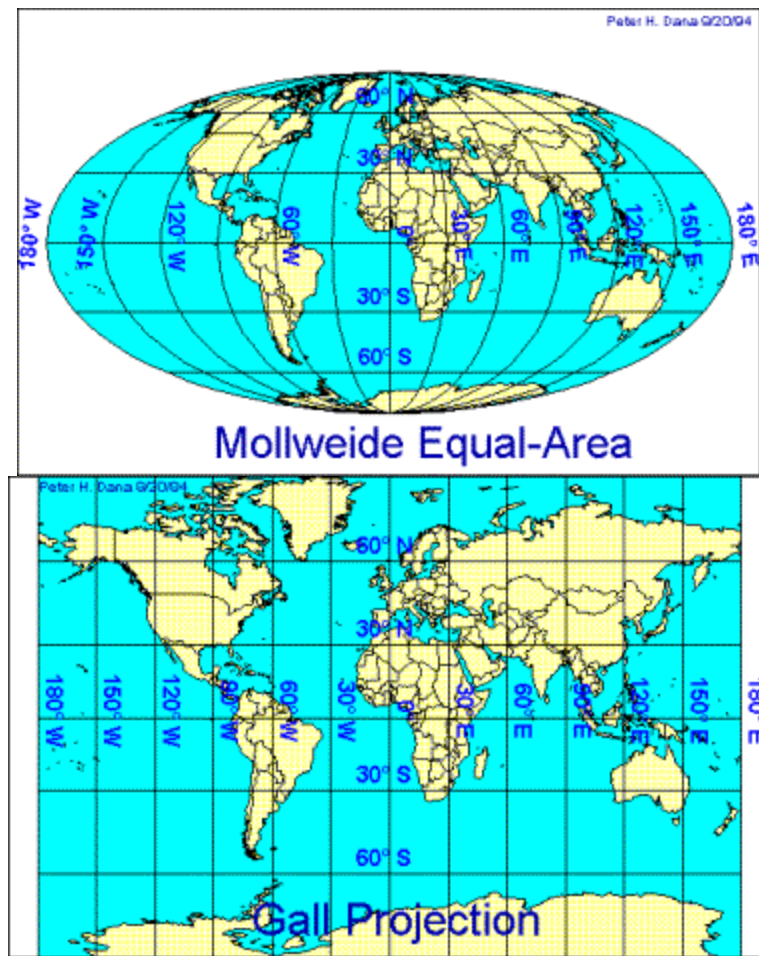


Figure 2.4.3 More map projections

1.4: Remote Sensing

Remote sensing is very important to physical geography. It allows geographers to look at change over a large area over time. In addition, remote sensing takes advantage of the interaction of earth materials with various wavelengths of the electromagnetic spectrum (recall last week's lecture). The chemical properties of some materials preferentially absorb or reflect certain wavelengths. For example, the iron in chlorophyll (the 'energy' producing element of all green plants) reflects very strongly in the near infrared (the wavelength slightly longer than red, and just outside the range of human vision). Chlorophyll also absorbs very strongly in the blue wavelengths. Therefore by looking at the near infrared wavelength and comparing it with the blue, you can pick out the vegetated areas by looking for areas that reflect strongly in red, and not in blue.

The following web pages are excerpts from a NASA tutorial on remote sensing. Some of the material is pretty technical, but read it carefully, and pay particular attention to the graphs:

- Electromagnetic Spectrum: Spectral Signatures
- Processing and Classification of Remotely Sensed Data

In the first graph, which compares Pinewood, Grassland, Red Sand Pit and Silty water, if you were looking at a remotely sensed image at 0.8 micrometers wavelength, which would you expect to appear the brightest? Which would appear the least bright?

The Grasslands would appear the brightest, as it reflects the most electromagnetic energy at that wavelength. The silty water would appear the darkest, as it would reflect the least at that wavelength. An example of this type of remote sensing is the Normalized Difference Vegetation Index or NDVI. NDVI is a ratio of near infrared wavelengths to visible wavelengths, and can be thought of as 'vegetation vigor'. The figure below is an example of global NDVI for January and July. Recall that December and June are the solstices or the height of summer or winter. The figures below are selected as January and July because vegetation generally has a lag-time between when the conditions are at a maximum (height of summer or winter) and when they are at their greenest. In the figure below, light colors indicate low vegetation vigor, while dark colors indicate high vegetation vigor.

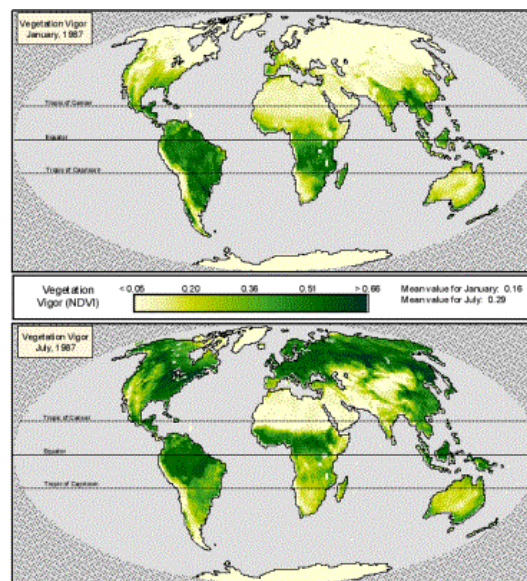


Figure 2.5.1 Global NDVI for January and July 1987

In addition to optical remote sensing (remote sensing that uses the visible and near infrared portion of the electromagnetic spectrum), another common type of remote sensing is radar. Radar remote sensing measures the 'roughness' of a surface. It is very useful for studies which look at land-use change because man-made features tend to be very smooth compared to vegetation which is rough. Think about if you were in an airplane looking down at a city and a forest. The forest looks 'fuzzy' and 'soft' while the buildings and roads of the city have large flat, 'smooth' surfaces. See a radar image of the San Francisco Bay Area. Note that the urban areas (smooth) reflect very strongly (have a bright color) and the vegetated hills surrounding the Bay Area (rough) do not reflect (appear dark).

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1.5: Geographic Information Systems (GIS)

A geographic information system (GIS) is a suite of map layers or 'themes' that are all georeferenced to the same location on earth, and their associated tabular spreadsheet data. A GIS is a map, a spreadsheet and an information management system all rolled into one. Conduct an internet search for a common rendition of a GIS. The map layers of a GIS are all stacked on top of one another in the computer, allowing the user to query all the layers at once. GIS are used in numerous professional fields, including Geography, Archaeology, Biology, Business, Forestry, Geology, Emergency Management and Law Enforcement.

