Earth & Space Science

MPS teachers

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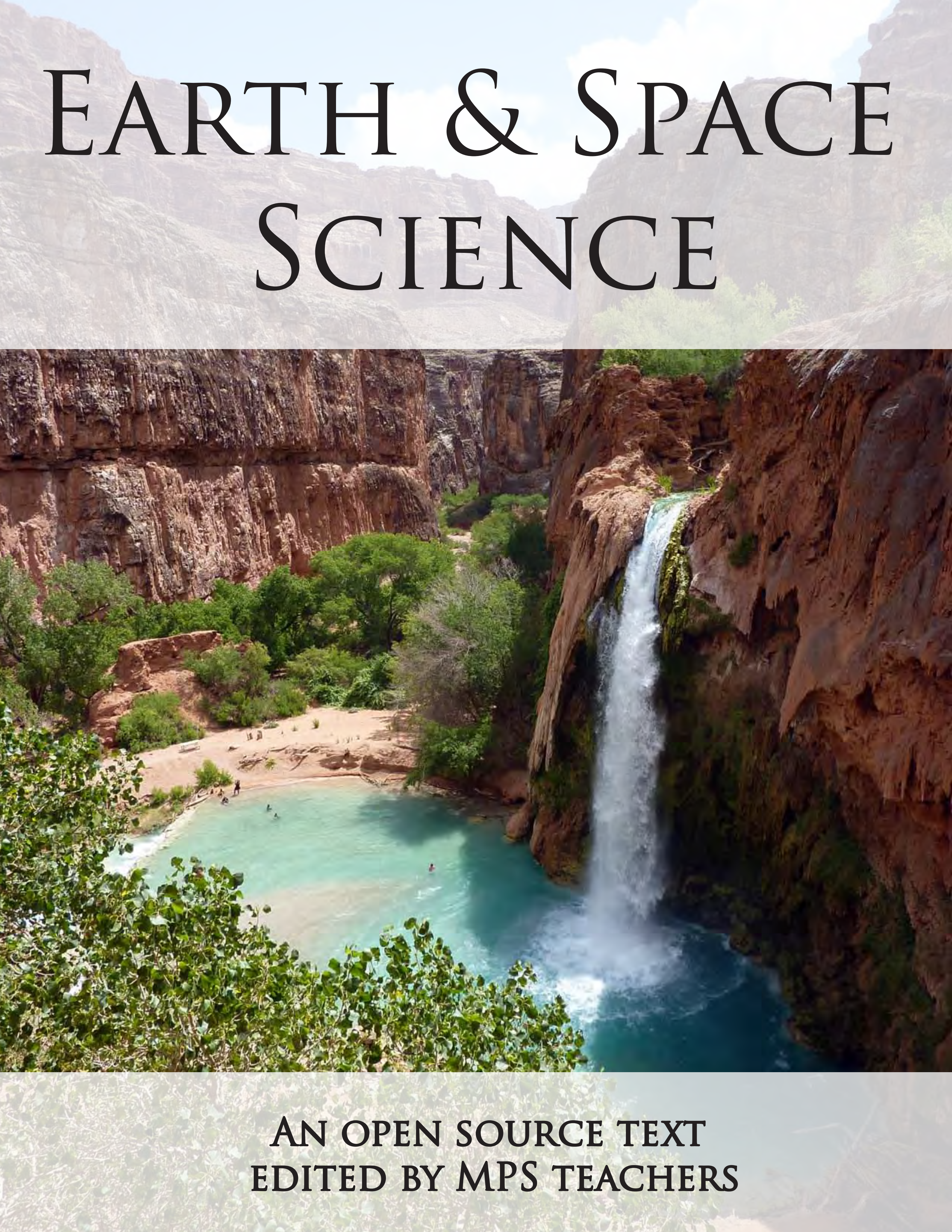
Earth & Space Science



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We also thank the amazing Mesa Public Schools science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and students in Mesa!

Please feel free to contact any of the collaborators to discuss how they are using the text with their students.

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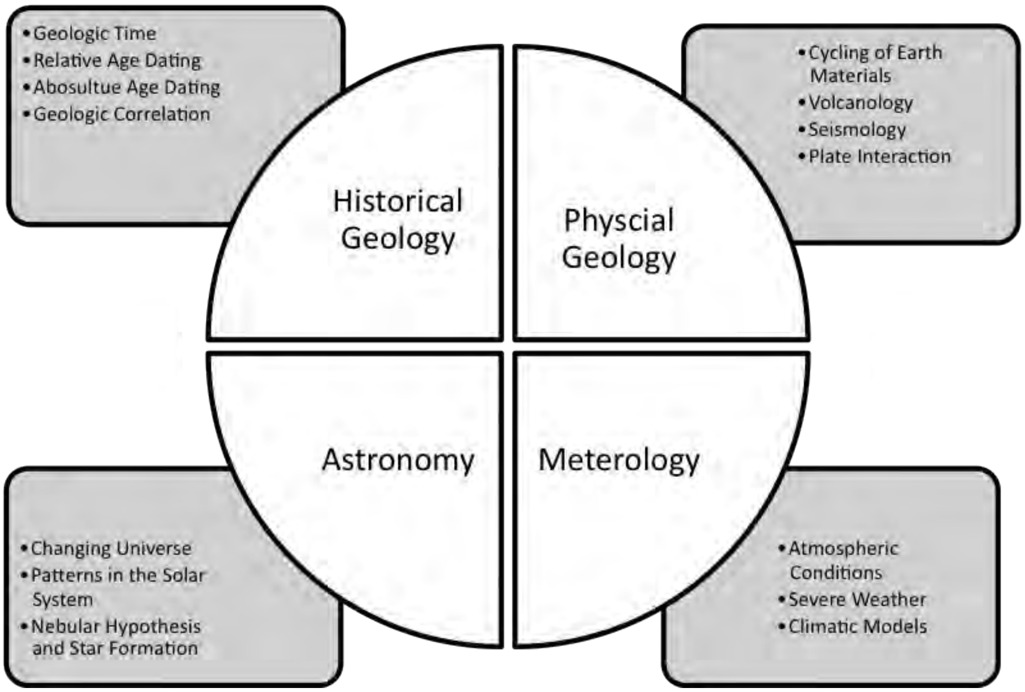
Introduction

This text is meant to act as an additional resource to the interactive, model-based Earth Science classroom that follows the Mesa Schools current curriculum map. In the tying of concepts, terms and connection in the dynamic Earth Science classroom, this book fits into a support or facilitator role, allowing students and teachers to an updated source to support their classroom curriculum.



There is no prescribed order to which you would undertake this information. It is the nature of the subject that should cycle through each topic while finding connections to past information.

"We shall not cease from exploration. And the end of all our exploring will be to arrive where we started and know the place for the first time." – T.S. Eliot *Little Gidding*

Physical Geology

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

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

Figure 1: Checkerboard Mesa in Zion National Park, Utah.

Ask a Question – Earth History

The outcrop in Figure 1 is at Checkerboard Mesa in Zion National Park, Utah. It has a very interesting pattern on it. As a geology student you may ask: how did this rock form?

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

Uniformitarianism

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

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

Answer a Question – Earth History

In this photo of the Mesquite sand dune in Death Valley National Park, California (Figure 2), we see that wind can cause cross-bedding in sand. Cross-bedding is due to changes in wind direction. There are also ripples caused by the wind waving over the surface of the dune.

Figure 2: The Mesquite sand dune in Death Valley National Park, California.

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

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

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

Mineralogy

How do compounds form? In other words, what makes atoms stick together?

When you think of bonding, do you think of bonding between tiny particles called atoms or do you think of bonding between people? When we think of people bonding, we think of them forming close relationships – we think of them "sticking together." Like people, atoms bond —

they stick together and form compounds rather than relationships. The big question is what makes atoms stick together? How do they bond?

Chemical Bonding

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Figure 3: Periodic Table of the Elements

An **element** is a type of matter made up of only one kind of atom. **Atoms** are the smallest units of matter that retain the properties of an element. There are approximately 90 naturally occurring elements, which are listed in the periodic table (Figure 3). Elements are arranged into families, or groups, which are vertical columns on the table. Families or groups of elements have similar properties. For example, the elements in the last column are called noble gases. These elements are all alike in that they do not form bonds with other elements. Elements are also arranged into horizontal rows based on periodically recurring properties. These horizontal rows are called periods.

An atom is made up of subatomic particles, particles that are even smaller than tiny atoms. These subatomic particles include **protons**, **neutrons**, and **electrons** (Figure 4). Protons and neutrons are found in the center of the atom. This central region is called the **nucleus**. Protons, which are positively charged, determine the identity of an element; it is the number of protons that define an element. For example, sodium, which has the chemical symbol Na, has 11 protons. If another proton were added to an atom of sodium, giving the atom 12 protons, it would

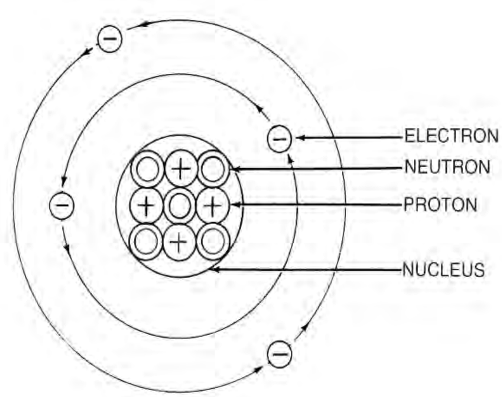


Figure 4: An atom with protons, neutrons, and electrons.

no longer be sodium—it would be magnesium. Magnesium, Mg, is defined as the element with 12 protons in its nucleus.

Neutrons are not charged; they are neutral. The number of neutrons in an atom's nucleus can vary without changing the identity of the element. When an element has atoms with different numbers of neutrons, these atoms are called **isotopes**. The element carbon has three isotopes, all of which have six protons. One carbon isotopes has six neutrons, a second has seven neutrons, and the third carbon isotope has eight neutrons. These isotopes of carbon are still carbon, though, since all of the atoms have six protons.

Electrons are negatively charged and are located outside of the nucleus in a region called the electron cloud. This electron cloud can be thought of as being made of layers or shells, not unlike the layers of an onion. The electrons occupying the outermost layer are called **valence electrons**. Valence electrons are very important because they are the part of an atom that interacts with other atoms. Valence electrons are what make atoms of different elements "stick together" to form compounds. The number of electrons that an atom has is equal to the atom's number of protons. Thus, carbon, with six protons, will also have six electrons.

When atoms of different elements stick together, they form **compounds**. A compound is made of two or more elements in a fixed or constant ratio. An example of a compound is water. Water is made of hydrogen which has the symbol H and oxygen which as the symbol O. Because water is made of two hydrogen atoms and one oxygen atom, it has the chemical formula H_2O. Water will always have a 2 to 1 ratio of hydrogen to oxygen atoms. If the ratio of atoms changes, then the compound changes. For example, hydrogen peroxide, which you may have used to disinfect cuts, has the chemical formula H_2O_2. Its ratio of hydrogen atoms to oxygen atoms is different, therefore it is a different compound. As compounds change, so do their properties. You can drink water, but you wouldn't want to drink hydrogen peroxide!

The joining or "sticking together" of atoms to form compounds is called **chemical bonding**. There are two main types of chemical bonds that are important in our discussion of **minerals** and rocks:

Ionic bonds:

Valence electrons can be transferred between atoms. As electrons are transferred, one atom will lose one or more of its valence electrons and another atom will receive or gain these electrons. When atoms gain or lose electrons, they form particles called **ions**.

Atoms are electrically neutral meaning that their positively charged protons are exactly equal in number to their negatively charged electrons. Ions, on the other hand, have either lost or gained electrons without changing their number of protons. This means that they are no longer neutral. When an atom loses electrons, it loses negatively charged electrons without losing any positively charged protons. This makes it positively charged and it is no longer considered to be an atom—it is now an ion. These positively charged ions are called **cations**.

When an atom gains electrons, it becomes negatively charged and is called an **anion**. It is gaining negatively charged electrons without changing its number of positively charged protons. This makes its overall charge negative. Cations and anions are oppositely charged and are able to attract one another. Have you ever heard the phrase "opposites attract?" Well, in the case of ions, it is true. This attraction between oppositely charged ions is an **ionic bond**. Ionic bonds are extremely strong and form very stable compounds.

Metals are located on the left side of the periodic table (Figure 3) and they tend to lose electrons to form cations. Nonmetals, located on the right side of the periodic table, tend to gain electrons to form anions. When a metal like lithium (Li) comes in contact with a nonmetal like fluorine (F), the lithium atom transfers an electron to the fluorine atom (Figure 5).

When the lithium atom loses its electron, it becomes a cation with a 1+ charge and when the fluorine atom gains the electron from lithium, it becomes an anion with a 1- charge. Once fluorine gains an electron, we call it fluoride. The Li^+ cation attracts the F^- anion, forming the **ionic compound** lithium fluoride, LiF. Ionic compounds form when metals transfer electrons to nonmetals, creating oppositely charged ions that attract one another.

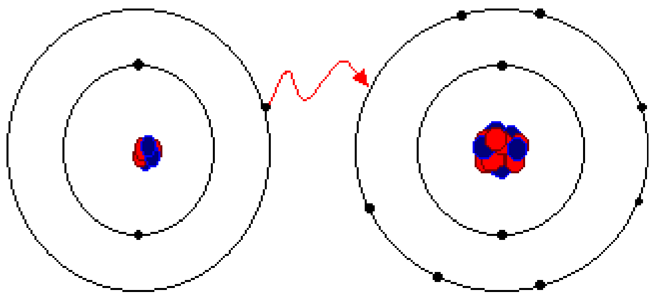


Figure 5: Lithium (left) and fluoride (right) form an ionic compound called lithium fluoride.

Covalent bonds:

Covalent bonds form between two nonmetals. Since nonmetals tend to gain electrons and two elements joining together can't both gain electrons, nonmetals must share their valence electrons in order to form bonds. When atoms share electrons in covalent bonds, they form **molecules**. A molecule is a group of atoms bonded together covalently. Thus, covalently bonded atoms form **molecular compounds**. Covalent bonds are also very strong, meaning it takes a lot of energy to break them apart.

Note that ionic compounds, then, do not form molecules. They actually connect to form networks of ions rather than individual molecules.

In Figure 6 at left, the compound methane, CH_4, forms when one carbon atom shares its valence electrons with four hydrogen atoms. Both carbon and hydrogen are nonmetals. Covalent bonding is prevalent in **organic compounds**. Organic compounds are those compounds that contain carbon atoms and are frequently found in living things. In fact, your body is chock full of compounds made with carbon.

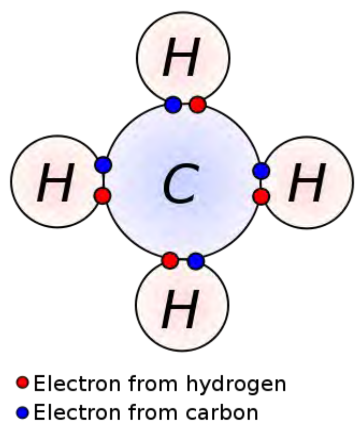


Figure 6: Methane is formed when four hydrogen atoms and one carbon atom covalently bond.

Another type of attractive force that is important in understanding minerals and rocks, hydrogen bonding, is discussed below.

Hydrogen bonds:

In the case of hydrogen bonds, the word bond is a bit deceiving. Hydrogen bonds do not cause individual atoms to stick together to form compounds. Rather, hydrogen bonds are forces that hold molecules together. Water, being made of the two nonmetals hydrogen and oxygen, is held together by covalent bonds and forms a molecular compound. Individual molecules of water attract one another well, explaining why water is a liquid at room

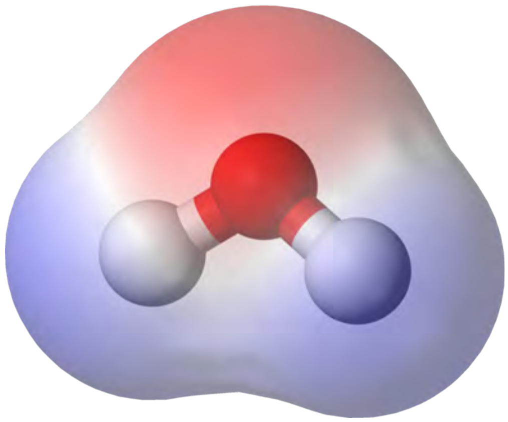


Figure 7: Water is a polar molecule. Because the oxygen atom has the electrons most of the time, the hydrogen side (blue) of the molecule has a slightly positive charge, while the oxygen side (red) has a slightly negative charge.

temperature. If the molecules of water had no attraction for each other, the molecules would fly apart and form a gas.

Water molecules are able to attract other water molecules because water is **polar**. A molecule is considered to be polar when it has a slightly positive side and a slightly negative side (see Figure 7 below). In fact, this property is why water is so good at dissolving things. The positive side of water attracts things that are negatively charged and the negative side of water attracts things that are positively charged. For example, table salt (NaCl) is an ionic compound that dissolves very well in water. Water is able to attract the positive metal cation Na^+ and the negative nonmetal anion Cl^-. Water pulls these ions apart from each other and mixes with them, dissolving the salt.

What is a Mineral?

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

A **mineral** possesses the following qualities:

It must be solid.

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

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

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

Crystalline Solid

Minerals are "crystalline" solids. A **crystal** is a solid in which the atoms are arranged in a regular, repeating pattern. Notice that in Figure 8 below, the green and purple spheres, representing sodium and chlorine, form a repeating pattern. In this case, they alternate in all directions.