The best way to experience GIS is to experiment with a GIS. Go to Ice Maps , at the UC Davis Information Center for the environment. Start out by selecting several layers to view. Some suggested combinations are listed below. Look at the legend, zoom in and out and pan around the state then discuss the following prompt in the DC.

Suggested theme combinations:

- Shaded Relief, Major California Rivers, Lakes, Jurisdictional Dams, Non Jurisdictional Dams
- Shaded Relief, Major Cities, State Highways, Federal Highways, Proposed Significant Natural Areas

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2: WEATHER AND CLIMATE

Learning Objectives

By the end of this chapter you should be able to

- Describe at least three mechanisms that will cause clouds to form
- Discuss the effects of violent weather such as hurricanes and tornadoes on people
- Apply geographic principles of climate introduced in class to predict climate in Modelland

2.1: Air Masses and Weather

2.2: Violent Weather

2.3: Global Climate Patterns

2.1: Air Masses and Weather

In chapter 3, we discussed how warm air had more energy, and therefore formed areas of low pressure in the atmosphere, while cold air was more dense and formed areas of high pressure in the atmosphere. In chapter 4, we discussed atmospheric and oceanic circulation and global temperatures. In the previous lesson, we talked about the water cycle and water resources on earth. In this unit, we are going to bring together these discussions about the atmosphere/hydrosphere interactions in our exploration of weather and global climate.

First, let's get some very important definitions out of the way. *Weather* and *climate* are not the same thing. *Weather* is the short-term, day to day condition of the atmosphere, while *climate* is the long term (over decades) average of weather conditions in a region. Climate change can only be documented by noting a rise the average annual global temperature over many years. Another way to think about is that weather is a series of short-term events, while climate is a long-term trend. A person who studies and predicts the weather is called a *meteorologist*. A person who studies long-term trends in weather and how climate changes over many years is called a *climatologist*.

Air masses are classified based on their moisture and temperature. Air masses pick up moisture when they are over bodies of water, and they lose that moisture when they are over land. Therefore, wet air masses are designated **m** for maritime, and dry air masses are designated **c** for continental. The temperature of an air mass is designated as follows: **A** for arctic, **P** for polar (high latitude, but not as high as arctic), **T** for tropical, **E** for equatorial and **AA** for Antarctic.

The following air masses affect the United States. Write down their abbreviations in the parenthesis below:

- Maritime Polar (___) affects the north west and north east coasts all year.
- Continental Polar (___) affects the north central USA in the summer and more severely in the winter.
- Maritime Tropical (___) affects the south west and south east coasts all year.
- Continental Tropical (___) affects the south central US during the summer.

Clouds and violent weather occur when air masses collide. When a cold mass pushes under a warm air mass, the warm air is cooled adiabatically (recall the average lapse rate of 6.4 degrees C per kilometer from lecture 3). The moist warm air quickly reaches its dew point and clouds form. If you watch the weather report on the evening news, you will note that the cold fronts are denoted by lines with triangles pointing in the direction that the front is advancing. Warm fronts are denoted by lines with half-circles pointing in the direction that the front is advancing.

Another important atmospheric lifting mechanism is *orographic* lifting. Orographic lifting occurs when air is forced up to high altitudes as it is pushed up a mountain front. The air cools adiabatically, and clouds form, and precipitation often results. The windward side of the mountain, therefore, receives much more precipitation than the leeward side. This is known as the '*rainshadow effect*'. One example of orographic lifting is the Sierra Nevada mountains. Moist air blows off of the Pacific ocean and is forcibly lifted upslope. This results in significant rain and snow on the western side of the Sierras (Tahoe, for example), and very little of the precipitation makes it over to the east side of the Sierras. This results in a dry desert on the eastern slope. If you have ever driven over highway 89 to Reno, or highway 120 past Yosemite, you will have seen this transformation first hand. The western side of the Sierras boast lush forests, while the eastern slope is a dry, sage brush desert.

2.2: Violent Weather

Two types of violent weather affect the United States each year: **tornados and hurricanes**. The U.S. has more tornadoes each year than any other country in the world. There are two conditions necessary for tornadoes to form. First, fast winds in the upper troposphere are slowed at the ground because of friction. This condition, of fast winds in the upper troposphere, and slower winds in the lower troposphere, causes a tube of horizontally rotating air to form. For a tornado to form, something must make that column of rotating air turn vertical. A strong updraft of rising hot air can be powerful enough to twist the horizontally rotating column of air into a vertical column of low pressure air.

Thunderstorms that precede tornadoes usually form in the late afternoon after the sun has warmed the ground. The air heated over the ground is buoyant and it rises and rapidly reaches the dew point causing the formation of massive cumulonimbus clouds. The updraft of the rising air is often enough to turn the horizontally rotating air in the troposphere into a vertical funnel cloud. In the late 1960's, Dr. T. Theodore Fujita, an authority on tornadoes at the University of Chicago, proposed a scale (called the Fujita scale) for classifying tornadoes according to their rotational wind speed and the damage done by the storm.

Browse this web page for more information:[NOAA FAQ about Tornadoes](#)

Tropical cyclones are another awesome expression of nature's power. Tropical cyclones go by several different names, depending on their location. *Hurricane* is the term used in the Atlantic and East Pacific, *Typhoon* is the term used in the Western Pacific, and *Cyclone* is the term used in the Indian Ocean or near Australia. Cyclones are zones of intense low pressure. The Atlantic basin cyclones that you investigated in Lab 3 generally started on the western coast of Africa as zones of low pressure resulting from superheated land. These low pressure zones then moved out over the central Atlantic and gathered the abundant energy stored as latent heat in the warm water. By the time that they reached the eastern coast of the Americas they were fully developed, powerful cyclones.

Browse this NOAA page on Hurricanes for more information.

Note that tornadoes can be a bi-product of hurricanes!

2.3: Global Climate Patterns

The interaction of the atmosphere with the hydrosphere and the lithosphere create weather and climate. The study of weather and climate is an entire course unto itself. Therefore, in this section I will be going over the bare essentials of how latitude and location on a continent affects the weather and climate of a place.

You may recall our discussion of how Hadley cells create bands of low pressure (due to the rising air masses) at the equator, and bands of high pressure (due to the falling air masses) at the tropics (23.5° North or South). You may also recall that high pressure is associated with dry, sunny weather, and low pressure is associated with wet, cloudy weather. In Africa, large bands of desert are approximately 23.5° North, and to a lesser extent in North America. You might want to research the bands of equatorial rainforest across Africa and South America.