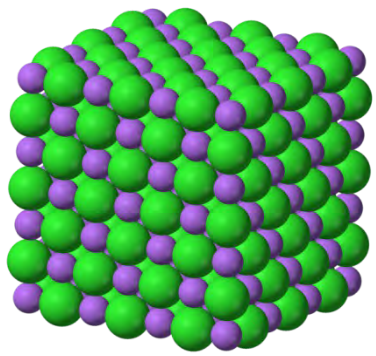


Figure 8: Sodium ions (purple balls) bond with chloride ions (green balls) to make table salt (halite). All of the grains of salt that are in a saltshaker have this crystalline structure.

Inorganic

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

Naturally Occurring

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

Chemical Composition

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

All minerals have a specific chemical composition. The mineral silver is made up of only silver atoms and diamond is made only of carbon atoms, but most minerals are made up of **chemical compounds**. Each mineral has its own chemical formula. Table salt (also known as halite), pictured in Figure 8 above, is NaCl (sodium chloride). Quartz is always made of two oxygen atoms (red) bonded to a silicon atom (grey), represented by the chemical formula SiO_2 (Figure 9).

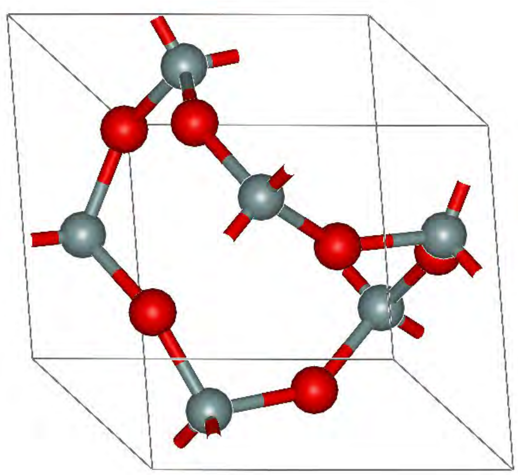


Figure 9: Quartz is made of two oxygen atoms (red) bonded to a silicon atom (grey).

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

Primary Physical Properties

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

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

Mineral Groups

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

Silicate Minerals

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

The basic building block for all silicate minerals is the **silica tetrahedron**, which is illustrated in Figure 10. To create the wide variety of silicate minerals, this pyramid-shaped structure is often bound to other elements such as calcium, iron, and magnesium.

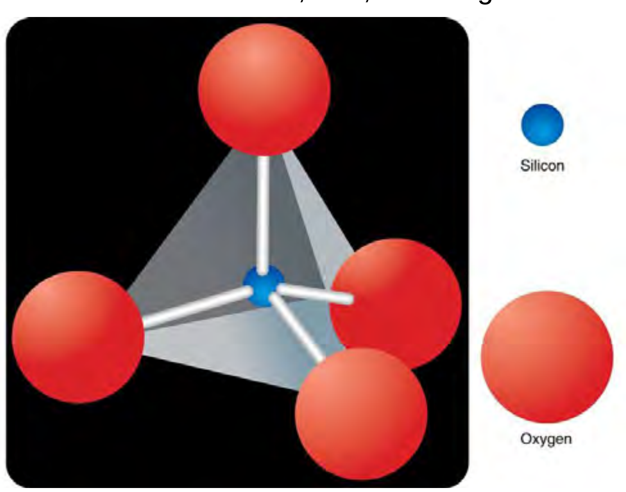


Figure 10: One silicon atom bonds to four oxygen atoms to form a silica tetrahedron.

Silica tetrahedrons combine together in six different ways to create different types of silicates (Figure 11). Tetrahedrons can stand alone, form connected circles called rings, link into single and double chains, form large flat sheets of pyramids, or join in three dimensions.

Figure 11: The different ways that silica tetrahedrons can join together cause these two minerals to look very different.

Figure 12: A gold nugget.

Native Elements

Native elements contain atoms of only one type of element. Only a small number of minerals are found in this category. Some of the minerals in this group are rare and valuable. Gold (Figure 12), silver, sulfur, and diamond are examples of native elements.

Carbonates

The basic carbonate structure is one carbon atom bonded to three oxygen atoms. Carbonates consists of some cation (like C, Fe, Cu, Mg, Ba, Sr, Pb) bonded to a carbonate molecule. Calcite ($CaCO_3$) is the most common carbonate mineral (Figure 13 and Figure 14).

Figure 13: Calcite.

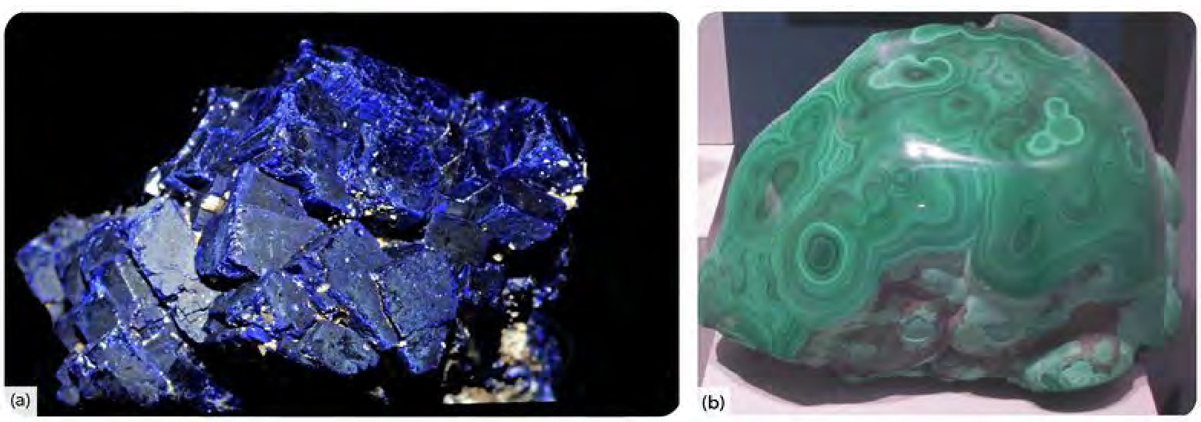


Figure 14: Two carbonate minerals: (a) deep blue azurite and (b) opaque green malachite. Azurite and malachite are carbonates that contain copper instead of calcium.

Halides

Halide minerals are salts that form when salt water evaporates. Halite is a halide mineral, but table salt is not the only halide. The chemical elements known as the halogens (fluorine, chlorine, bromine, or iodine) bond with various metallic atoms to make halide minerals. All halides are minerals formed from ionic bonding, which means that they are typically soluble in water.

Oxides

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

Phosphates

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

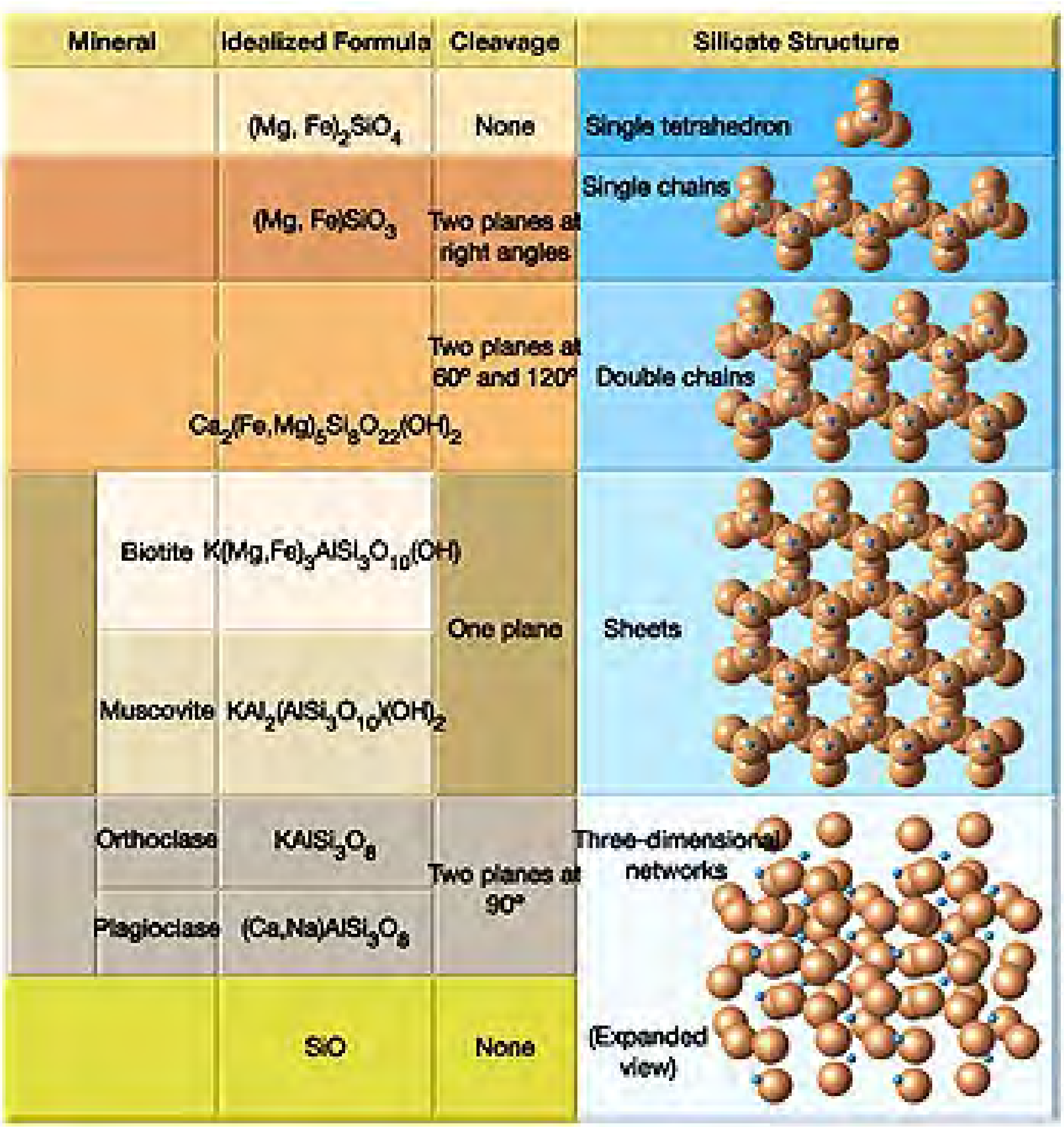
Figure 15: 11-meter gypsum crystals

Sulfates

Sulfate minerals contain sulfur atoms bonded to four oxygen atoms, just like silicates and phosphates. Like halides, they form where salt water evaporates. The most common sulfate mineral is probably gypsum ($CaSO_4(OH)_2$) Some gigantic 11-meter gypsum crystals have been found (Figure 15). That is about as long as a school bus!

Sulfides

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



Mineral	Idealized Formula	Cleavage	Silicate Structure
	$(Mg, Fe)_2SiO_4$	None	Single tetrahedron
	$(Mg, Fe)SiO_3$	Two planes at right angles	Single chains
	$Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)$	One plane	Sheets
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	One plane	Sheets
Orthoclase	$KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks
Plagioclase	$(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks
	SiO	None	(Expanded view)

Mineral Formation

Minerals form in a variety of ways:

- Crystallization from molten rock
- Precipitation from ions in solution
- Biological activity
- A change to a more stable state as in metamorphism
- Precipitation from vapor

Formation from Magma

Magma is melted rock inside Earth, a molten mixture of substances that can be hotter than 1,000°C. Magma cools slowly inside Earth, which gives mineral crystals time to grow large enough to be seen clearly (Figure 16).

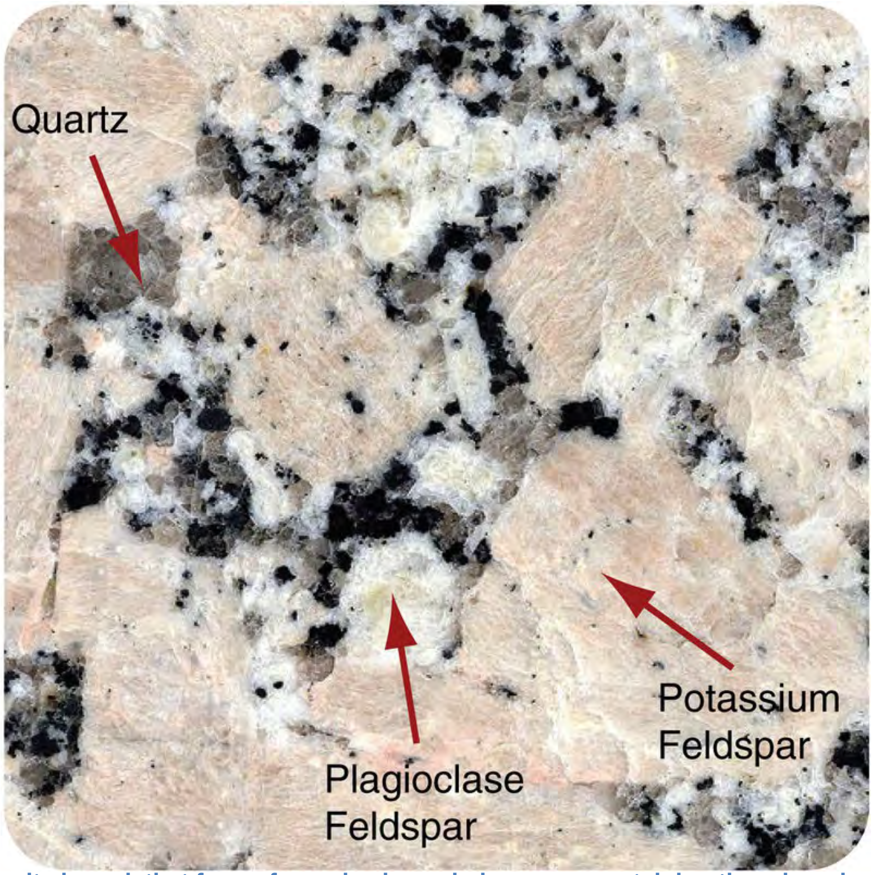


Figure 16: Granite is rock that forms from slowly cooled magma, containing the minerals quartz (clear), plagioclase feldspar (shiny white), potassium feldspar (pink), and biotite (black).

When molten rock below Earth's surface, called magma, erupts onto the surface, it is called **lava**. Lava cools much more rapidly than magma. Crystals in lava have less time to grow, and as a result, are very small. The chemical composition between minerals that form rapidly or slowly is often the same, only their size differs.

Formation from Solutions

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

Minerals from Salt Water

When water evaporates, it leaves behind a solid precipitate of minerals, as shown in Figure 17.

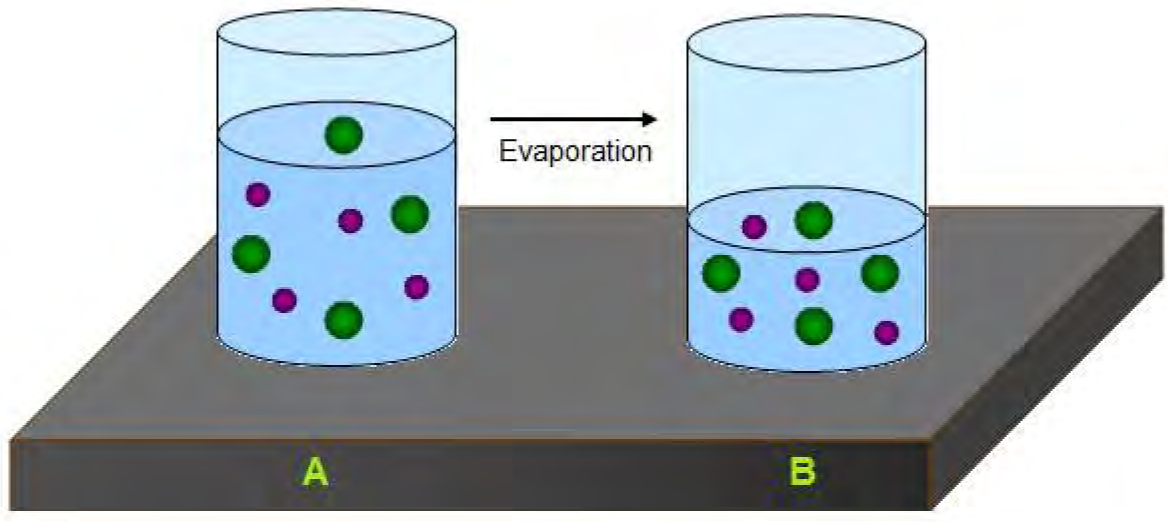


Figure 17: When the water in glass A evaporates, the dissolved mineral particles are left behind.

Water can only hold a certain amount of dissolved minerals and salts. When the amount is too great to stay dissolved in the water, the particles come together to form mineral solids, which settle to the bottom of the solution. When mineral solids settle to the bottom of a solution, it is called **precipitation.** Halite easily precipitates out of water, as does calcite. Some lakes, such as Mono Lake in California (Figure 18) or The Great Salt Lake in Utah, contain many mineral precipitates.

Figure 18: Tufa towers form when calcium-rich spring water at the bottom of Mono Lake bubbles up into the alkaline lake. The tufa towers appear when lake level drops.

Minerals from Hot Underground Water

When magma heats nearby underground water, the water reacts with the rocks around it to pick up dissolved particles. As the water flows through open spaces in the rock and cools, it deposits solid minerals. The mineral deposits that form when a mineral fills open spaces (cracks in rocks) are called **veins** (Figure 19).

Figure 19: Quartz veins formed in this rock.

When minerals are deposited in open spaces, large crystals form (Figure 20).

Figure 20: Amethyst formed when large crystals grew in open spaces inside the rock. These special rocks are called geodes.

Minerals Under Pressure

In the last several years, many incredible discoveries have been made exploring how minerals behave under high pressure, like rocks experience inside the Earth. Carbon, for example, when buried deep underground and exposed to very high temperatures and pressures, will form diamonds!

What Are Rocks?

A **rock** is a naturally formed, non-living Earth material.

Rocks are made of collections of mineral grains that are held together in a firm, solid mass. How is a rock different from a mineral? Rocks are made of minerals.

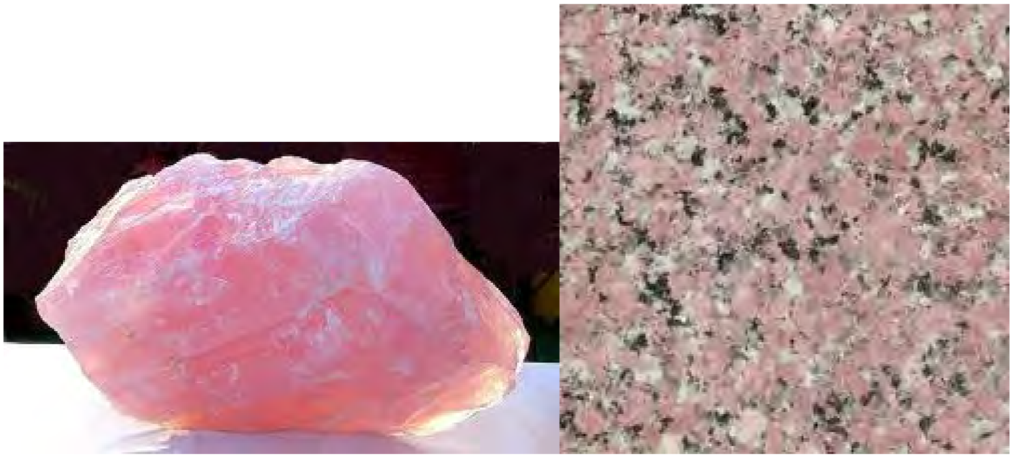


Figure 21: On the left is a sample of the mineral quartz. On the right is the rock called granite which is composed of grains of pink quartz (and other darker minerals)

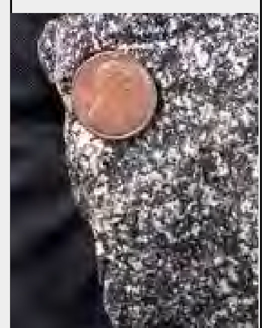
The mineral grains in a rock may be so tiny that you can only see them with a microscope, or they may be as big as your fingernail or even your finger (Figure 22).

Figure 22: This figure illustrates the two types of grains: those that can only be seen using a microscope, and those that might be as large as your fingernail.

Texture is a description of the size, shape, and arrangement of mineral grains. 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 (Figure 23).

Figure 23: The fine grained rock on the left contains lots of small grains of quartz. The coarse grained granite on the right also contains quartz, but in larger grains.

Table 1: Diorite vs Andesite

Sample	**Minerals**	**Texture**	**Formation**	**Rock type**	
Sample 1	plagioclase, hornblende, pyroxene	Crystals, visible to naked eye (coarse grain)	Magma cooled slowly	Diorite	
Sample 2	plagioclase, hornblende, pyroxene	Crystals are microscopic (fine grain)	Magma erupted and cooled quickly	Andesite	

As seen in Table 1, these two rocks have the same chemical composition and contain mostly the same minerals, but they do not have the same texture. Sample 1 has visible mineral grains, but Sample 2 has some visible grains. The two different textures indicate different histories. Sample 1 is a diorite, a rock that cooled slowly from magma (molten rock) underground. Sample

2 is an andesite, a rock that cooled rapidly from a very similar magma that erupted onto Earth's surface.

A few rocks are not made of minerals at all. Coal, for example, is made of organic material, which is not a mineral. Can you think of other rocks that are not made of minerals?

The Rock Cycle

The **rock cycle**, illustrated in Figure 24, depicts how the three major rock types – igneous, sedimentary, and metamorphic - convert from one to another. Arrows connecting the rock types represent the processes that accomplish these changes.

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

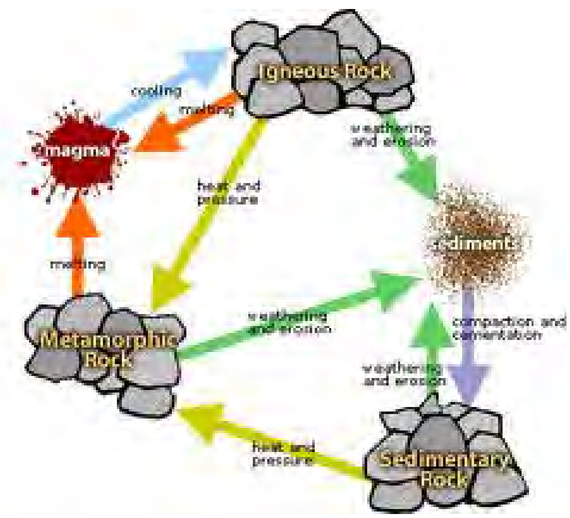


Figure 24: The Rock Cycle.

The Three Rock Types

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

- **Igneous rocks** form from the cooling and hardening of molten magma in many different environments. The chemical composition of the magma and the rate at which it cools determine what rock forms. Igneous rocks can cool slowly beneath the surface or rapidly at the surface. These rocks are identified by their composition and texture. More than 700 different types of igneous rocks are known.
- **Sedimentary rocks** form by the compaction and cementing together of **sediments**, broken pieces of rock-like gravel, sand, silt, or clay. Those sediments can be formed from the **weathering** and erosion of preexisting rocks. Sedimentary rocks also include chemical **precipitates**, the solid materials left behind after a liquid evaporates.

- **Metamorphic rocks** form when the minerals in an existing rock are changed by heat or pressure below the surface.

A simple explanation of the three rock types and how to identify them can be seen in this video:

- **http://www.youtube.com/watch?v=tQUe9C40NEE&feature=fvw**.

This video discusses how to identify igneous rocks:

- **http://www.youtube.com/watch?v=Q0XtLjE3siE&feature=channel**.

This video discusses how to identify a metamorphic rocks:

- **http://www.youtube.com/watch?v=qs9x_bTCiew&feature=related**.

The Processes of the Rock Cycle

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

Crystallization

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

Erosion and Sedimentation

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

Metamorphism

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

Intrusive and Extrusive Igneous Rocks

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

Intrusive Igneous Rocks

Igneous rocks are called **intrusive** when they cool and solidify beneath the surface. Intrusive rocks form plutons and so are also called **plutonic**. A **pluton** is an igneous intrusive rock body that has cooled below the surface. 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. Andesite is a form of granite. Granite is the most common intrusive igneous rock (see Figure 25 for an example).

Figure 25: Andesite is made of: plagioclase, hornblende, pyroxene.

Igneous rocks make up most of the rocks on Earth. Most igneous rocks are buried below the surface and covered with sedimentary rock, or are buried beneath the ocean water. In some places, geological processes have brought igneous rocks to the surface. Figure 26 shows a landscape in California's Sierra Nevada Range made of granite that has been raised, creating mountains.

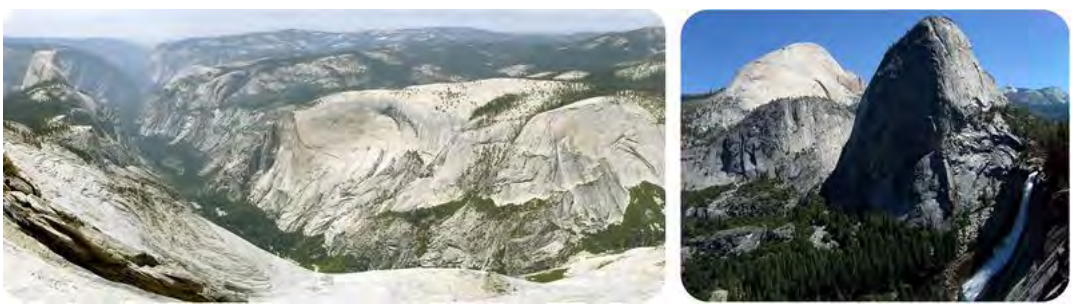


Figure 26: California's Sierra Nevada is intrusive igneous rock exposed at Earth's surface.

Extrusive Igneous Rocks

Igneous rocks are called **extrusive** when they cool and solidify above the surface. These rocks usually form from a volcano, so they are also called **volcanic rocks** (Figure 27).

Figure 27: Extrusive igneous rocks form after lava cools above the surface.

Extrusive igneous rocks cool much more rapidly than intrusive rocks. There is little time for crystals to form, so extrusive igneous rocks have tiny crystals (Figure 28).

Figure 28: Cooled lava forms basalt with no visible crystals. Why are there no visible crystals?

What does the andesite photo (Figure 25**)** in the lesson "Types of Rocks" indicate about how that magma cooled? The rock has large crystals set within a matrix of tiny crystals. In this case, the magma cooled enough to form some crystals before erupting. Once erupted, the rest of the lava cooled rapidly. This is called **porphyritic** texture.

Cooling rate and gas content create other textures (see Figure 29 for examples of different textures). Lavas that cool extremely rapidly may have a glassy texture. Those with many holes from gas bubbles have a **vesicular** texture.

Obsidian is lava that cools so rapidly crystals do not form, creating natural glass.

Pumice contains holes where gas bubbles were trapped in the molten lava, creating vesicular texture. The holes make pumice so light that it can float on water.

The most common extrusive igneous rock is basalt because it makes up most of the seafloor, These are examples of basalt below the South Pacific Ocean.

Figure 29: Different cooling rates and gas content resulted in these different textures.

Igneous Rock Classification

Igneous rocks are first classified by their composition, from **felsic** to ultramafic. The characteristics and example minerals in each type are included in Table 2.

Table 2: Properties of Igneous Rock Compositions			
Composition	**Color**	**Density**	**Minerals**
Felsic	Light	Low	Quartz, orthoclase feldspar
Intermediate	Intermediate	Intermediate	Plagioclase feldspar, biotite, amphibole
Mafic	Dark	High	Olivine, pyroxene
Ultramafic	Very dark	Very high	Olivine

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

Table 3: Silica Composition and Texture of Major Igneous Rocks			
Type	**Amount of Silica**	**Extrusive**	**Intrusive**
Ultramafic	<45%	Komatiite	Peridotite
Mafic	45-52%	Basalt	Gabbro
Intermediate	52-63%	Andesite	Diorite
Intermediate-Felsic	63-69%	Dacite	Granodiorite
Felsic	>69% SiO_2	Rhyolite	Granite

Some of the rocks in Table 3 were pictured earlier in this concept. Look back at them and, using what you know about the size of crystals in extrusive and intrusive rocks and the composition of **felsic** and **mafic** rocks, identify the rocks in the photos in Figure 30:

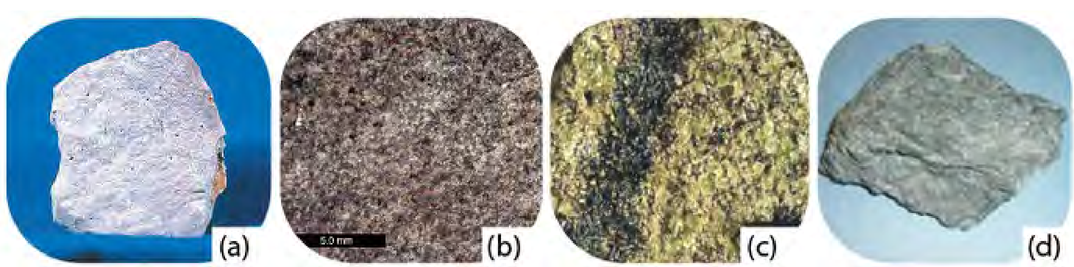


Figure 30: These are photos of A) rhyolite, B) gabbro, C) peridotite, and D) komatiite.

Magma Composition

There are as many types of volcanic eruptions as there are eruptions. Actually more since an eruption can change character as it progresses. Each volcanic **eruption** is unique, differing in size, style, and composition of erupted material.

One key to what makes the eruption unique is the chemical composition of the magma that feeds a volcano, which determines (1) the eruption style, (2) the type of volcanic cone that forms, and (3) the composition of rocks that are found at the volcano.

Different minerals within a rock melt at different temperatures. The amount of partial melting and the composition of the original rock determine the composition of the magma.

The words that describe composition of igneous rocks also describe magma composition.

- Mafic magmas are low in silica and contain darker 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 its **viscosity**. Viscosity is a liquid's resistance to flow.

Felsic magma is viscous and does not flow easily. Most felsic magma will stay deeper in the crust and will cool to form igneous intrusive rocks such as granite and granodiorite. If felsic magma rises into a magma chamber, it may be too viscous to move, so it gets stuck. Dissolved gases become trapped by thick magma. The magma churns in the chamber and the pressure builds. These conditions will result in a highly explosive volcano.

Viscosity determines what the magma will do. Mafic magma is not viscous and will flow easily to the surface. These conditions will result in a volcano that is not explosive.

		Granitic (Felsic)	Andesitic (Intermediate)	Basaltic (Mafic)	Ultramafic
Chemical Composition		Granitic (Felsic)	Andesitic (Intermediate)	Basaltic (Mafic)	Ultramafic
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
TEXTURE	Coarse-grained (phaneritic)	**Granite**	**Diorite**	**Gabbro**	**Peridotite**
TEXTURE	Fine-grained (aphanitic)	**Rhyolite**	**Andesite**	**Basalt**	Uncommon
TEXTURE	Porphyritic	"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
TEXTURE	Glassy	**Obsidian** (compact glass) **Pumice** (frothy glass)			Uncommon

Sedimentary Rocks

Sediments

Sandstone is one of the common types of sedimentary rocks that form from sediments. 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

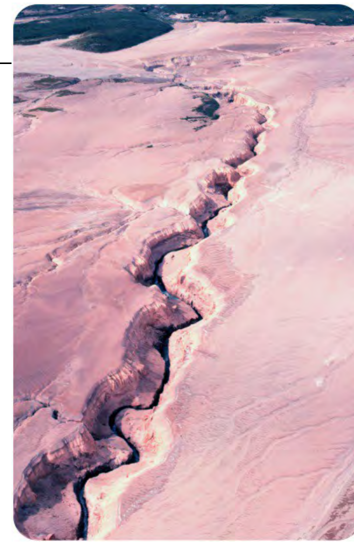


Figure 31: Water erodes the land surface in Alaska's Valley of Ten Thousand Smokes

Rocks at the surface are broken down into sediments by mechanical (physical) or chemical weathering.

Mechanical weathering simply breaks the rocks apart. For example, when water freezes in the open spaces of a rock, it expands and forces the rock to break apart.

Figure 32: This statue has been exposed to extensive chemical weathering.

Chemical weathering changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineral composition of the rock adjusts to the environment. New or secondary minerals develop from the original minerals of the rock. Chemical weathering dissolves some minerals more quickly than others. For example, limestone in statues is often dissolved by acid rain (Figure 32).

Erosion

While weathering is the "breakdown" of rocks, **erosion** is when the sediments are transported by **wind, water, ice, and gravity** (Figure 33).

Figure 33: A river dumps sediments along its bed and on its banks.

Streams carry huge amounts of sediment (Figure 33). The more energy the water has, the larger the particle of sediment 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. When the sediments are dropped, they accumulate and are called **deposits**. This process is referred to as **deposition.**

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

Sedimentary Rock Formation

Accumulated sediments harden into rock by **lithification**, as illustrated in Figure 34. 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**. If organic material is included, they are **bioclastic** rocks.

2. Liquids fill in the spaces between the loose particles of sediment and crystallize to create a rock by **cementation.** Cemented, non-organic sediments become **clastic** rocks.

The sediment size in clastic sedimentary rocks varies greatly (see Table 6).

Figure 34: This cliff is made of sandstone. Sands were deposited and then lithified.

Types of Sedimentary Rock

How do you know that this is a sedimentary rock?

Figure 35: Sandstone weathered into unique shapes.

Figure 36: Sandstone as seen up close.

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

Table 4: Types of Sedimentary Rocks

Sedimentary rock sizes and features.		
Rock	**Sediment Size**	**Other Features**
Conglomerate	Large	 Rounded
Breccia	Large	 Angular
Sandstone	Sand-sized	
Siltstone	Silt-sized, smaller than sand	
Shale	Clay-sized, smallest	

When sediments settle out of calmer water, they form horizontal layers. One layer is deposited first, and another layer is deposited on top of it. So each layer is younger than the layer beneath it. When the sediments harden, the layers are preserved. Sedimentary rocks formed by the crystallization of chemical precipitates are called **chemical sedimentary rocks**. As discussed in the "Minerals" lessons, dissolved ions in fluids precipitate out of the fluid and settle out, just like the halite in Figure 37.

Biochemical sedimentary rocks form in the ocean or a salt lake. Living creatures remove ions, such as calcium, magnesium, and potassium, from the water to make shells or soft tissue. When the organism dies, it sinks to the ocean floor to become a biochemical sediment, which may then become compacted and cemented into solid rock (Figure 38).

Figure 37: The evaporite, halite, on a cobble from the Dead Sea, Israel.

Figure 38: Fossils in a biochemical rock, limestone, in the Carmel Formation in Utah.

The table **below** shows some common types of sedimentary rocks.