Climate is classified by both average annual precipitation and average annual temperature ranges. Note the graphs at the bottom of the world climate map. These are called *climatograms*. They are a type of graph that shows you annual temperature ranges and precipitation totals for an average year (would this be *weather* or *climate*?). The x-axis represents the months of the year. The left y-axis represents the temperature in degrees F. The right y-axis represents precipitation in inches (can you find the typo in the atlas?).

Modelland is an imaginary continent on our earth. All of the patterns of ocean circulation and predominate winds apply to it. You might think of Modelland as a picture of the earth past, or a future vision of the earth. The letters denote locations whose climate will be discussed below. Test yourself by matching the climate descriptions with the letters below.

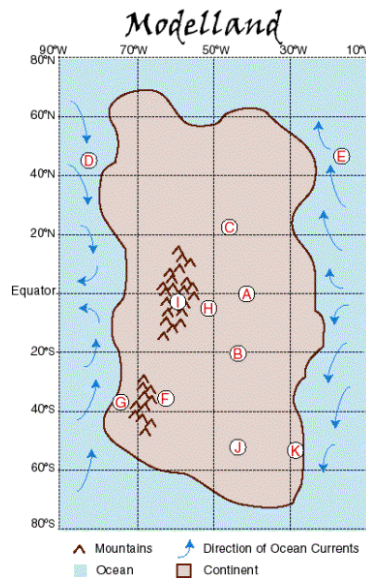


Figure 6.4.1 Modelland

- **B & C** are deserts because it is located in a zone of high pressure.
- **A** is a lush tropical forest because it is located in a zone of low pressure.
- **F** is located in a rainshadow.
- **D** are cool polar currents.
- **E** are warm tropical currents.
- **J** is an example of continentality.
- **K** is an example of oceanality.
- **I** is much more cool than H because it is at a higher altitude.

Below are examples of temperature profiles for H & I (effect of altitude on temperature) and J & K (oceanality/continality effects)

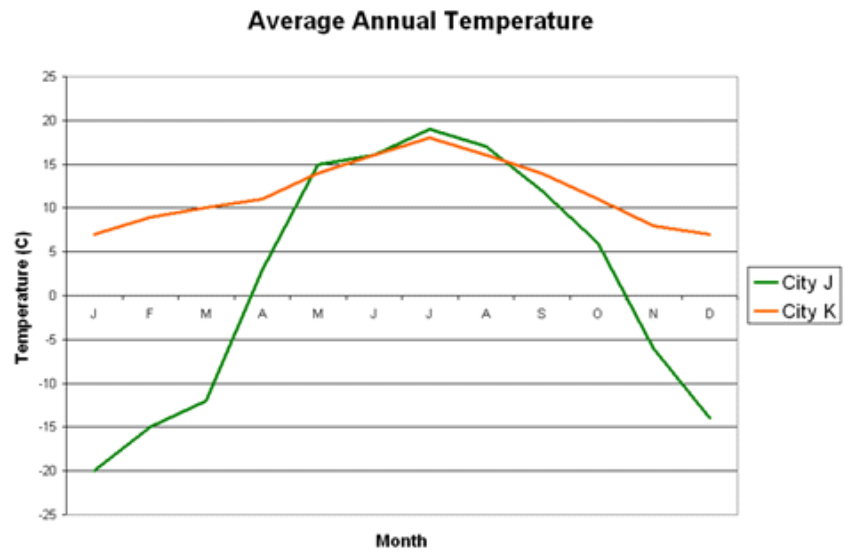


Figure 6.4.2 Effect of Oceanality on Temperature

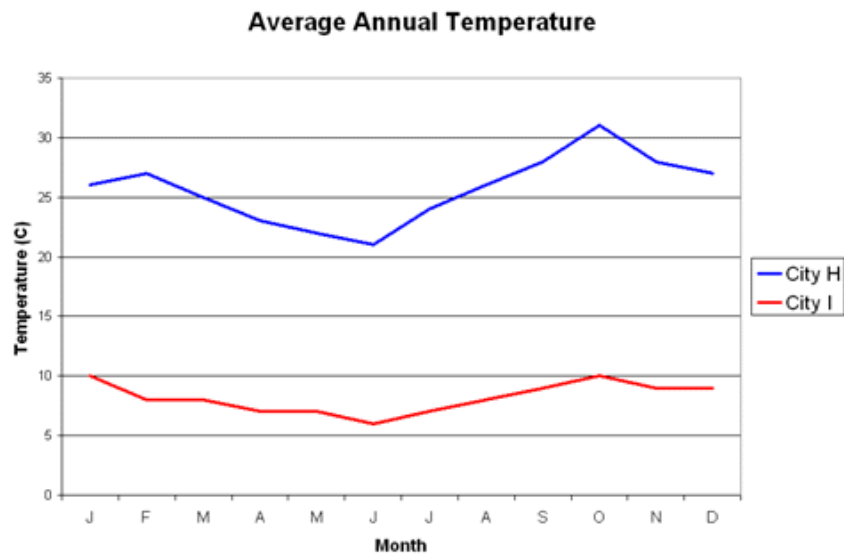


Figure 6.4.3 Effect of Altitude on Temperature

3: EARTH MATERIALS - THE LITHOSPHERE

Learning Objectives

By the end of this chapter you should be able to

- Describe the physical structure of the Earth
- Apply an analogy to the age of the Earth and major events in the development of the biosphere
- Discuss the mechanism that drives plate tectonics
- Review the rock cycle in terms of the processes that form the three major rock types

3.1: The Earth's Structure

3.2: Geologic Time

3.3: Plate Tectonics

3.4: The Rock Cycle

3.1: The Earth's Structure

We are half way through the course, and we have discussed the atmosphere and the hydrosphere. We will focus on the lithosphere for the next two weeks and discuss the formation and composition of our home planet, and discuss the processes that shape it. The earth is one of nine planets that orbit our sun. It is believed that the sun and the planets formed around the same time from a cloud of dust and gas comprised mostly of hydrogen and helium (the two lightest elements). This is called the *nebular hypothesis*. Around 4.5 billion years ago, for reasons that are not well understood, this enormous cloud of dust and gas began to contract under its own gravitational influence, and the planets and the sun were formed. The sun was comprised mostly of the lighter elements: hydrogen and helium. The heavier elements are believed to have stuck together forming small particles which collided forming bigger particles, eventually creating rocky masses that gained their own gravitational force and developed into the nine planets of our solar system.