Table 5: Common Sedimentary Rocks

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic (fragments of non-organic sediments)
	Breccia	Clastic

Table 5: Common Sedimentary Rocks		
Picture	**Rock Name**	**Type of Sedimentary Rock**
	Sandstone	Clastic
	Siltstone	Clastic
	Shale	Clastic
	Rock Salt	Chemical precipitate
	Rock Gypsum	Chemical precipitate
	Dolostone	Chemical precipitate

Table 5: Common Sedimentary Rocks		
Picture	**Rock Name**	**Type of Sedimentary Rock**
	Limestone	Bioclastic (sediments from organic materials, or plant or animal remains)
	Coal	Organic

Table 6

Scheme for Sedimentary Rock Identification

INORGANIC LAND-DERIVED SEDIMENTARY ROCKS					
TEXTURE	GRAIN SIZE	COMPOSITION	COMMENTS	ROCK NAME	MAP SYMBOL
Clastic (fragmental)	Pebbles, cobbles, and/or boulders embedded in sand, silt, and/or clay	Mostly quartz, feldspar, and clay minerals; may contain fragments of other rocks and minerals	Rounded fragments	Conglomerate	
			Angular fragments	Breccia	
	Sand (0.2 to 0.006 cm)		Fine to coarse	Sandstone	
	Silt (0.006 to 0.0004 cm)		Very fine grain	Siltstone	
	Clay (less than 0.0004 cm)		Compact; may split easily	Shale	
CHEMICALLY AND/OR ORGANICALLY FORMED SEDIMENTARY ROCKS					
TEXTURE	GRAIN SIZE	COMPOSITION	COMMENTS	ROCK NAME	MAP SYMBOL
Crystalline	Varied	Halite	Crystals from chemical precipitates and evaporites	Rock Salt	
	Varied	Gypsum		Rock Gypsum	
	Varied	Dolomite		Dolostone	
Bioclastic	Microscopic to coarse	Calcite	Cemented shell fragments or precipitates of biologic origin	Limestone	
	Varied	Carbon	From plant remains	Coal	

Formation of Sediment

What is the history of this rock face?

Walnut Canyon, just outside Flagstaff, Arizona, is a high desert landscape displaying cliff dwellings built 700 years ago by a long gone people. On the opposite side from the trail around the mesa is this incredible rock. In this rock you can see that the rock has slumped, and also see signs of mechanical weathering (fractures) and chemical weathering (dissolution). If you get a chance, go see the rock (and the cliff dwellings) for yourself.

Weathering

Weathering is the process that changes solid rock into sediments. Sediments were described in the chapter "Materials of Earth's Crust." With weathering, rock is disintegrated. It breaks into pieces. Once these sediments are separated from the rocks, **erosion** is the process that moves the sediments.

While **plate tectonics** forces work to build huge mountains and other landscapes, the forces of weathering gradually wear those rocks and landscapes away. Together with erosion, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas.

Weathering Takes Time

No human being can watch for millions of years as mountains are built, nor can anyone watch as those same mountains gradually are worn away. But imagine a new sidewalk or road. The new road is smooth and even. Over hundreds of years, it will completely disappear, but what happens over one year? What changes would you see? What forces of weathering wear down a 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, but smaller. That means the rock has changed physically without changing its composition. The smaller pieces have the same minerals, in just the same proportions as the original rock.

Ice Wedging

There are many ways that rocks can be broken apart into smaller pieces. **Ice wedging** is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point (Figure 39**).** 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.

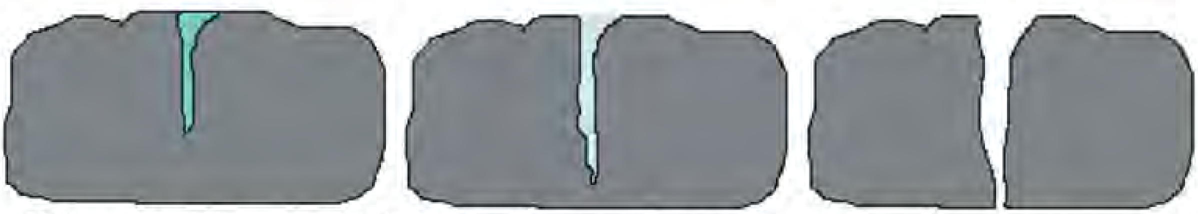


Figure 39: Ice wedging.

Ice wedging breaks apart so much rock that large piles of broken rock are seen at the base of a hillside, as rock fragments separate and tumble down. Ice wedging is common in Earth's polar regions and mid latitudes, and also at higher elevations, such as in the mountains.

Abrasion

Abrasion is another form of mechanical weathering. In abrasion, one rock bumps against another rock.

- Gravity causes abrasion as a rock tumbles down a mountainside or cliff.
- Moving water causes abrasion as particles in the water collide and bump against one another.
- Strong winds carrying pieces of sand can sandblast surfaces.
- Ice in glaciers carries many bits and pieces of rock.
- Rocks embedded at the bottom of the glacier scrape against the rocks below.

Figure 40: Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

Abrasion makes rocks with sharp or jagged edges smooth and round. If you have ever collected beach glass or cobbles from a stream, you have witnessed the work of abrasion (Figure 40).

Organisms

Now that you know what mechanical weathering is, can you think of other ways it could happen? Plants and animals can do the work of mechanical weathering (Figure 41**).** This could happen slowly as a plant's roots grow into a crack or fracture in rock and gradually grow larger, wedging open the crack. Burrowing animals can also break apart rock as they dig for food or to make living spaces for themselves.

Humans

Human activities are responsible for enormous amounts of mechanical weathering, by digging or blasting into rock to build homes, roads, and subways, or to quarry stone.

Figure 41: (a)Humans are tremendous agents of mechanical weathering. (b) Salt weathering of building stone on the island of Gozo, Malta.

How do rocks turn red?

In the desert Southwest, red rocks are common. Tourists flock to Sedona, Arizona to see the beautiful red rocks, which are set off very nicely by the snow in this photo. What makes the rocks red? The same process that makes rust red!

Chemical Weathering

Chemical weathering is the other important type of weathering. Chemical weathering may change the size of pieces of rock materials, but definitely changes the composition. So one type of mineral changes into a different mineral. Chemical weathering works through chemical reactions that cause changes in the minerals.

No Longer Stable

Most minerals form at high pressure or high temperatures deep in the crust, or sometimes in the mantle. When these rocks are uplifed onto Earth's surface, they are at very low temperatures and pressures. This is a very different environment from the one in which they formed and the minerals are no longer stable. In chemical weathering, minerals that were stable inside the crust must change to minerals that are stable at Earth's surface.

Clay

Remember that the most common minerals in Earth's crust are the silicate minerals. Many silicate minerals form in igneous or metamorphic rocks. The minerals that form at the highest temperatures and pressures are the least stable at the surface. Clay is stable at the surface and chemical weathering converts many minerals to clay (Figure 42).

Figure 42: Deforestation in Brazil reveals the underlying clay-rich soil.

There are many types of chemical weathering because there are many agents of chemical weathering.

Chemical Weathering by Water

A water molecule has a very simple chemical formula, H_2O, two hydrogen atoms bonded to one oxygen atom. But water is pretty remarkable in terms of all the things it can do. Remember that water is a polar molecule. The positive side of the molecule attracts negative ions and the negative side attracts positive ions. So water molecules separate the ions from their compounds and surround them. Water can completely dissolve some minerals, such as salt.

Figure 43: Weathered rock in Walnut Canyon near Flagstaff, Arizona.

Check out this animation of how water dissolves salt:

- **http://www.northland.cc.mn.us/biology/Biology1111/animations/dissolve.html.**

Hydrolysis is the name of the chemical reaction between a chemical compound and water. When this reaction takes place, water dissolves ions from the mineral and carries them away. These elements have been **leached**. Through hydrolysis, a mineral such as potassium feldspar is leached of potassium and changed into a clay mineral. Clay minerals are more stable at the Earth's surface.

Chemical Weathering by Carbonic Acid

Carbon dioxide (CO_2) combines with water as raindrops fall through the atmosphere. This makes a weak acid, called carbonic acid. Carbonic acid is a very common in nature, where it works to dissolve rock. Pollutants, such as sulfur and nitrogen from fossil fuel burning, create sulfuric and nitric acid. Sulfuric and nitric acids are the two main components of **acid rain**, which accelerates chemical weathering (Figure 44). Acid rain is discussed in Concept Human Impacts on Earth's Systems.

Figure 44: This chimera at Notre Dame Cathedral in Paris exhibits damage from acid rain.

Figure 45: When iron-rich minerals oxidize, they produce the familiar red color found in rust.

Chemical Weathering by Oxygen

Oxidation is a chemical reaction that takes place when oxygen reacts with another element. Oxygen is very strongly chemically reactive. The most familiar type of oxidation is when iron reacts with oxygen to create rust (Figure 45). Minerals that are rich in iron break down as the iron oxidizes and forms new compounds. Iron oxide produces the red color in **soils**.

Plants and Animals

Now that you know what chemical weathering is, can you think of some other ways chemical weathering might occur? Chemical weathering can also be contributed to by plants and animals. As plant roots take in soluble ions as nutrients, certain elements are exchanged. Plant roots and bacterial decay use carbon dioxide in the process of respiration.

Mechanical and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases (Figure 46**)**. With more surfaces exposed, there are more surfaces on which chemical weathering can occur.

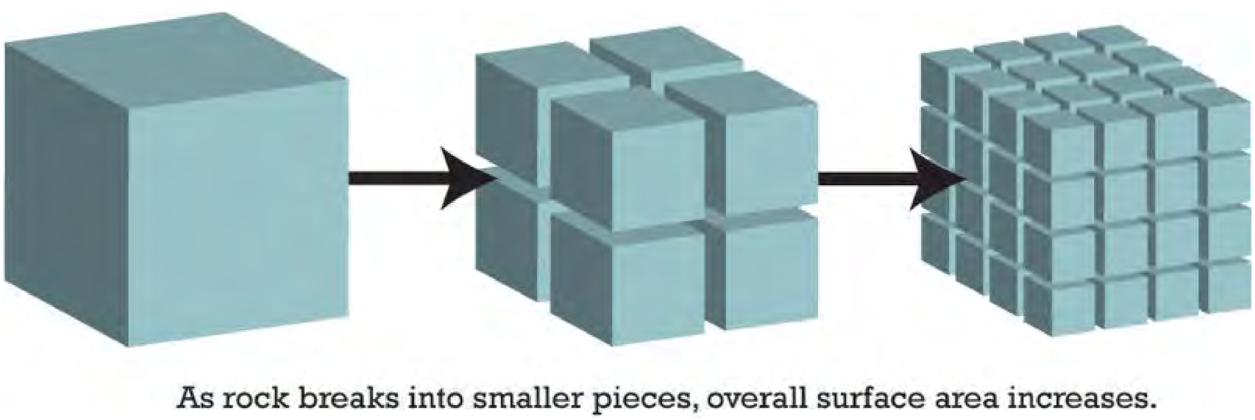


Figure 46: Mechanical weathering may increase the rate of chemical weathering.

What circumstances allow for the most intense weathering?

The rate and intensity of weathering depend on the climate of a region and the rocks materials that are being weathered. Material in Baraboo, Wisconsin weathers a lot more readily than similar material in Sedona, Arizona.

Factors affecting the rate of weathering

Rock and Mineral Type

Different rock types weather at different rates. Certain types of rock are very resistant to weathering. Igneous rocks, especially intrusive igneous rocks such as granite, weather slowly because it is hard for water to penetrate them. Other types of rock, such as limestone, are easily weathered because they dissolve in weak acids.

Rocks that resist weathering remain at the surface and form ridges or hills. Shiprock in New Mexico is the throat of a volcano that's left after the rest of the volcano eroded away. The rock that's left behind is magma that cooled relatively slowly and is harder than the rock that had surrounded it.

Figure 47: The Shiprock formation in northwest New Mexico is the central plug of resistant lava from which the surrounding rock weathered and eroded away.

Different minerals also weather at different rates. Some minerals in a rock might completely dissolve in water, but the more resistant minerals remain. In this case, the rock's surface becomes pitted and rough. When a less resistant mineral dissolves, more resistant mineral grains are released from the rock. A beautiful example of this effect is the "Stone Forest" in China, see the video below:

- **http://www.youtube.com/watch?feature=player_embedded&v=Ln5K3_8Cxrc**

Climate

A region's **climate** strongly influences weathering. Climate is determined by the temperature of a region plus the amount of precipitation it receives. Climate is weather averaged over a long period of time. Chemical weathering increases as:

- Temperature increases: Chemical reactions proceed more rapidly at higher temperatures. For each 10°C increase in average temperature, the rate of chemical reactions doubles.
- Precipitation increases: More water allows more chemical reactions. Since water participates in both mechanical and chemical weathering, more water strongly increases weathering.

Figure 48: Wet, warm tropical areas have the most weathering.

So how do different climates influence weathering? A cold, dry climate will produce the lowest rate of weathering. A warm, wet climate will produce the highest rate of weathering. The warmer a climate is, the more types of vegetation it will have and the greater the rate of biological weathering (Figure 48). This happens because plants and bacteria grow and multiply faster in warmer temperatures.

Resources from Weathering

Some resources are concentrated by weathering processes. In tropical climates, intense chemical weathering carries away all soluble minerals, leaving behind just the least soluble components. The aluminum oxide, bauxite, forms this way and is our main source of aluminum ore.

Erosion (transportation of sediment)

Erosion by Surface Water

Water that flows over Earth's surface includes **runoff**, streams, and rivers. All these types of flowing water can cause erosion and deposition.

Erosion by Runoff

When a lot of rain falls in a short period of time, much of the water is unable to soak into the ground. Instead, it runs over the land. Gravity causes the water to flow from higher to lower ground. As the runoff flows, it may pick up loose bits of soil and sand.

Figure 49: Runoff has eroded small channels through this bare field.

Runoff causes more erosion if the land is bare. Plants help hold the soil in place. The runoff water pictured below (Figure 49**)** is brown because it eroded soil from a bare, sloping field. Can you find evidence of erosion by runoff where you live? What should you look for?

Much of the material eroded by runoff is carried into bodies of water, such as streams, rivers, ponds, lakes, or oceans. Runoff is an important cause of erosion. That's because it occurs over so much of Earth's surface.

Erosion by Streams

Streams erode sediment from their banks. They pick up and transport sediments.

Figure 50: A stream in the desert rushes past its banks. The power of the water erodes the cliff face.

A stream in the desert rushes past its banks. The power of the water erodes the cliff face.

As a stream erodes its banks, it creates a V-shaped valley (Figure 50**).** This contrasts with the U-shaped valleys created by glaciers.

Erosion and Water Speed:

Erosion by a stream depends on the velocity of the water. Fast water erodes more material than slow water. Eventually, the water deposits the materials. As water slows, larger particles are deposited first. As the water slows even more, smaller particles are deposited. The graph pictured below (Figure 51) shows how water velocity and particle size influence erosion and deposition.

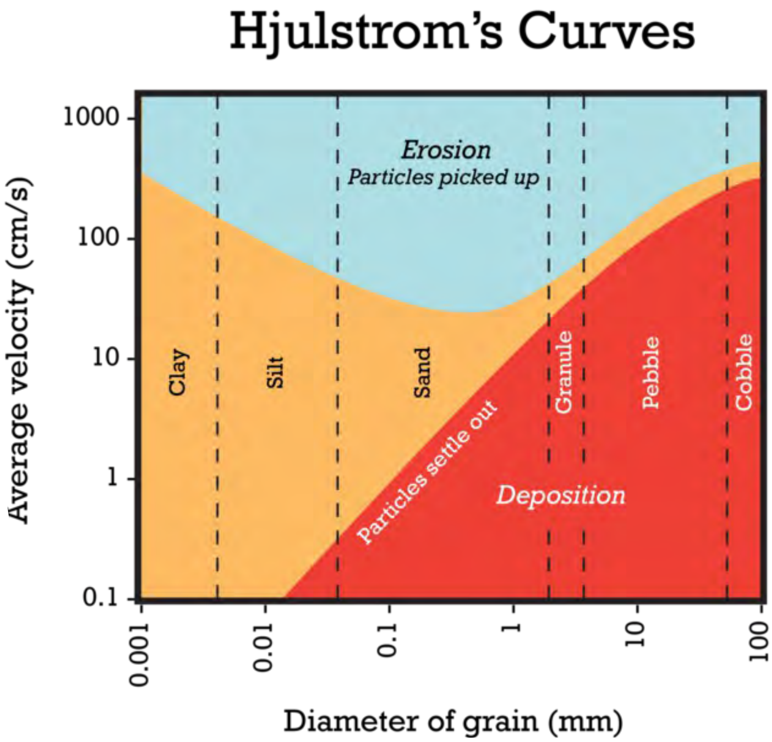


Figure 51: Flowing water erodes or deposits particles depending on how fast the water is moving. It also depends on how big the particles are.

Erosion in the Mountains:

Streams often start in mountains, where the land is very steep (Figure 52). A mountain stream flows very quickly because of the steep slope. This causes a lot of erosion and very little deposition. The rapidly falling water digs down into the streambed and makes it deeper. It carves a narrow, V-shaped channel.

Figure 52: This mountain stream is in Whitney Portal in the Sierra Nevada of California. The slope is so steep that water cascades down in a waterfall.

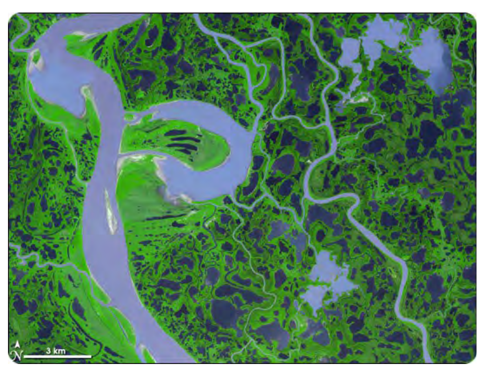


Figure 53: An oxbow lake forms in the Mackenzie River Delta, Canada

Erosion by Slow-Flowing Rivers

Streams eventually run onto flatter ground. Rivers flowing over gentle slopes erode the sides of their channels more than the bottom. Large curves, called **meanders**, form because of erosion and deposition by the moving water. The curves are called meanders because they slowly "wander," or meander, over the land. Below, you can see how this happens (Figure 54).

As meanders erode from side to side, they create a **floodplain**. This is a broad, flat area on both sides of a river. Eventually, a meander may become cut off from the rest of the river. This forms an **oxbow lake** (Figure 53).

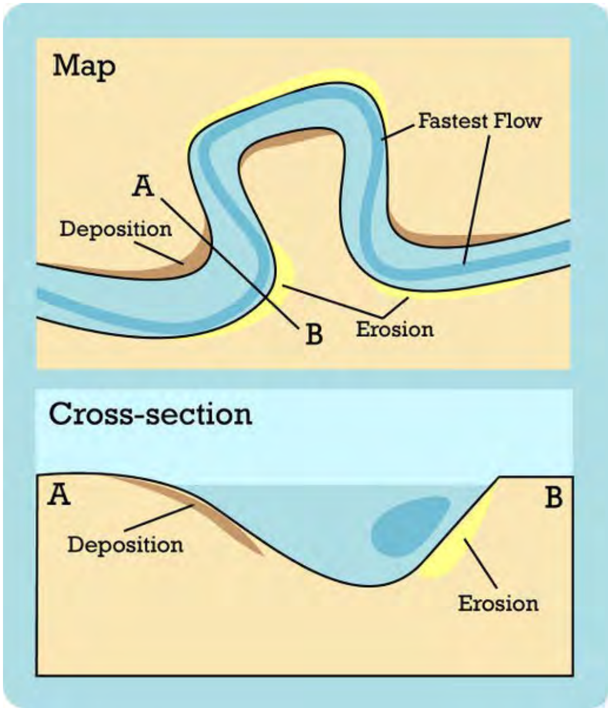


Figure 54: Meanders form because water erodes the outside of curves and deposits eroded material on the inside. Over time, the curves shift position.

Erosion by Wind

Is wind the greatest erosional force in the desert?

Wind can do remarkable things. It can erode rock to make beautiful shapes. Wind has eroded this rock so that it looks like a rabbit. This limestone formation is in the Sahara Desert in Egypt. Water is the most important erosional force even in the desert. But wind makes its mark in many ways.

Sediment Transport by Wind

Like flowing water, wind picks up and transports particles. Wind carries particles of different sizes in the same ways that water carries them **(Figure 55**).

- Tiny particles, such as clay and silt, move by **suspension**. They hang in the air, sometimes for days. They may be carried great distances and rise high above the ground.
- Larger particles, such as sand, move by **saltation**. The wind blows them in short hops. They stay close to the ground.
- Particles larger than sand move by **creep**. The wind rolls or pushes them over the surface. They stay on the ground.

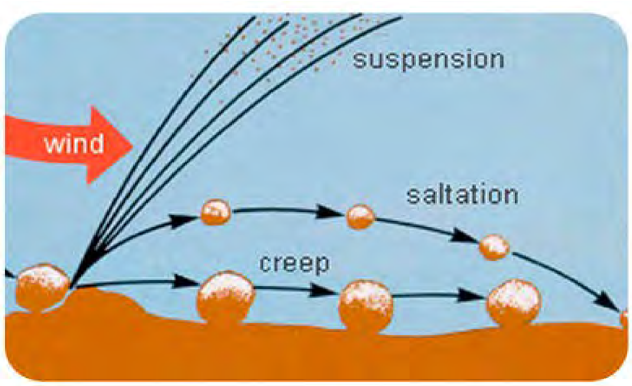


Figure 55: Wind transports particles in different ways depending on their size.

Wind Erosion

Dust storms (Figure 56) are more common in dry climates. The soil is dried out and dusty. Plants may be few and far between. Dry, bare soil is more easily blown away by the wind than wetter soil or soil held in place by plant roots.

Figure 56: When winds whip up in the desert, they can create tremendous dust storms.

Deflation

Wind blows small particles away. As a result, the ground surface gets lower and rockier; this is called **deflation**. The rocks that are left are called **desert pavement**. Desert pavement is a surface covered by gravel-sized particles that are not easily moved by wind.

Abrasion

Did you ever see workers sandblasting a building to clean it? Sand is blown onto the surface to scour away dirt and debris. Wind-blown sand has the same effect. It scours and polishes rocks and other surfaces. Wind-blown sand may carve rocks into interesting shapes (Figure 57). This form of erosion is called abrasion. It occurs any time rough sediments are blown or dragged over surfaces. Can you think of other ways abrasion might occur?

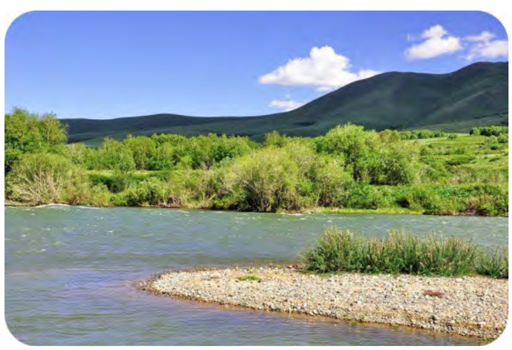
Figure 57: Bryce Canyon in Utah has incredible rock formations that are the result of wind erosion.

Desert Varnish

Exposed rocks in desert areas often develop a dark brown or black coating called **desert varnish** (Figure 58). Wind transports clay-sized particles that chemically react with other substances at high temperatures. The coating is formed of iron and manganese oxides.

Figure 58: Ancient people carved these petroglyphs into desert varnish near Capital Reef National Park in Utah.

Deposition of Sediment



Why is there a pile of cobbles in that stream?

A river meanders causing erosion on one side of its bank. On the other side, sediments are deposited. In this photo of a meander, where is there erosion and where is there deposition?

Sediment Transport

The size of particles determines how they are carried by flowing water; this is illustrated below (Figure 59).

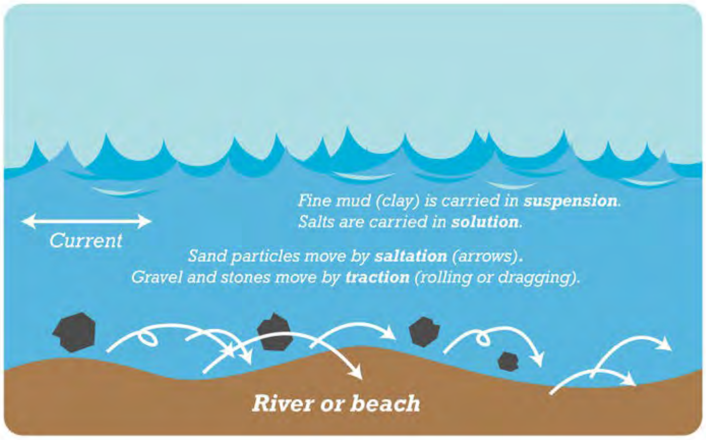


Figure 59: How Flowing Water Moves Particles. How particles are moved by flowing water depends on their size.

Sediments are carried as:

- **Dissolved load**: Dissolved ions are carried in the water. These ions usually travel all the way to the ocean.

- **Suspended load**: Sediments carried as solids as the stream flows are suspended load. The size of particles that can be carried is determined by the stream's velocity (Figure 60**).**

Figure 60: The Connecticut River is brown from the sediment it carries. The river drops the sediment offshore into Long Island Sound.

- **Bed load**: Some particles are too large to be carried as suspended load. These sediments are bumped and pushed along the streambed as bed load. Bed load sediments do not move continuously. This intermittent movement is called **saltation**. Streams with high velocities that flow down steep slopes cut down into the streambed. The sediments that travel as bed load do a lot of the downcutting.

- An animation of saltation is found here: **http://www.weru.ksu.edu/new_weru/multimedia/movies/dust003.mpg**.

- A video of bedload transport is found here: **http://faculty.gg.uwyo.edu/heller/SedMovs/Sed%20Movie%20files/bdld.mov**.

Deposition by Streams and Rivers
When a stream or river slows down, it starts dropping its sediments. Larger sediments are dropped in steep areas, but smaller sediments can still be carried. Smaller sediments are dropped as the slope becomes less steep.

Alluvial Fans
In arid regions, a mountain stream may flow onto flatter land. The stream comes to a stop rapidly. The deposits form an **alluvial fan** (Figure 61).

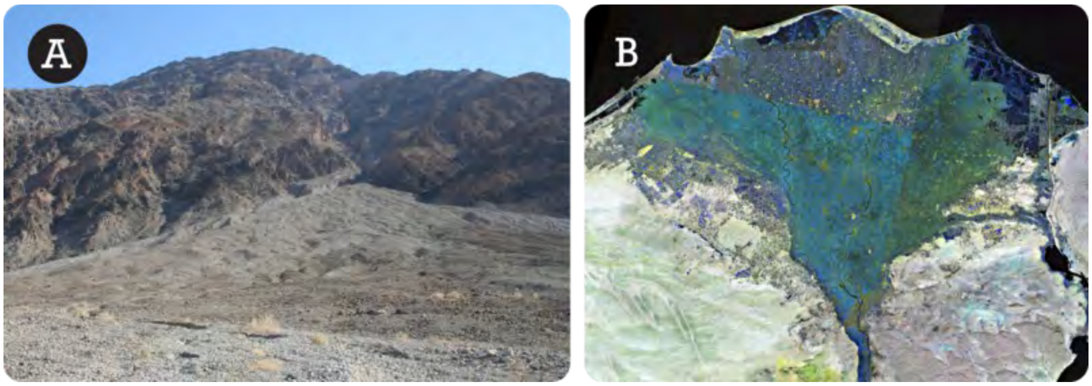


Figure 61: An alluvial fan in (A) Death Valley, California, (B) Nile River Delta in Egypt.

Deltas
Deposition also occurs when a stream or river empties into a large body of still water. In this case, a **delta** forms. A delta is shaped like a triangle. It spreads out into the body of water. An example is pictured below (Figure 61).

Deposition by Flood Waters
A flood occurs when a river overflows it banks. This might happen because of heavy rains.

Floodplains
As the water spreads out over the land, it slows down and drops its sediment. If a river floods often, the floodplain develops a thick layer of rich soil because of all the deposits. That's why floodplains are usually good places for growing plants. For example, the Nile River in Egypt provides both water and thick sediments for raising crops in the middle of a sandy desert.

Natural Levees
A flooding river often forms natural levees along its banks. A **levee** (Figure 62) is a raised strip of sediments deposited close to the water's edge. Levees occur because floodwaters deposit their biggest sediments first when they overflow the river's banks.

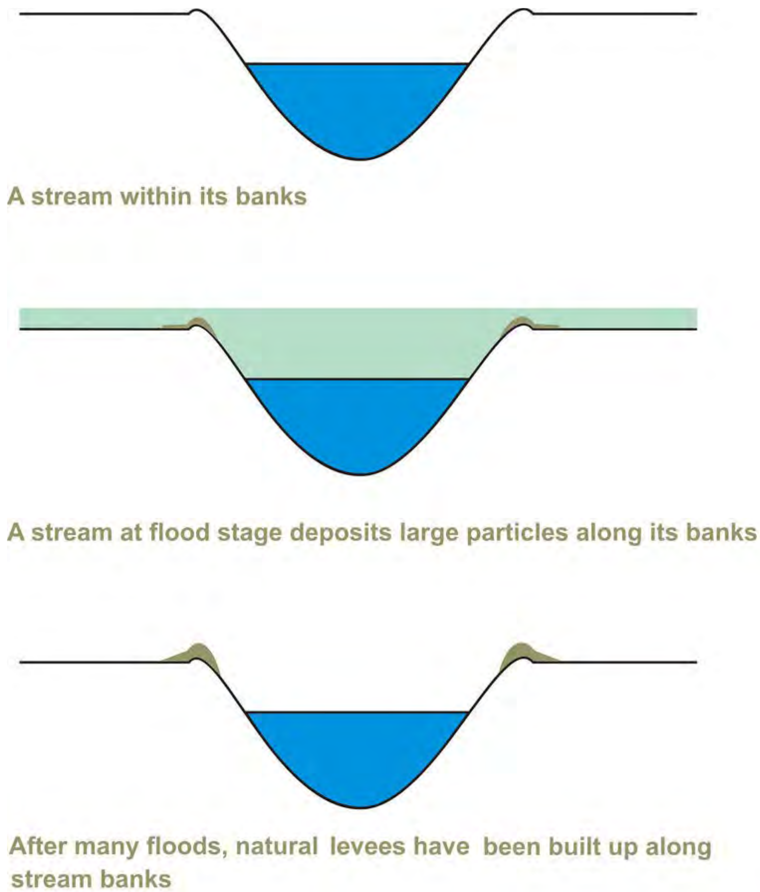


Figure 62: This diagram shows how a river builds natural levees along its banks.

How does deposition by wind modify landscapes?

On the right is a desert mountain in Arizona. The surface in the foreground is desert pavement. How did wind modify this landscape? On the left is a desert mountain with sand dunes in Death Valley, California. How did wind modify this landscape? Erosion and deposition by wind leave very different landscapes behind.

Deposition by Wind

Like water, when wind slows down it drops the sediment it's carrying. This often happens when the wind has to move over or around an obstacle. A rock or tree may cause wind to slow down.

As the wind slows, it deposits the largest particles first. Different types of deposits form depending on the size of the particles deposited.

Sand Dunes

When the wind deposits sand, it forms small hills. These hills are called **sand dunes** (Figure 63). For sand dunes to form, there must be plenty of sand and wind. Sand dunes are found mainly in deserts and on beaches.

Figure 63: A runner strides across sand dunes. Sand is picked up by her foot as it leaves the dune.

How Sand Dunes Form

What causes a sand dune to form? It starts with an obstacle, such as a rock. The obstacle causes the wind to slow down. The wind then drops some of its sand. As more sand is deposited, the dune gets bigger. The dune becomes the obstacle that slows the wind. This causes more sand to drop. The hill takes on the typical shape of a sand dune (Figure 64).

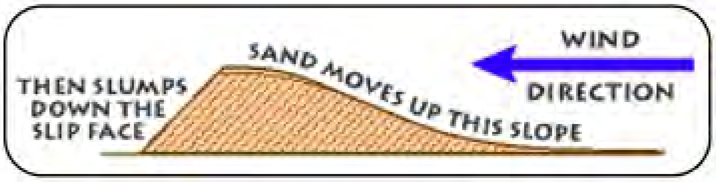


Figure 64: A sand dune has a gentle slope on the side the wind blows from. The opposite side has a steep slope. This side is called the slip face.

Migration of Sand Dunes

Once a sand dune forms, it may slowly migrate over the land. The wind moves grains of sand up the gently sloping side of the dune. This is done by saltation. When the sand grains reach the top of the dune, they slip down the steeper side. The grains are pulled by gravity. The constant movement of sand up and over the dune causes the dune to move along the ground. A dune moves in the same direction that the wind usually blows. Can you explain why?

Loess

When the wind drops fine particles of silt and clay, it forms deposits called **loess** (Figure 65). Loess deposits form vertical cliffs. Loess can become a thick, rich soil. That's why loess deposits are used for farming in many parts of the world.

Figure 65: Loess hills in Missouri are home to the Squaw Creek Wildlife Refuge.

Seafloor Mud

Fine-grained mud in the deep ocean comes from silts and clays brought from the land by wind. The particles are deposited on the sea surface. They slowly settle to the deep ocean floor, forming brown, greenish, or reddish clays. Volcanic ash may also settle on the seafloor.

Metamorphism

Can you decipher the history of this rock?

Figure 66: A foliated metamorphic rock.

The rock to the left in Figure 66 is a banded gneiss. The bands are of different composition, more felsic and more mafic, that separated as a result of heat and pressure. The waviness of the bands also shows how the rock was hot enough to alter but not to melt all the way.

Any type of rock – igneous, sedimentary, or metamorphic — can become a metamorphic rock. All that is needed is enough heat and/or pressure to alter the existing rock's physical or chemical makeup without melting the rock entirely. Rocks change during metamorphism because the minerals need to be stable under the new temperature and pressure conditions. The need for stability may cause the structure of minerals to rearrange and form new minerals. Ions may move between minerals to create minerals of different chemical composition. Hornfels, with its alternating bands of dark and light crystals, is a good example of how minerals rearrange themselves during metamorphism. Hornfels is shown in Table 7 "Metamorphic Rock Classification."

Texture

Extreme pressure may also lead to **foliation**, the flat layers that form in rocks as the rocks are squeezed by pressure (Figure 66, right). Foliation normally forms when pressure is exerted in only one direction. Metamorphic rocks may also be **non-foliated**. Quartzite and limestone, shown in Table 7 are non-foliated.

Types of Metamorphism

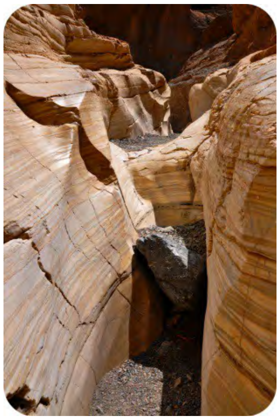
The two main types of metamorphism are both related to heat within Earth:

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:

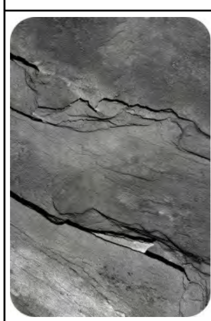
Changes in a rock that is in contact with magma. The changes occur because of the magma's extreme heat.