Soon after the earth was formed, the decay of radioactive elements, coupled with the heat resulting from the energy of the colliding particles produced some melting of the interior of our planet. The heavier elements (iron and nickel) sunk while the lighter elements floated, forming the dense iron-nickel core, and light, silica rich crust.

We do not know for certain how the solar system or the earth formed. The above is simply a hypothesis which provides an explanation for our present day observations of the planet, and tries to answer the geographer's question of *how*. *How did our planet form?*

The earth as we know it (land and ocean) is only a thin shell which covers the very dense, hot interior of our planet. The earth is composed of a dense iron-nickel core which has a radius of approximately 1,216 kilometers (756 miles). The core of the earth is very hot (3000°-6650°C) and it is so compacted that it is nearly five times as dense as the rocks on the surface of the earth. Atop the inner core of the earth is the outer core, which is where our magnetic field is believed to be generated from.

The liquid lower mantle sits atop the outer core, and is composed of iron silicates. The liquid upper mantle is also composed of iron magnesium silicates, and is relatively thin (compared with the layers below it) at only about 400 kilometers in thickness. The next layer in the earth is called the athenosphere, which is a little less than 200 kilometers thick. The athenosphere is semisolid, and deforms 'plastically' or like silly putty. Atop the athenosphere is the crust of the earth. You might want to look for figures that demonstrate the relative thickness of the earth's crust. If the center of the earth were Halifax Nova Scotia, the core and mantle would stretch to the California/Nevada border. The crust would barely reach from Livermore to San Francisco.

There are two types of earth crust: continental crust (or what we call 'land') and ocean crust (the bottom of the sea). Continental crust is about three times as thick as ocean crust, and it is also much lighter than ocean crust. Continental crust is composed mostly of relatively light silicate rocks, while the ocean crust is composed of rocks formed from iron-magnesium silica compounds.

3.2: Geologic Time

It was pointed out in the previous section that the earth is approximately 4.5 billion years old. The magnitude of geologic time is of great importance to our understanding of earth processes that we have discussed in this class. Last week when we discussed weather and climate, it was pointed out that ‘weather’ refers to a short term event – on the order of a few days, while ‘climate’ describes trends in weather over decades. Thus, the concept of ‘climate change’ becomes greatly altered when we consider the length of earth history. We humans often try to put everything in the perspective of a person’s lifetime (perhaps a century). However, most earth processes operate on the scale of a millennium (1000 years) or more. The history of the earth is vast, and its appearances and processes have developed over a time scale which is significantly greater than ours.

Read over William Newman’s discussion of Geologic Time, focusing on *Geologic Time*, *The Relative Time Scale*, and the *Age of the Earth*.

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3.3: Plate Tectonics

Accurate world maps were not completed until the middle of the 16th century. Back then, people were mapping coastlines from the decks of ships, and physical features such as mountains and rivers by traversing them on foot. Soon after the world was well mapped, people began to recognize that certain coastlines seemed to 'fit' together (most notably the east coast of South American and the west coast of Africa). As data on the rock types and ages around the world were compiled, the relationships between the continents became more clear.

In 1912, a German named Alfred Wegener proposed the theory of continental drift. Wegener provided evidence for how all the earth's present-day landmasses were united in a single supercontinent he dubbed 'Pangaea' about 225 million years ago. Wegener's ideas were built upon and modified as later scientific discoveries added to his theory. More was learned about the composition of the continental and ocean crust, and as the bottoms of the oceans were thoroughly mapped, scientists began to recognize features in the ocean floor which pointed to a more complex theory of the movement of the continents. Ocean bottom imaging revealed deep trenches around the rim of some continents, and linear ridges running down the middle of some ocean floors. These observations led to the theory of plate tectonics.

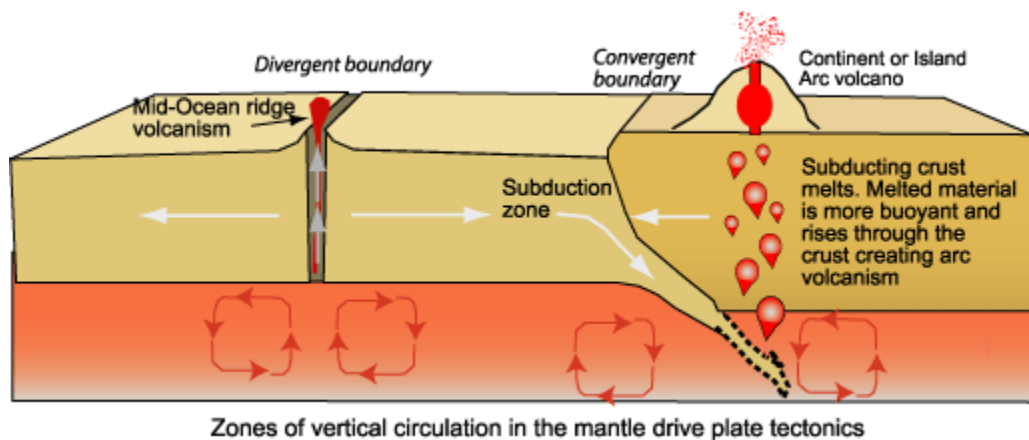


Figure 7.4.1 Plate Tectonics

The theory of *plate tectonics* provides us with a comprehensive model of the earth's inner workings. According to the model, the earth's rigid outer shell, the lithosphere, is broken into several individual pieces called plates. From Wegener's model we understood that these rigid plates are slowly and continually moving. The plate tectonics theory provides a mechanism for this motion: the circulation of molten rock in the earth's mantle. The circulation of material in the mantle is not unlike the circulation in the atmosphere. Hot material from deep in the mantle rises because it is more buoyant, this drives powerful thermal cycles which push the plates laterally. The thermal circulations in the earth's mantle provided the critical *mechanism* that brought together the theory of Plate Tectonics (see schematic below)

Ultimately, this movement of the earth's lithosphere plates generates earthquakes, volcanic activity and the deformation of large masses of rock into mountains. Because each plate moves as a distinct unit, interactions between plates occur at their boundaries.



You may want to search for images that illustrate the fourteen plates that currently cover the earth's surface. (Public Domain; USGS).