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

Metamorphic Rocks

Table 7 shows some common metamorphic rocks and their original parent rock

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Slate	Foliated	Metamorphism of shale
	Phyllite	Foliated	Metamorphism of slate, but under greater heat and pressure than slate
	Schist	Foliated	Often derived from metamorphism of claystone or shale; metamorphosed under more heat and pressure than phyllite

Picture	Rock Name	Type of Metamorphic Rock	Comments
	Gneiss	Foliated	Metamorphism of various different rocks, under extreme conditions of heat and pressure
	Hornfels	Non-foliated	Contact metamorphism of various different rock types
	Quartzite	Non-foliated	Metamorphism of quartz sandstone
	Marble	Non-foliated	Metamorphism of limestone
	Metaconglomerate	Non-foliated	Metamorphism of conglomerate

“With such wisdom has nature ordered things in the economy of this world, that the destruction of one continent is not brought about without the renovation of the earth in the production of another.” — James Hutton, *Theory of the Earth, with Proofs and Illustrations, Vol. 1*, 1795.

Hutton’s quote predates plate tectonics theory by about one-and-a-half centuries, but it seems as if he was talking about **divergent** and **convergent plate boundaries**. The next step in understanding the development of plate tectonics theory is to learn what it is that moves around on Earth’s surface. It’s not really a continent; it’s a plate. What is a plate?

What is a Plate?

What portion of Earth makes up the “plates” in plate tectonics? Again, the answer came about in part due to war. In this case, the Cold War.

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the **earthquakes** around the planet. The seismic records were used to locate an earthquake’s **epicenter**, the point on Earth’s surface directly above the place where the earthquake occurs.

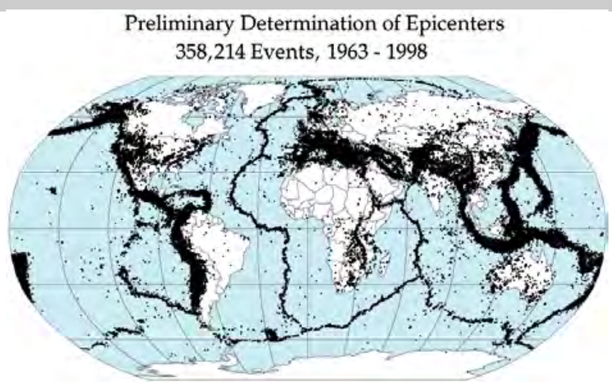


Figure 67: Earthquakes outline the plates.

Why is this relevant? It turns out that earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other.

The **lithosphere** is divided into a dozen major and several minor plates (Figure 67). A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.

The movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading?

This goes back to Arthur Holmes' idea of mantle convection. Picture two convection cells side by side in the mantle, similar to the illustration in Figure 68.

Mantle convection is shown in these animations:

- **http://www.youtube.com/watch?v=p0dWF_3PYh4**
- **http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html**

1. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
2. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
3. The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
4. The material sinks to the core and moves horizontally.
5. The material heats up and reaches the zone where it rises again.

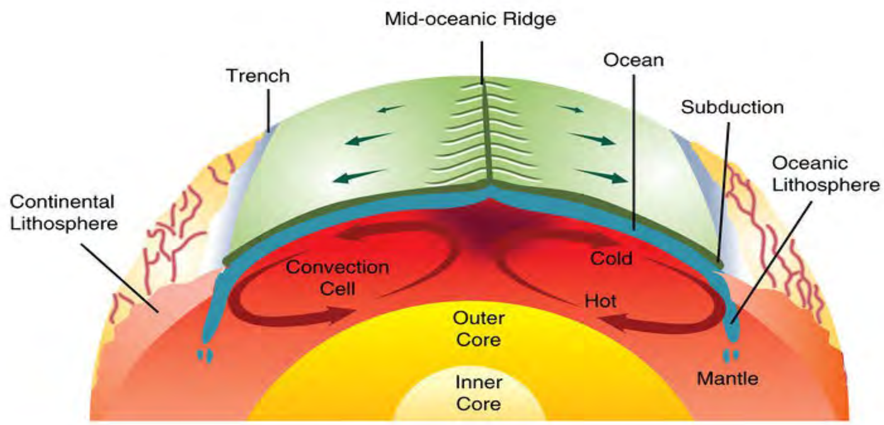


Figure 68: Mantle convection drives plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Plate Boundaries

Plate boundaries are the edges where two plates meet. How can two plates move relative to each other? Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. The features found at these plate boundaries are the mid-ocean ridges, trenches, and large transform **faults** (Figure 68).

- **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.

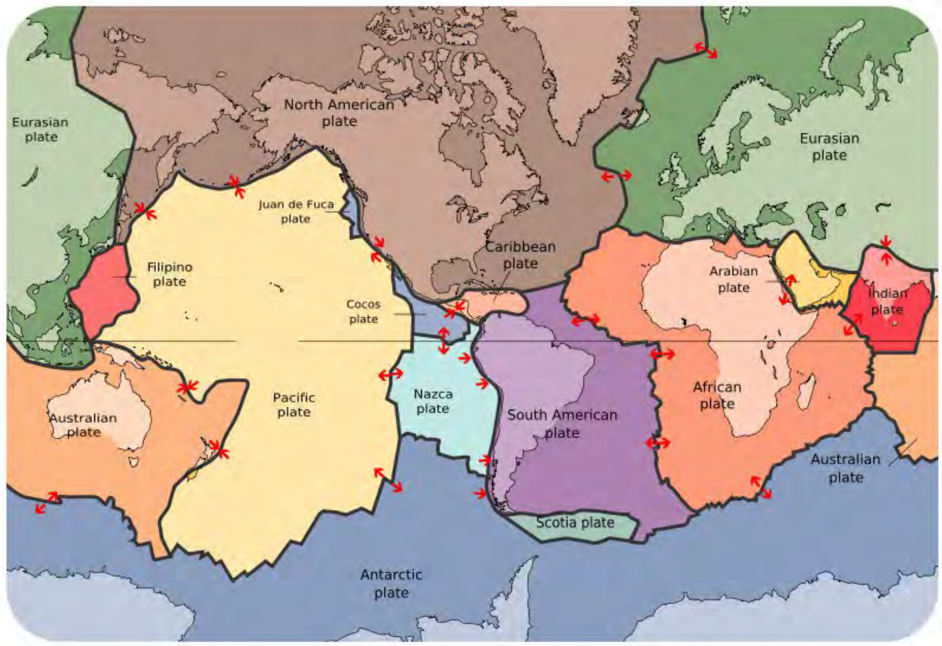


Figure 69: The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there. We can visit each of these types of plate boundaries on land or at sea.

Plate Tectonics and the Past

That map is sort of familiar, but what is it?
Wegener's persistent search for evidence that the continents had been joined paid off. Scientists who came after him developed an understanding of seafloor spreading, which was the mechanism for Wegener's **continental drift**. Geologists know that Wegener was right because the movements of continents explain so much about the geological activity we see.

The existence of Wegener's supercontinent **Pangaea** is completely accepted by geologists today. But did it all begin with Pangaea? Or were there other supercontinents that came before?

Plate Tectonics Theory

First, let's review plate tectonics theory. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.

- some places are prone to earthquakes while others are not.
- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and **fossil** species are found where they are.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Supercontinent Cycle

Remember that Wegener used the similarity of the mountains on the west and east sides of the Atlantic as evidence for his continental drift hypothesis. Those mountains rose at the convergent plate boundaries where the continents were smashing together to create Pangaea. As Pangaea came together about 300 million years ago, an ocean where the Atlantic is now separated the continents. The proto-Atlantic ocean shrank as the Pacific Ocean grew.

Figure 70: The Appalachian Mountains in New Hampshire.

The Appalachian mountains of eastern North America formed at a convergent plate boundary as Pangaea came together (Figure 70). About 200 million years ago, they were probably as high as the Himalayas, but they have been weathered and eroded significantly since the breakup of Pangaea.

Pangaea has been breaking apart since about 250 million years ago. Divergent plate boundaries formed within the continents to cause them to rift apart. The continents are still moving apart, since the Pacific is shrinking as the Atlantic is growing. If the continents continue in their current directions, they will come together to create a supercontinent on the other side of the planet in around 200 million years.

If you go back before Pangaea there were earlier supercontinents, such as Rodinia, which existed 750 million to 1.1 billion years ago, and Columbia, at 1.5 to 1.8 billion years ago. This **supercontinent cycle** is responsible for most of the geologic features that we see and many more that are long gone (Figure 71).

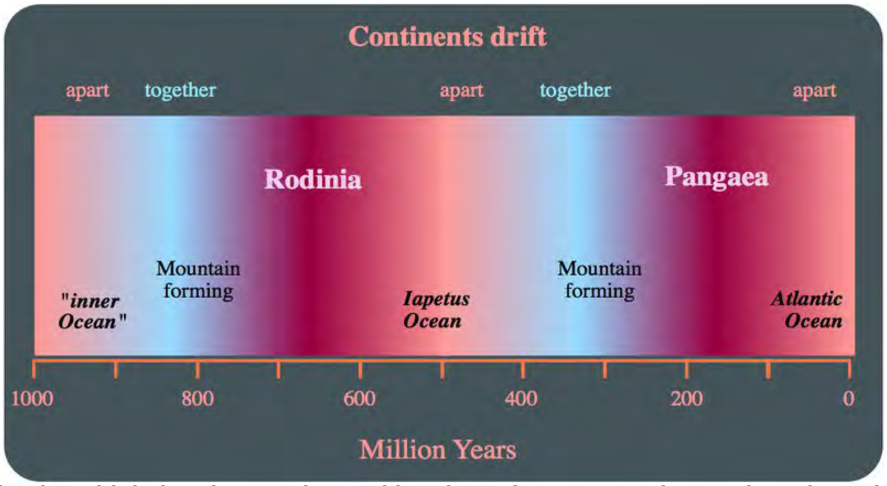
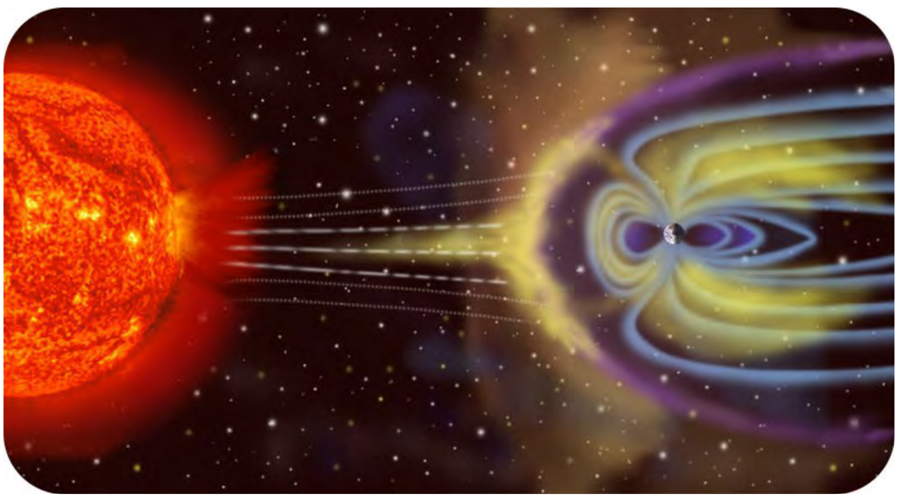


Figure 71: Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years. The supercontinent before Pangaea was Rodinia. A new continent will form as the Pacific ocean disappears.

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

- **http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html.**

Evidence of plate movement



What would happen if Earth suddenly lost its magnetic field?

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

Earth's Magnetism

Earth is surrounded by a **magnetic field** (Figure 72) that behaves as if the planet had a gigantic bar magnet inside of it. Earth's magnetic field also has a north and south pole. The magnetic field arises from the convection of molten iron and nickel metals in Earth's liquid **outer core**.

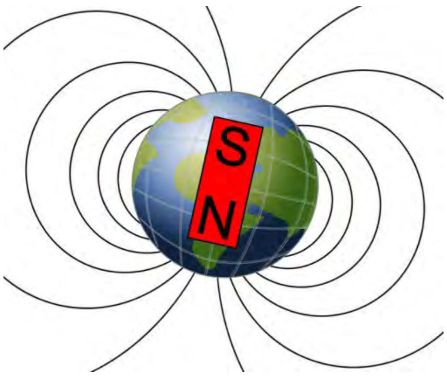


Figure 72: Earth's magnetic field is like a bar magnet resides in the center of the planet.

Magnetic Reversals

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

"The Wegener hypothesis has been so stimulating and has such fundamental implications in geology..."

"...as to merit respectful and sympathetic interest from every geologist. Some striking arguments in his favor have been advanced, and it would be foolhardy indeed to reject any concept that offers a possible key to the solution of profound problems in the Earth's history." - Chester R. Longwell, "Some Thoughts on the Evidence for Continental Drift," 1944

Wegener and his supporters did all they could do to find evidence to support continental drift. But without a mechanism the idea would not be accepted. What was needed was the development of technologies that would allow scientists to find more evidence for the idea and help them describe a mechanism. But first, they would find still more evidence that the continents had moved.

Magnetic Polarity Evidence

Figure 73: Magnetite crystals.

The next breakthrough in the development of the theory of plate tectonics came two decades after Wegener's death. **Magnetite** crystals are shaped like a tiny bar magnet. As basalt lava cools, the magnetite crystals line up in the magnetic field like tiny magnets. When the lava is completely cooled, the crystals point in the direction of magnetic north pole at the time they form. How do you expect this would help scientists see whether continents had moved or not?

As a Wegener supporter, (and someone who is omniscient), you have just learned of a new tool that may help you. A **magnetometer** is a device capable of measuring the magnetic field intensity. This allows you to look at the magnetic properties of rocks in many locations. First, you're going to look at rocks on land. Which rocks should you seek out for study?

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Geologists noted important things about the magnetic polarity of different aged rocks on the same continent:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole no matter what continent or where on the continent the rocks are located.
- Older rocks that are the same age and are located on the same continent point to the same location, but that location is not the current north magnetic pole.
- Older rocks that are of different ages do not point to the same locations or to the current magnetic north pole.

In other words, although the magnetite crystals were pointing to the magnetic north pole, the location of the pole seemed to wander. Scientists were amazed to find that the north magnetic pole changed location over time.

Can you figure out the three possible explanations for this? They are:

1. The continents remained fixed and the north magnetic pole moved.
2. The north magnetic pole stood still and the continents moved.
3. Both the continents and the North Pole moved.

Magnetic Polarity on Different Continents with Rocks of the Same Age

How do you figure out which of those three possibilities is correct? You decide to look at magnetic rocks on different continents. Geologists noted that for rocks of the same age but on different continents, the little magnets pointed to different magnetic north poles.

- 400 million-year-old magnetite in Europe pointed to a different north magnetic pole than magnetite of the same age in North America.
- 250 million years ago, the north poles were also different for the two continents.

Now look again at the three possible explanations. Only one can be correct. If the continents had remained fixed while the north magnetic pole moved, there must have been two separate north poles. Since there is only one North Pole today, what is the best explanation? The only reasonable explanation is that the magnetic north pole has remained fixed but that the continents have moved.

Wegener was Right!

How does this help you to provide evidence for continental drift? To test the idea that the pole remained fixed but the continents moved, geologists fitted the continents together as Wegener had done. It worked! There has only been one magnetic north pole and the continents have drifted (Figure 74). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander**.

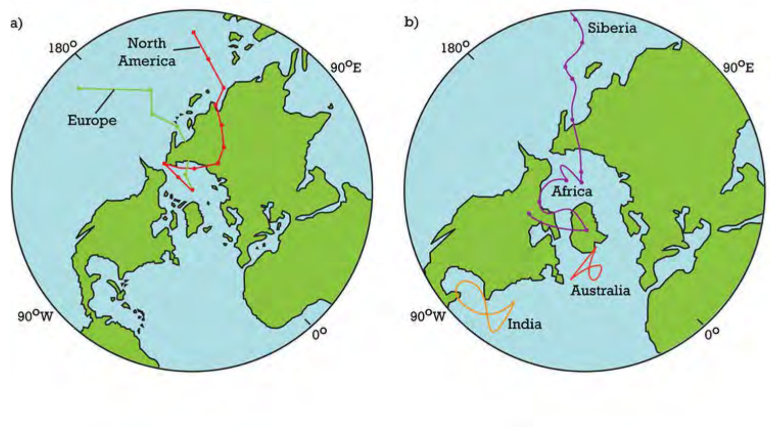
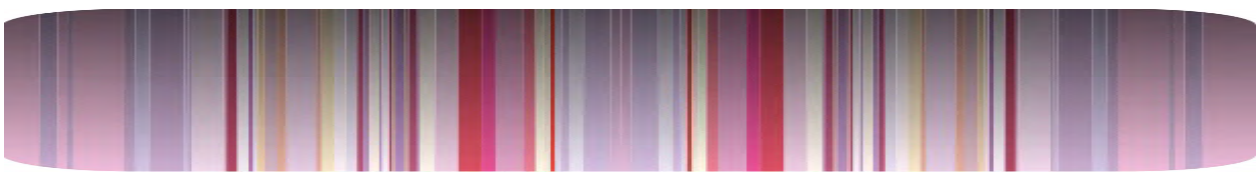


Figure 74: On the left: The apparent north pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.



What causes the strange stripes on the seafloor?

This pattern of stripes could represent what scientists see on the seafloor. Note that the stripes are symmetrical about the central dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What could cause this? What could it possibly mean?

Seafloor Magnetism

On the transit to the Mid-Atlantic ridge, scientists tow a magnetometer behind the ship. Shipboard magnetometers reveal the magnetic polarity of the rock beneath them. The practice of towing a magnetometer began during WWII when navy ships towed magnetometers to search for enemy submarines.