There are three distinct types of plate boundaries:

- *Divergent boundaries* are zones where plates move apart, leaving a gap between them. One example of divergent boundaries between ocean plates is the mid-ocean ridge in the middle of the Atlantic. Another example of a divergent boundary between two continental plates is the East African Rift zone, part of which has formed the Persian Gulf.
- *Convergent boundaries* are zones where plates move together. When an ocean plate meets a continental plate, the heavier ocean plate is pushed beneath the continental plate. When two continental plates collide, they smash into each other, forming a large mountain belt (like the Himalayas).
- *Transform boundaries* form where plates slide past each other, scraping and deforming as they pass.

Each plate is bounded by a combination of these zones. Look for more graphic examples of plate motion.

Outside links

- You should check out more graphics of Pangaea at the Paleomap Project.

3.4: The Rock Cycle

One of the primary effects of plate motion is to put new material from deep in the earth's mantle onto the surface of the earth, and at the same time, destroy old crust. This creation, modification, and destruction of the surface materials of the earth is called the rock cycle. However, before we begin our discussion of the rock cycle, let's clarify a very important point: *rocks and minerals are not the same thing!* A mineral is a naturally occurring, inorganic, solid element or compound, with a definite composition or compositional range and a regular internal crystal structure. A rock is a solid, cohesive aggregate of one or more minerals or mineral materials.

The key difference between a rock and a mineral is the 'regular internal crystal structure' of a mineral. For example, Quartz is a mineral (SiO_2), while Granite is a rock. If you were to look at a quartz crystal at the molecular level, the entire crystal would be made up of identical building blocks (SiO_2 molecules). Granite, on the other hand is not homogenous. Therefore, one chunk of a piece of granite, when viewed at the molecular level would appear very different from another chunk viewed at the molecular level because the first chunk might be a quartz crystal, while the second chunk might be another type of crystal.

Rocks are categorized by how they are formed. Rocks that are formed directly from liquid rock, or magma that wells up from deep in the earth are called *igneous rocks*. Rocks that form at, or just below the surface of the earth from weathered and decomposed bits of other rocks are called *sedimentary rocks*. Igneous or sedimentary rocks which are subjected to intense pressure or temperature (but not enough to melt them) form *metamorphic rocks*. A graphic illustration of the rock cycle is provided below.

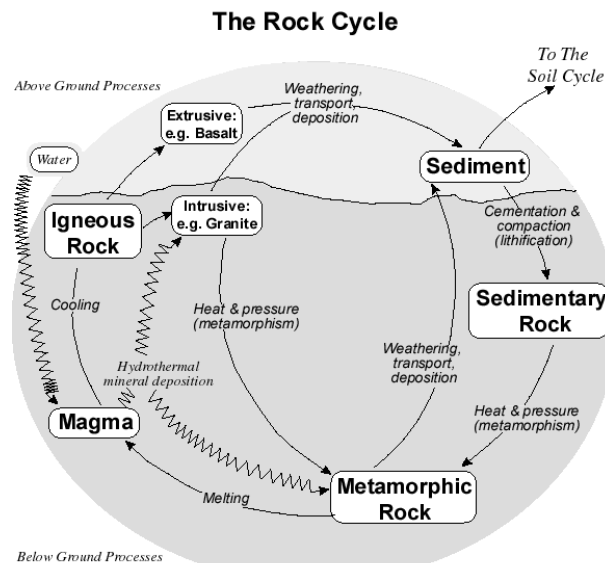


Figure 7.5.1 Rock Cycle

Igneous Rocks

Igneous rocks are formed from magma (liquid rock) which is pushed up through the earth's crust. There are two types of igneous rocks. Extrusive igneous rocks are 'extruded' onto the surface of the earth through a volcanic eruption where they are rapidly cooled in the air or water of the ocean. The size of crystals in igneous rocks is inversely related to the speed at which the rock cooled. Therefore, extrusive igneous rocks have very small crystals or no crystals at all because they cooled so rapidly. Basalt is a common example of an extrusive igneous rock.

Intrusive igneous rocks are formed when magma is forced just below the surface of the earth. There, it cools very slowly and large (1 cm to 1 m) crystals can form. Over time, the material that covers the intrusive igneous rock wears away, revealing it at the surface. Granite is an example of an intrusive igneous rock. Most of the Sierra Nevada and Cascade mountain ranges are made up of granite.

Sedimentary Rocks

Rocks at the surface of the earth are broken down by weathering processes (more on that in lecture 9) to form sediment. Sediment is a loose term for anything ranging from fist-sized chunks of rock in a stream bed to gravel, sand and mud. Dead organic material is also sediment. Basically, all the unconsolidated material you see at the surface of the earth is sediment.

There are two types of sedimentary rocks. The first is the *clastic sedimentary rock*. Over time (geologic time) new sediment covers up old sediment, and there is enough pressure on the sediment to *lithify* it. *Lithification* is the process of compaction, cementation and hardening of sediments into sedimentary rocks. Clastic sedimentary rocks are composed of fragments of other rocks. They are often stacked in distinct layers with the oldest material on the bottom. An example of a common clastic sedimentary rock is sandstone, such as the sandstone layers of the Grand Canyon.

The second type of sedimentary rock, the *chemical sedimentary rock*, forms when water seeps through sediments and dissolves certain minerals, then deposits the minerals in a new location. An example of this is deposits of gypsum or halite (table salt) which often form in the desert after rain. Another example of a chemical sedimentary rock is limestone. Limestone is precipitated calcium carbonate (CaCO_3). Limestone is the primary component of much of the central United States. One problem with chemical sedimentary rocks is that it is very easy for water to re-dissolve them. Sink holes form where water has dissolved limestone in the ground, forming a cave which then collapses. Sink holes are a common hazard of areas that have thick limestone deposits.

Metamorphic Rocks

Metamorphic rocks form in the earth's crust from existing sedimentary or igneous rocks. Metamorphic rocks have been subjected to such severe pressures and/or temperatures that the chemical elements that make up the minerals in the rock rearrange themselves to form new minerals. Metamorphic rocks reach the surface the same way that intrusive igneous rocks reach the surface, through uplift, weathering and erosion. Metamorphism (the process that creates metamorphic rocks) also changes the appearance of landscapes. You can often see twisted and folded layers of rocks in metamorphic regions.

4: SHAPING THE LITHOSPHERE

Learning Objectives

- Describe the physical structure of the Earth
- Apply an analogy to the age of the Earth and major events in the development of the biosphere
- Discuss the mechanism that drives plate tectonics
- Review the rock cycle in terms of the processes that form the three major rock types

4.1: Volcanoes

4.2: Volcanic Hazards

4.3: Orogenesis, Faults and Earthquakes

4.1: Volcanoes

In chapter 7, we introduced the inner workings of the earth: the composition of the earth, plate tectonics and the rock cycle. In this chapter we are going to expand upon those topics and discuss in detail the mechanisms which shape the lithosphere.

The location of volcanoes are concentrated around the Pacific rim, the east African rift, and the Atlantic ridge – especially on Iceland. There are also some stray volcanoes in the middle of the Pacific and Atlantic oceans. The majority of the earth's surface is devoid of volcanic activity. Why do volcanoes cluster in these regions?

Volcanism is directly related to the theory of plate tectonics. Volcanoes are found only at particular types of plate boundaries and rarely in the middle of ocean plates. In the following discussion we will summarize the three circumstances which explain the formation of nearly every volcano on earth. First, though, let's go over the two types of volcanoes.

In an earlier chapter, we described two types of earth crust: The thick, relatively buoyant and light weight silica rich continental crust, and the heavy, thin ocean crust made of iron and magnesium-silicate rocks. Two types of magma correspond to these two types of crust (liquid rock is called *magma* when it is below the surface of the earth – above the surface it is called *lava*). Volcanoes on the ocean floor are made of the same material that makes up the ocean floor – iron or magnesium silicate minerals. This magma is very runny, or not viscous. It forms broad *shield volcanoes* such as the island of Hawaii which erupts large quantities of lava. On the other hand, volcanoes that form from silica rich magma tend to be steep and tall, such as Mount St. Helens in Washington. Silica rich magma is also very thick, or viscous, and tends to cause very violent, ash-rich eruptions without a lot of lava.

Volcanism Where Plates Collide

There are two types of plate collisions: Ocean-continent, and ocean-ocean. The plate that is subducted melts partway down (*partial melting*), and the melted material rises up through the crust and forms a volcano. The melted material contains bits of the sea floor that were pulled down with it and water, so it is more silica rich and buoyant than pure ocean crust. As the magma rises it melts additional crust around it, making it even more silica rich – especially when it rises through continental crust. As discussed above, this silica rich magma is much more viscous than its *mafic* (magma that is rich in iron and magnesium, and has less than 50% silica) cousin. The rising magma often forms plugs in the neck of the volcano, leading to pressure buildup within the magma chamber, and eventually a highly explosive eruption. Oftentimes, the magma does not get out of the chamber, and ends up cooling slowly just below the surface, forming granite or some other type of intrusive igneous rock.

Where plates collide, two types of volcanoes are formed. When an ocean plate collides with a continental plate, volcanic mountains are formed on the continental plate. Examples of active volcanic mountains today are the Cascade Range in Washington, and the Andes in South America. Sometimes, following a plug of silica-rich magma in a volcano is a volume of more runny mafic magma from deep in the earth. When this mafic magma is erupted, it spreads rapidly, covering large areas. The flood basalts of the Colombian Plateau in Oregon-Washington covered the region 12 million years ago.

Where two ocean plates collide, volcanoes are formed in an 'island arc'. Island arcs are characterized by their linear structure, mirroring the plate boundary. Japan, the Philippines, and New Zealand are examples of island arcs.

Volcanism Where Plates Diverge

Earlier, we noted that there was a series of volcanoes in eastern Africa, and we also noted several near the mid-Atlantic ridge, and on the island of Iceland. These are examples of volcanoes which form where plates diverge. The driving force behind plates moving apart is the upwelling of hot magma in the mantle which spreads laterally, driving plate motion. Sometimes, some of that hot magma melts the crust that overlies it, causing the crust to thin, and volcanoes form.

The east African rift is a zone of crustal thinning and movement, where the African continent is in the process of splitting in two. This is an example of volcanism at the formation of a plate boundary. Here, the continental crust is much more thin than normal because of an upwelling of hot magma from deep in the earth's crust. This is the beginning of a new plate boundary. The volcanoes of the east African rift are a combination of the silica rich, explosive type, and the silica-poor mafic type.

The island of Iceland sits atop the mid-Atlantic ridge, and is an example of a series of volcanoes which form where ocean plates

diverge. The volcanoes that comprise Iceland are all mafic, so they have formed an island with shallowly sloping mountains or *shield volcanoes*. Shield volcanoes are large, gently sloping summits formed from successive eruptions of mafic lava.

Hot Spot Volcanoes in the Middle of Ocean Plates

Sometimes, for reasons that are still not well understood, an upwelling of hot magma forms a 'hot spot' in the middle of an ocean plate. The hot spot creates a shield volcano. Often, the hot spot will remain in the same place, while plate moves over it, creating a series of islands. One example of this is the Hawaiian island chain. The oldest island, Niihau is located northwest of the youngest island, Hawaii. The island chain documents the motion of the Pacific plate as it passed over the hotspot.

4.2: Volcanic Hazards

As volcanoes modify the surface of the earth, they also enrich it, drawing people to live in volcanically active areas in order to cultivate the soil. The ash from volcanic eruptions provides vital nutrients to enrich and renew the soil, and soil formed from decomposed basalt (volcanic rock) is very fertile. Consequently, volcanic areas such as Hawaii, the Philippines the Andes of South America and eastern Africa all have large populations living at the bases of active volcanoes. Predicting and understanding the hazards that these people face is of great importance to earth scientists and emergency management personnel.

The first, and most obvious hazard of volcanoes is lava. However, lava is generally not life threatening because most lava flows move at the speed of a few kilometers per hour, so one can avoid advancing lava, even on foot. Lava temperatures range from 500°C to 1400°C, so combustible materials, such as homes and forests often burn. In addition, in regions that are covered by new lava flows, the cooled lava forms rock, rendering the land unusable for cultivation.

One of the most dangerous byproducts of a volcanic eruption, especially an eruption from a silica rich volcano, is a *pyroclastic flow*. A pyroclastic flow is a mixture of hot gas (about 1000°C), rocks and ash that sweep down the sides of a volcano at speeds in excess of 1000 kilometers per hour. Pyroclastic flows are extremely dangerous because they are often produced with the first stage of a large eruption, and can catch residents unaware, and they move so quickly they are impossible to escape. The majority of the damage from the 1980 eruption of Mount St. Helens in Washington was the result of a pyroclastic flow.

Another danger from volcanic eruptions is *lahars* or mudslides. When Mount Pinatubo erupted in the Philippines in 1991, the torrential rains that followed the eruption turned all of the ash into a heavy cement-like sludge that raced down mountain valleys obliterating small villages in their path. Read about [the lahars of Mount Pinatubo](#) at this USGS web site.