When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern.

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.
- Stripes form mirror images on either side of the mid-ocean ridges (Figure 75).
- Stripes end abruptly at the edges of continents, sometimes at a deep-sea trench (Figure 75).

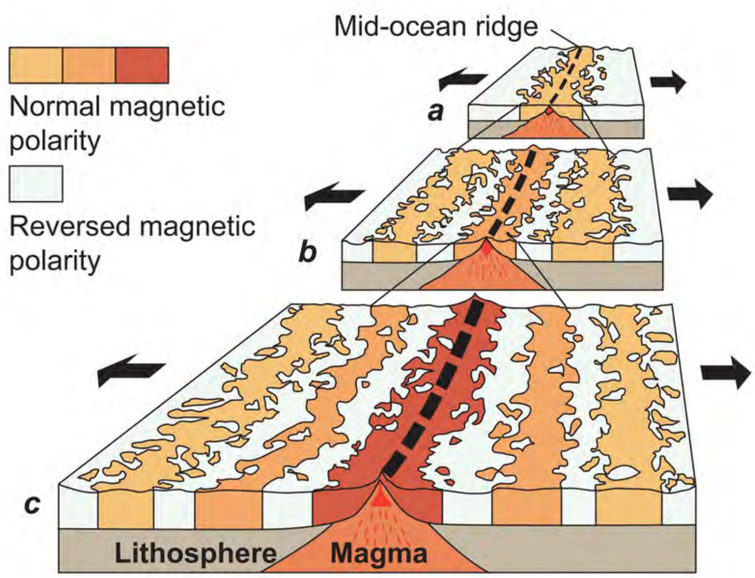


Figure 75: Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The magnetic stripes are what created the map above. Research cruises today tow magnetometers to add detail to existing magnetic polarity data.

Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with **radiometric age dating** and fossil ages, scientists came up with a time scale for the magnetic reversals. The first four magnetic periods are:

- Brunhes normal - present to 730,000 years ago.
- Matuyama reverse - 730,000 years ago to 2.48 million years ago.
- Gauss normal - 2.48 to 3.4 million years ago.
- Gilbert reverse – 3.4 to 5.3 million years ago.

The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, abutting continents.

Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in Table 8.

Table 8	Rock ages	Sediment thickness	Crust thickness	Heat flow
At ridge axis	youngest	none	thinnest	hottest

Table 8	Rock ages	Sediment thickness	Crust thickness	Heat flow
With distance from axis	becomes older	becomes thicker	becomes thicker	becomes cooler

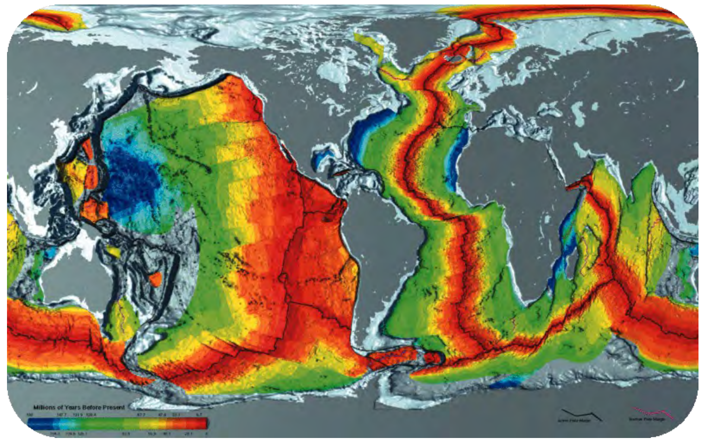


Figure 76: Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates the warmth of a region, is highest at the ridge crest.

A map of sediment thickness is found here:

- **http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sedimentthickness.html**.

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (Figure 76). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

How can you explain the observations that scientists have made in the oceans? Why is rock younger at the ridge and oldest at the farthest points from the ridge? The scientists suggested that seafloor was being created at the ridge. Since the planet is not getting larger, they suggested that it is destroyed in a relatively short amount of geologic time.

This 65 minute video explains “The Role of **Paleomagnetism** in the Evolution of Plate Tectonic Theory”:

- **http://online.wr.usgs.gov/calendar/2004/jul04.html**.

Types of Plate Interaction

Can plate tectonics explain the differences in these beaches?

Plate tectonics explains why some beaches have lots of cliffs and some do not. A beach with lots of cliffs is near a plate boundary. A gentle beach is not. There are exceptions to this rule, but it works in some cases.

Continental Margins

Think of a continent, like North America. Surrounding the continent are **continental margins**. Continental crust grades into oceanic crust at continental margins. Continental margins are under water. Almost all of North America sits on the North American Plate (Figure 77). Both sides of the continent have continental margins, but each is very different. One continental margin of North America is an active margin. The other is a passive margin. Can you guess which is which?

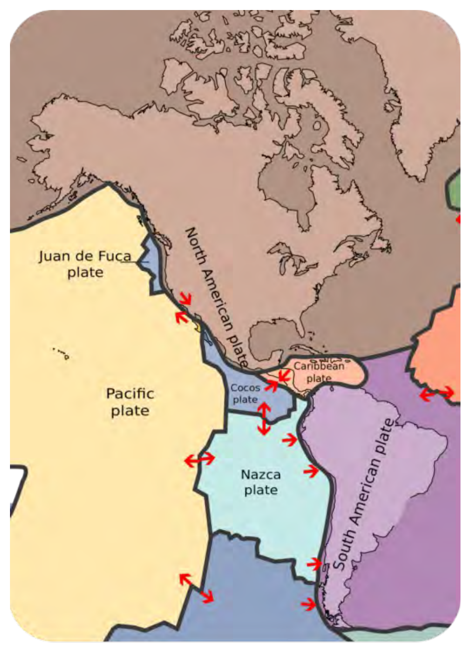


Figure 77: The North American plate and the plates that surround it.

Active Margins

If a continental margin is near a plate boundary, it is an **active margin**. The continental margin of western North America is near a set of plate boundaries. There are convergent boundaries, like where there is subduction off of the Pacific Northwest. There is a **transform boundary**, the San Andreas Fault. The small amount of the North American continent that is not on the North American Plate is across the San Andreas Fault. It is on the Pacific Plate. Western North America has a lot of volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of this active margin (Figure 78).

Passive Margins

There are no volcanoes and very few earthquakes on the eastern edge of North America. The continental margin is a smooth transition from continental to oceanic lithosphere. The continental margin there becomes oceanic lithosphere, but both are on the North American Plate. There is no plate boundary. The far eastern edge of the North American Plate is the mid-Atlantic Ridge. The portion of a plate that does not meet another plate has no geological activity. It is called a **passive margin** (Figure 79).

Figure 78: Big Sur, in central California, has beautiful cliff-lined beaches.

Figure 79: The eastern U.S. is a passive margin. Daytona Beach in Florida is flat and sandy, typical of a passive margin.

Plate Divergence in the Ocean

Iceland provides us with a fabulous view of a mid-ocean ridge above sea level (Figure 80**).** As you can see, where plates diverge at a mid-ocean ridge is a rift valley that marks the boundary between the two plates. Basalt lava erupts into that rift valley and forms new seafloor. Seafloor on one side of the rift is part of one plate and seafloor on the other side is part of another plate.

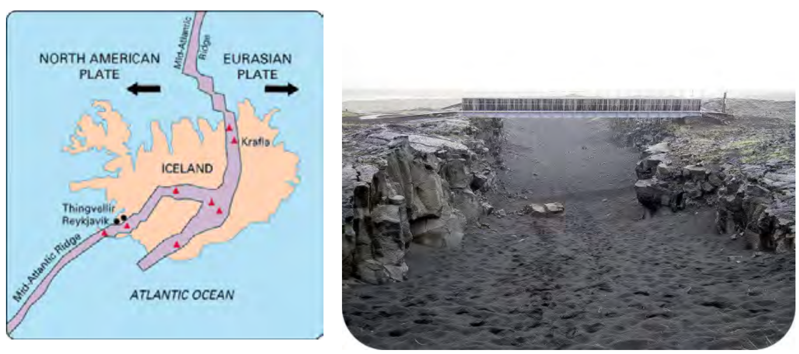


Figure 80: Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates

Leif the Lucky Bridge straddles the divergent plate boundary. Look back at the photo at the top. You may think that the rock on the left side of the valley looks pretty much like the rock on the right side. That's true – it's all basalt and it even all has the same magnetic polarity. The rocks on both sides are extremely young. What's different is that the rock one side of the bridge is the youngest rock of the North American Plate while the rock on the other side is the youngest rock on the Eurasian plate.

This is a block diagram of a divergent plate boundary. Remember that most of these are on the seafloor and only in Iceland do we get such a good view of a divergent plate boundary in the ocean.

Convection Cells at Divergent Plate Boundaries

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking.

USGS animation of divergent plate boundary at mid-ocean ridge:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200**.

Divergent plate boundary animation:

- **http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov**

Divergent plate boundaries on land

Tectonic Features of Western North America

We're on a new trip now. We will start in Mexico, in the region surrounding the Gulf of California, where a divergent plate boundary is rifting Baja California and mainland Mexico apart. Then we will move up into California, where plates on both sides of a transform boundary are sliding past each other. Finally we'll end up off of the Pacific Northwest, where a divergent plate boundary is very near a **subduction zone** just offshore.

In Figure 81 a red bar where seafloor spreading is taking place. A long black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

Figure 81: This map shows the three major plate boundaries in or near California.

Plate Divergence on Land

A divergent plate boundary on land rips apart continents.

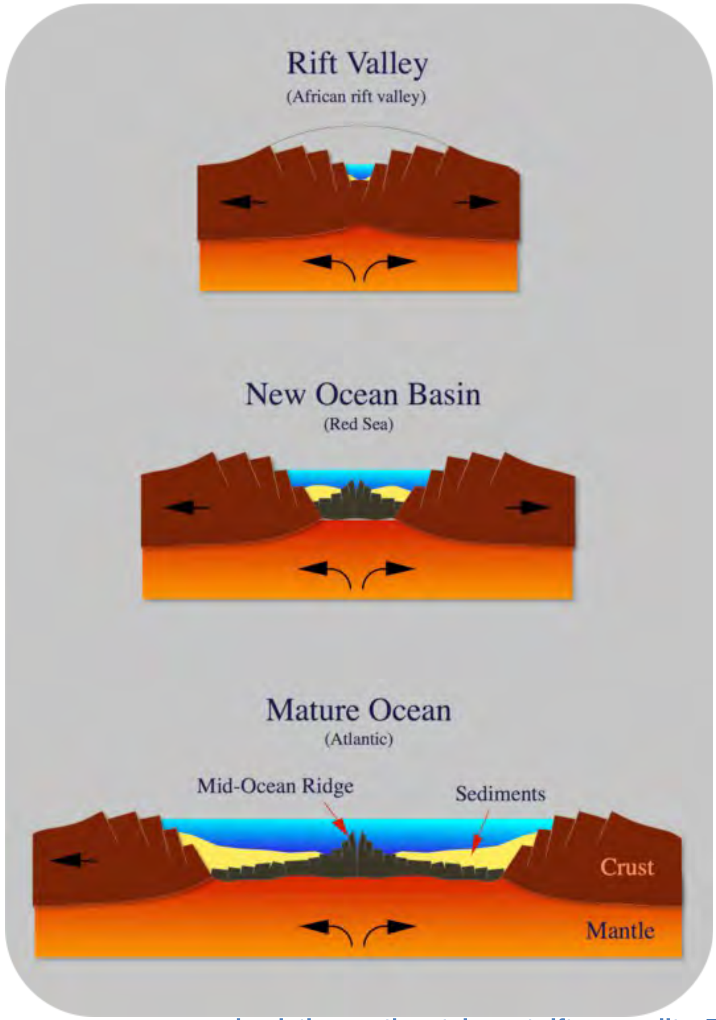


Figure 82: When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.

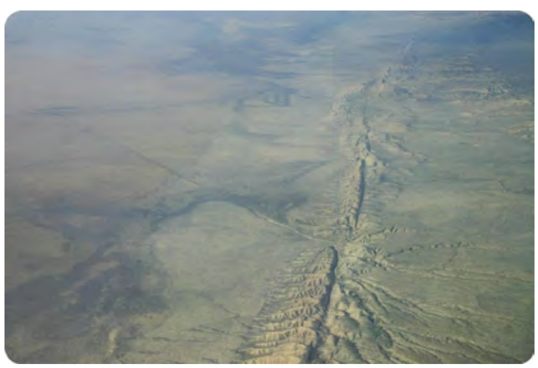
Baja California

Baja California is a state in Mexico just south of California. In the image Figure 84, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the image above. Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

Figure 84: Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

Figure 83: Volcanism in Baja California is evidence of rifting.



What could cause such an enormous scar on the land?

A transform plate boundary! As we continue up the West Coast, we move from a divergent plate boundary to a transform plate boundary. As in Iceland, where we could walk across a short bridge connecting two continental plates, we could walk from the Pacific Plate to the North American plate across this transform plate boundary. In this image, the San Andreas Fault across central California is the gash that indicates the plate boundary.

Transform Plate Boundaries

With transform plate boundaries, the two slabs of lithosphere are sliding past each other in opposite directions. The boundary between the two plates is a **transform fault**.

Transform Faults On Land

Transform faults on continents separate two massive plates of lithosphere. As they slide past each other, they may have massive earthquakes.

The San Andreas Fault in California is perhaps the world's most famous transform fault. Land on the west side is moving northward relative to land on the east side. This means that Los Angeles is moving northward relative to Palm Springs. The San Andreas Fault is famous because it is the site of many earthquakes, large and small (Figure 85).

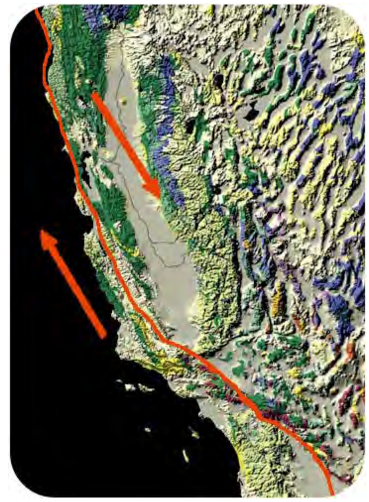


Figure 85: Transform plate boundaries are also found in the oceans.

Transform plate boundaries are also found in the oceans. They divide mid-ocean ridges into segments. In the diagram of western North America, the mid-ocean ridge up at the top, labeled the Juan de Fuca Ridge, is broken apart by a transform fault in the oceans. A careful look will show that different plates are found on each side of the ridge: the Juan de Fuca plate on the east side and the Pacific Plate on the west side.

Convergent Plate Boundaries

What do you see at an ocean-continent convergent boundary?

We continue our field trip up the West Coast. Just offshore from Washington, Oregon, and Northern California is a subduction zone, where the Juan de Fuca Plate is sinking into the mantle. The Juan de Fuca Plate is being created at a spreading center, the Juan de Fuca Ridge. Let's see the results of subduction of the Juan de Fuca Plate.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. The three possibilities are oceanic crust to oceanic crust, oceanic crust to continental crust, or continental crust to continental crust. If at least one of the slabs of lithosphere is oceanic, that oceanic plate will plunge into the trench and back into the mantle. The meeting of two enormous slabs of lithosphere and subduction of one results in magma generation and earthquakes. If both plates meet with continental crust, there will be mountain building. Each of the three possibilities is discussed in a different lesson.

In this lesson we look at subduction of an oceanic plate beneath a continental plate in the Pacific Northwest.

Ocean-Continent Convergence

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches. The entire region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (Figure 86). The volcanoes are known as a **continental arc**.

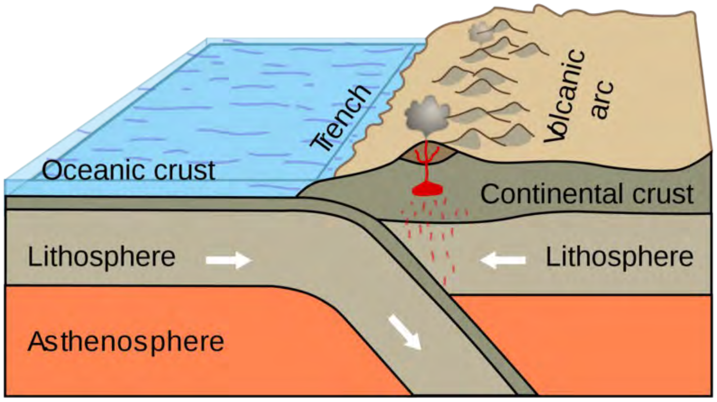


Figure 86: Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here:

- **http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html**.

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc:

- **http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html**.

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Cascades Volcanoes

The volcanoes of northeastern California — Lassen Peak, Mount Shasta, and Medicine Lake volcano — along with the rest of the Cascade Mountains of the Pacific Northwest, are the result of subduction of the Juan de Fuca plate beneath the North American plate (Figure 87). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

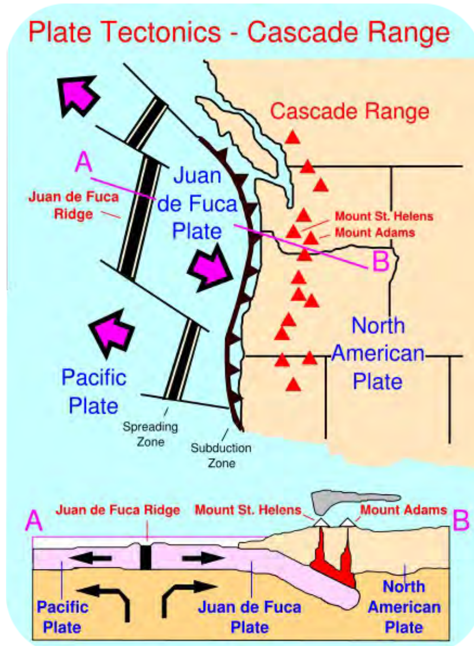


Figure 87: The Cascade Mountains of the Pacific Northwest are a continental arc.