Toxic gasses are another danger in volcanically active areas. Volcanoes release gasses such as carbon dioxide, water vapor, hydrochloric and hydrofluoric acids and various sulfuric gasses. In late 1986, in Cameroon, Africa, 1700 people and many animals died when accumulated gasses trapped in the sediment of Lake Nyos, the crater of a dormant volcano, were released. Carbon dioxide is odorless and more dense than regular air, so it accumulated in a layer near the ground, suffocating any living thing that passed through it.

4.3: Orogenesis, Faults and Earthquakes

Orogenesis is the term used for mountain building. A common geologist joke is that 'subduction leads to orogeny.' Orogenesis is often the byproduct of a continent-ocean subduction zone, where a volcanic belt is formed (see above). Orogenesis can also occur when continental plates collide with other continental plates (such as the Himalayas), or when ocean plates collide with ocean plates, forming island arc volcanoes (again, see above). However, not all mountain belts are the result of *active* plate collisions. The Appalachian mountains of the eastern USA are between 250 and 300 million years old. They are a scar of an old continental collision that created the super continent of Pangaea.

When plates collide, one plate is not neatly pushed beneath the other. Significant forces are exerted on the crust, causing it to bend and deform. This bending can result in 'folded landscapes.' Often the crust of the earth will be pushed so hard that it will break along a zone of weakness or maximum pressure. This is how faults are formed. Faults generally come in clusters, as a large force is exerted over a large area, the earth will release the pressure along a *fault zone*.

Faults can be classified into three types, based on the forces and the direction of movement. The stresses in the earth can be resolved into three mutually perpendicular directions: vertical (S_v), maximum horizontal (S_{Hmax}) and minimum horizontal (S_{Hmin}). Faulting occurs in the direction that the forces are the weakest.

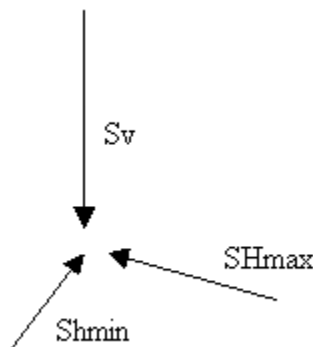


Figure 8.4.1 Faults

- When the vertical stress (S_v) is the greatest, then *normal faulting* occurs. The vertical force (gravity) basically pushes one part of the crust down to relieve stress at the zone of weakness. **This puts younger rocks on top of older rocks.**
- When the vertical stress is the least, then *thrust, or reverse* faulting occurs. The vertical force has the lowest resistance, so the tension is released by **pushing older rocks on top of younger rocks.**
- When the vertical stress is the intermediate stress, (S_{Hmax} is the greatest, and S_{Hmin} is the least), then strike-slip faulting occurs. In strike slip faulting the two sides of the fault do not move up or down, but rather right or left. The direction of the fault movement is denoted as 'right lateral' or 'left lateral'.

When tension is suddenly released on a fault and the earth moves in one of the manners described above, an *earthquake* occurs. The place on the fault where the energy was released is termed the *epicenter*. The earth is literally covered with faults. Most faults are very small (some less than 10 meters long), and most are either inactive, or release energy in such small increments that we do not notice the resulting earthquakes. There are, however, a few large faults which build up and release large amounts of energy, resulting in catastrophic earthquakes.

The San Andreas fault runs through south-central California and veers westward and out into the ocean just north of San Francisco. The San Andreas is a major *right lateral strike-slip* fault. This means that the western side of it is moving north, while the eastern side is moving south. Look at this air photo of the San Andreas in Southern California. Note the river that is offset.



Aerial view of the San Andreas fault slicing through the Carrizo Plain in the Temblor Range east of the city of San Luis Obispo. (Photograph by Robert E. Wallace, USGS.)

Earthquakes occur constantly. For a list of recent earthquakes in California, check out this USGS web site for quakes in [California](#). Have you felt any of the recent quakes? Probably not, as most have less than a magnitude of 3. What do we mean when we talk about earthquake magnitude? Magnitude is traditionally measured on the Richter scale. The Richter scale is a logarithmic scale which describes the amount of energy released by a quake with a number. Each whole number increase in the Richter scale (say, from a 6.0 to a 7.0) reflects a 10-fold increase in the amount of energy released. That is to say, that a magnitude 7 quake is much, much worse than a magnitude 6. Another measurement of earthquakes is the Mercalli intensity scale, which rates a quake on a roman-numeral scale from I to XII. The Mercalli scale is based on the damage an area received. Therefore, the Loma Prieta quake, which rated a 7.1 on the Richter scale, might have received a IX or X on the Mercalli scale near its epicenter, but it received a IV where I lived in Modesto, some 200 miles from the epicenter. You may want to do some research to learn more about the characteristics of damages and the frequency expected from earthquakes on both intensity scales.

5: THE RIVER AND THE SEA

Learning Objectives

Discuss the importance of fluvial processes in shaping the lithosphere

- Explain the three major forms of stream transport
- Describe the interaction of humans with flood plains
- Compare the effect of wave-action weathering on active and passive margins
- Explain why the ocean is salty

5.1: Fluvial Processes

5.2: Stream Transport

5.3: Flood Management

5.4: Where River Meets Sea - The Coastal Environment

5.5: The Oceans

5.1: Fluvial Processes

Recall from Lecture 5 that water in rivers and streams on earth makes up only 0.003% of all fresh water on earth. Yet, this very small fraction of the hydrosphere has a huge influence on the shape of the lithosphere. Water is a primary instrument in weathering processes (Lecture 9) with its unique ability to expand in its solid form, and in its liquid form dissolve nearly every rock-forming mineral. The process by which water wears away at the lithosphere is called *erosion*. The mechanism by which the eroded material is moved by the stream is called *transport*. When the material is deposited by the water in a new location, it is called *deposition*.

Stream related processes are called **fluvial** processes. The term *river* is applied to large flows of runoff, while *stream* applies to smaller flows. When water initially falls on the ground through precipitation, if it is not absorbed by the ground it runs off through sheet flow or overland flow. The water follows the pull of gravity and runs to lower areas, eventually collecting in the stream basins. A *drainage basin* or *watershed* is the terrain surrounding a stream valley that contributes to the water and sediments carried by the stream. Drainage basins are determined by topography and gravity. Water always runs down with gravity, so watersheds are always bowl or trough shaped. Watersheds can be divided from large to smaller and smaller units. The largest watershed unit in America is the Continental Divide which runs through the Rocky Mountains. Water that falls on the west of the continental divide eventually drains into the Pacific Ocean, water that falls east of the continental divide eventually drains into the Atlantic Ocean.

You can find the watershed that you live in through the EPA's Surf Your Watershed site.

Watersheds are open systems with inputs of precipitation from the atmosphere and material weathered from the lithosphere. Energy and materials are redistributed as the water and lithosphere material are carried to new locations. The topography of a region determines the *drainage pattern* of the area.

5.2: Stream Transport

The volume of water that passes through a stream in a given period of time is called the **discharge** or flow rate. The *discharge* (Q) of a stream can be calculated by multiplying the *width of the channel* (w) by the *depth of the channel* (d) by the *stream velocity or speed* (v). This formula,

$$Q = wdv \quad (5.2.1)$$

is usually expressed in cubic meters per second, or cubic feet per second (cfs).

The discharge of a river usually increases downstream as more and more tributaries, or small streams, join the major river. The Mississippi River is an example of this phenomenon. In equatorial regions of the world, streams sometimes flow from humid regions to arid regions, causing the discharge to decrease downstream because of high potential evapotranspiration rates. The Nile river is an example of this phenomenon, called an *exotic stream*.

Streams are an important mechanism in the transport of sediment. If you have ever visited the Mississippi river, the Green River in Utah, the Colorado River, or the American River near Sacramento, you may have noticed that you cannot easily see to the bottom of the river because the water is very cloudy or muddy. These rivers all have a large *dissolved load* and *suspended load*, typical of large, placid rivers.

- **Dissolved load** is the material carried in water as dissolved minerals such as calcium from limestone bedrock.
- **Suspended load** is the sediment held up by running water, like silt and clay particles. These particles are so small that they stay suspended in the water until the water is nearly stationary.
- **Bed load** is the larger pieces of sediment which are moved by the river, but cannot be suspended in the running water, such as sand, gravel and boulders. These materials roll and bounce along the bed of the river. The higher the discharge in a river is, the larger the bed load can be. Flood events, where the discharge rate is very high, results in large transport of bedload materials.

When the bed load exceeds the streams capacity (its ability to carry materials as bedload), the stream channel becomes tangled with material which used to be bedload. This results in a braided stream.

5.3: Flood Management

A *flood* is a high water level that overflows the natural (or artificial) banks or levees along any portion of a stream. A flood plain is the region adjacent to a river that is frequently flooded. Floods are a natural part of a riverine environment, and occasional floods enrich soils. For example, the Nile river delta in Egypt experiences flooding nearly every year. This flooding keeps the land around the Nile fertile.

The fertility of frequently flooded land is what draws people to cluster near rivers. Worldwide, many people live within the 50 or 100 year flood plain of rivers. Flood plains are rated statistically based on how often they flood. For example, a 50 year flood plain floods, on average, every 50 years. People who live near rivers often build *levees* or artificially high banks around the river to contain it and try to avoid periodic flooding events. However, while levees keep one area from flooding, they heighten the flood risk for areas further down stream by constraining the water and 'pushing' more of it downstream.

5.4: Where River Meets Sea - The Coastal Environment

Nearly all rivers eventually run into the sea. The region where a river runs into the ocean is called a *river delta*. The river delta is prone to frequent flood events, and is also strongly affected by the tides.

The coastal environment is known as the *littoral zone*. The littoral zone extends from the highest water line that occurs on shore during a storm, to the point in the ocean where the land is too deep for storm waves to move sediments on the floor (60 m or 200 feet). The point of contact between the ocean and the land is known as the *shoreline* or the *coastline*. **Mean Sea Level (MSL)** is a value based on the average tidal levels recorded hourly at a given site over many years.

The ocean is a powerful force in the shaping of the lithosphere. Ocean waves are continually weathering, or wearing away at the land and changing the shape of the coastline of our continents. Coastlines in areas of active tectonic uplift, such as along the western coast of North and South America, tend to be rugged and high relief. Sea cliffs are formed by the undercutting action of the sea. As the waves wear away, a greater amount of the land along the coast, gravity will often take over and cause a portion of the cliff to fall away into the sea.

While in areas of active tectonic uplift, the ocean is primarily an erosional force, in passive margins, such as along the eastern coast of North and South America, wave are a constructive force. Waves create small islands of sand parallel to the coast line, called *barrier islands* or *barrier spits*. If a barrier island grows so large that it connects with the land, it can form a *lagoon*.

The currents of ocean waves transport sediments (primarily sand) along the coastline in a process known as *longshore drift*. **Beaches** are not just made up of white sand. From the standpoint of physical geography, beaches are the portion of the coastline where accumulated sediment is in motion, so to geographers, beaches can be made up of gravel, rocks or boulders. Beaches act to stabilize a shoreline by absorbing wave energy.

5.5: The Oceans

We have already discussed the oceans in terms of the hydrologic cycle. Recall that oceans store 97% of water on earth. A common question when we are discussing the oceans in class is: how did the ocean get to be salty? The answer is that the salts in the ocean have accumulated over millions of years. They came from the minerals in the lithosphere. As water percolates through rocks, it dissolves small amounts of minerals. Water dissolves over half of the elements found in nature. The minerals then are carried with the water to the ocean. Over time, water is evaporated from the oceans (recall the hydrologic cycle), but the minerals stay behind. A smaller scale example of this is inland lakes which have no river outlets, such as the Great Salt Lake in Utah, and Mono Lake in the Eastern Sierras. Because these lakes have no outlet, they are like mini oceans, with the dissolved minerals in their waters becoming more and more concentrated each year.

As a result of the dissolving properties of water, most natural elements and compounds can be found in a dissolved form in the ocean. The dissolved compounds are called *solutes* and the concentration of the dissolved solutes is called the **salinity** of the ocean. Seven elements account for over 99% of the dissolved solids in seawater:

- Chloride (Cl^-)
- Sodium (Na^+)
- Magnesium (Mg^{+2})
- Sulfur (as a sulfate SO_4^{-2})
- Calcium (Ca^{2+})
- Potassium (K^+)
- Bromide (Br^-)

These elements are all considered 'salts'. The salinity of ocean water is 35 g/kg or 35,000 parts per million (ppm). Water that is more salty than 35,000 ppm is called **brine**, and water that is less salty than 35,000 PPM is called **brackish**.

6: QUIZZES AND EXAMS

6.1: Quizzes

6.2: Exams

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6.1: Quizzes

Each chapter has a corresponding quiz.

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6.2: Exams

This sections consists of a sample Midterm and Final.

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