Intrusions at a Convergent Boundary

Figure 88: The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range. California has an ancient set of batholiths that make up the Sierra Nevada Mountains (Figure 88).

An animation of an ocean continent plate boundary is seen here:

- **http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov**.

What do you see in this satellite photo?

We continue our trip up western North America to find a convergent plate boundary where oceanic crust subducts beneath oceanic crust. North of the contiguous U.S. lies Canada, and north of Canada lies Alaska. A line of volcanoes, known as the Aleutian Islands, is the result of ocean-ocean convergence. In this satellite image is an erupting volcano, topped by snow or ice, and surrounded by seawater—a member of the Aleutian chain. Let's take a look at this boundary and the volcanic arc.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. We explored what happens when oceanic crust meets continental crust. Another type of convergent plate boundary is found where two oceanic plates meet. In this case the older, denser slab of oceanic crust will plunge beneath the less dense one.

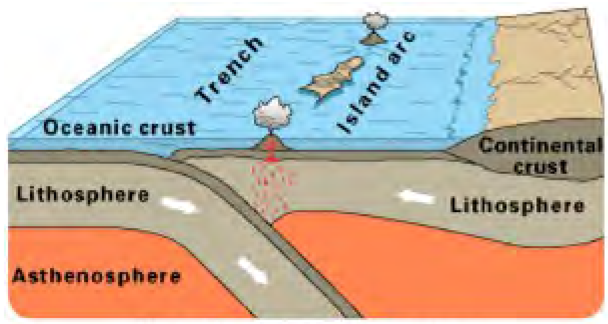


Figure 89: Subduction of an ocean plate beneath other oceanic crust results in a volcanic island arc, an ocean trench, and many earthquakes Pictured here: the lithosphere and asthenosphere**.**

Ocean-Ocean Convergence

The features of a subduction zone where an oceanic plate subducts beneath another oceanic plate are the same as a continent-ocean subduction zone. An ocean trench marks the location where the plate is pushed down into the mantle. In this case, the line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (Figure 89)?

In the north Pacific, the Pacific Plate is subducting beneath the North American Plate just as it was off of the coast of the Pacific Northwest. The difference is that here the North American plate is covered with oceanic crust. Remember that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active. Airplanes sometimes must avoid flying over these volcanoes for fear of being caught in an eruption.

Figure 90: The arc of the island arc that is the Aleutian Islands is easily seen in this map of North Pacific air routes over the region.

Continent-Continent Convergence

Continental plates are too buoyant to subduct. What happens to continental material when it collides? It has nowhere to go but up!

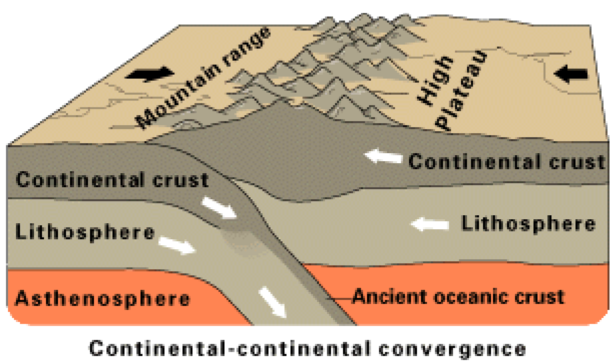


Figure 91: A diagram of two sections of continental crust converging.

Continent-continent convergence creates some of the world's largest mountains ranges. Magma cannot penetrate this thick crust, so there are no volcanoes, although the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

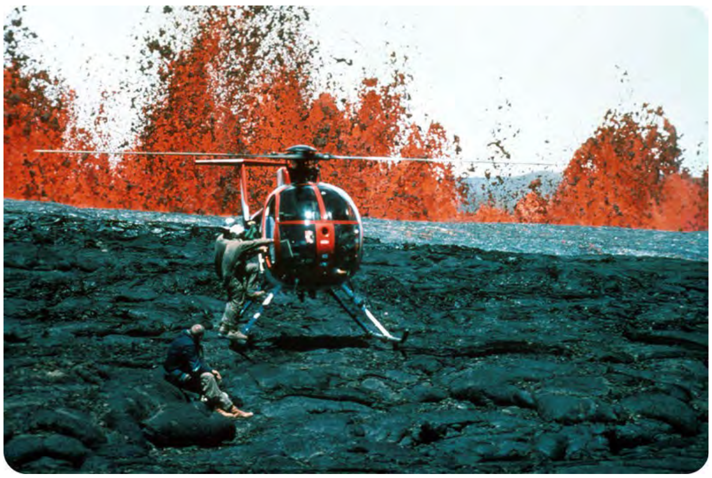
A short animation of the Indian Plate colliding with the Eurasian Plate:

- **http://www.scotese.com/indianim.htm**.

An animation of the Himalayas rising:

- **http://www.youtube.com/watch?v=ep2_axAA9Mw&NR=1**.

The Appalachian Mountains along the eastern United States are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago. This was part of the formation of Pangaea.



What would you think if you heard that all geological activity does NOT take place at plate boundaries?

These photos of fabulous geological activity are going to rock your world. Why? After all of these lessons in which you learned that volcanoes and earthquakes are located around plate boundaries, this last lesson in "Concept Plate Tectonics" doesn't quite fit. These volcanoes are located away from plate boundaries. Two such locations are Hawaii and Yellowstone. Yellowstone is in the western U.S. and Hawaii is in the central Pacific.

Intraplate Activity

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. The release of pressure causes melting near the surface to form a **hotspot**. Eruptions at the hotspot create a volcano.

Hotspot volcanoes are found in a line (Figure 92). Can you figure out why? *Hint*: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot.

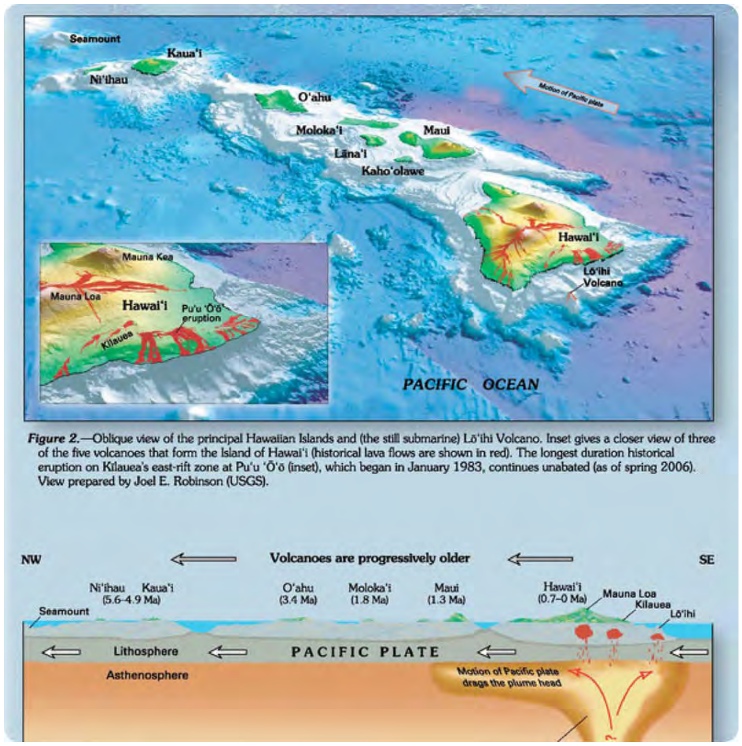


Figure 92: The Hawaiian Islands have formed from volcanic eruptions above the Hawaii hotspot.

An animation of the creation of a hotspot chain is seen here:

http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_hawaii.html.

Intraplate Activity in the Oceans

The first photo above is of a volcanic eruption in Hawaii. Hawaii is not in western North America, but is in the central Pacific Ocean, near the middle of the Pacific Plate.

The Hawaiian Islands are a beautiful example of a hotspot chain in the Pacific Ocean. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a slower rate. The islands get progressively older to the northwest because they are further from the hotspot. This is because the Pacific Plate is moving toward the northwest over the hotspot. Loihi, the youngest volcano, is still below the sea surface.

Since many hotspots are stationary in the mantle, geologists can use some hotspot chains to tell the direction and the speed a plate is moving (Figure 93). The Hawaiian chain continues into the Emperor Seamounts. The bend in the chain was caused by a change in the direction of the Pacific Plate 43 million years ago. Using the age and distance of the bend, geologists can figure out the speed of the Pacific Plate over the hotspot.

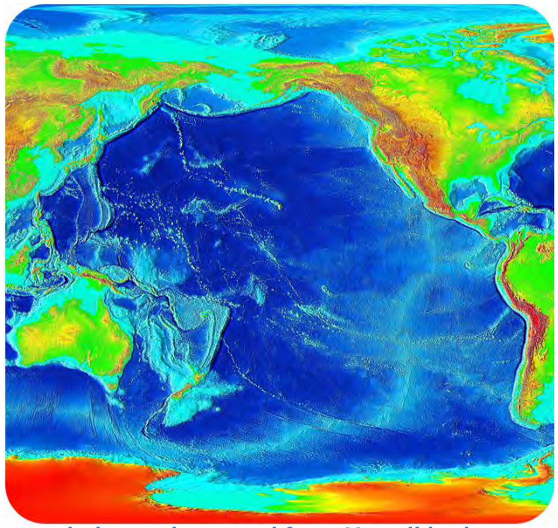


Figure 93: The Hawaiian-Emperor chain can be traced from Hawaii in the central Pacific north of the equator into the Aleutian trench, where the oldest of the volcanoes is being sub ducted. It looks like a skewed "L".

Intraplate Activity on the Continents

The second photo in the introduction is of a geyser at Yellowstone National Park in Wyoming. Yellowstone is in the western U.S. but is inland from the plate boundaries offshore.

Hotspot magmas rarely penetrate through thick continental crust, so hotspot activity on continents is rare. One exception is the Yellowstone hotspot (Figure 94). Volcanic activity above the Yellowstone hotspot on can be traced from 15 million years ago to its present location on the North American Plate.

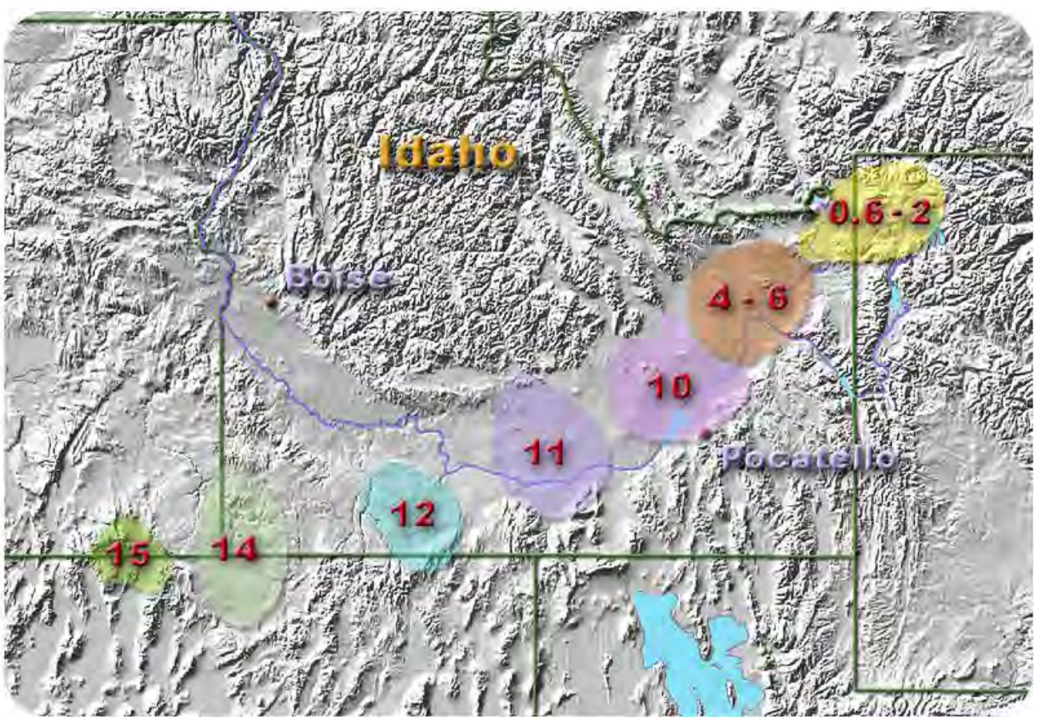


Figure 94: The ages of volcanic activity attributed to the Yellowstone hotspot.

Practice and Review

1. What is the direction of plate motion at a divergent plate boundary?
2. Describe the relationship between the convection cell and volcanism at the mid-ocean ridge.
3. Why is the Leif the Lucky Bridge so interesting?
4. How is a divergent plate boundary on land different from one in the ocean?
5. What is happening to the Baja California peninsula?
6. How did continental rifting play into the breakup of Pangaea?
7. What is the direction of plate motion at a transform plate boundary?
8. Why are transform faults on continents prone to massive earthquakes?
9. How do transform faults in the oceans compare with those on land?
10. What is the direction of plate motion at a convergent plate boundary?
11. Describe the relationship between the convection cell and subduction at a trench.
12. Subduction is sometimes called crustal recycling. Why do you think this is the case?
13. What happens if magma is too viscous to rise through the crust to erupt at the surface?

14. Compare and contrast the features of an ocean-ocean convergent plate boundary with the features of an ocean-continent convergent plate boundary.

15. How do the Aleutian volcanoes differ from the Cascades volcanoes?

16. How do island arcs get their name?

17. Compare and contrast the features of a continent-continent convergent plate boundary with the features of an ocean-continent convergent plate boundary.

18. What causes mountain ranges to rise in this type of plate boundary?

19. Why are there earthquakes but not volcanoes in this type of plate boundary?

20. Describe the continental margin of Western North America.

21. Describe the continental margin of Eastern North America.

22. Why are there mountain ranges at passive margins?

23. What is a mantle plume and how is it related to a hotspot?

24. How do scientists use hotspot volcanism to tell the direction and speed of a plate?

25. Why are hotspot volcanoes much more common in the oceans than on continents?

Results of Plate Interaction

How do plate motions create mountains?

Plate tectonic processes create some of the world's most beautiful places. The North Cascades Mountains in Washington State are a **continental volcanic arc**. The mountains currently host some glaciers and there are many features left by the more abundant ice age glaciers. Changes in altitude make the range a habitable place for many living organisms.

Mountain Building

Converging Plates

Converging plates create the world's largest mountain ranges. Each combination of plate types — continent-continent, continent-ocean, and ocean-ocean — creates mountains.

Converging Continental Plates

Two converging continental plates smash upwards to create gigantic mountain ranges (Figure 95). Stresses from this **uplift** cause folds, **reverse faults**, and thrust faults, which allow the crust to rise upwards. As was stated previously there is currently no mountain range of this type in the western U.S., but we can find one where India is pushing into Eurasia.

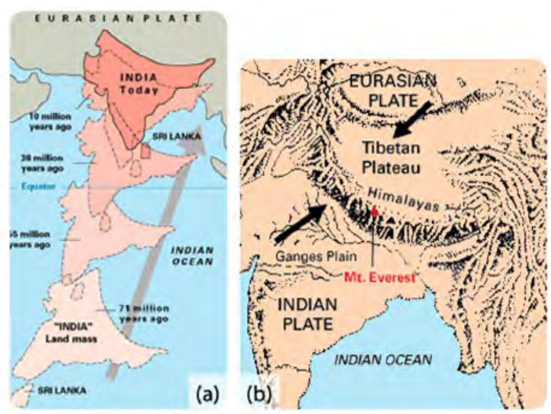


Figure 95: (a) The world's highest mountain range, the Himalayas, is growing from the collision between the Indian and the Eurasian plates. (b) The crumpling of the Indian and Eurasian plates of continental crust creates the Himalayas.

Subducting Oceanic Plates

Subduction of oceanic lithosphere at convergent plate boundaries also builds mountain ranges. This happens on continental crust, as in the Andes Mountains (Figure 96), or on oceanic crust, as with the Aleutian Islands, which we visited earlier. The Cascades Mountains of the western U.S. are also created this way.

Figure 96: The Andes Mountains are a chain of continental arc volcanoes that build up as the Nazca Plate subducts beneath the South American Plate.

Diverging Plates

Amazingly, even divergence can create mountain ranges. When tensional stresses pull crust apart, it breaks into blocks that slide up and drop down along **normal faults**. The result is alternating mountains and valleys, known as a basin-and-range (Figure 97). In basin-and-range, some blocks are uplifted to form ranges, known as horsts, and some are down-dropped to form basins, known as grabens.

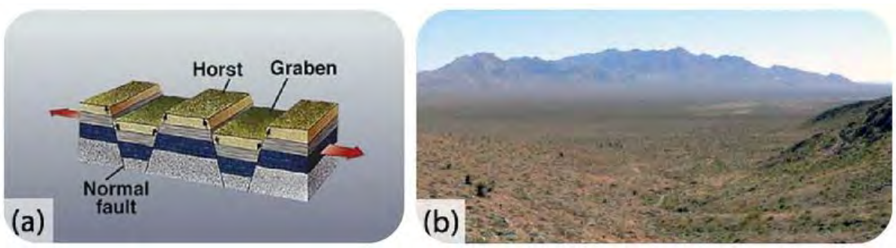
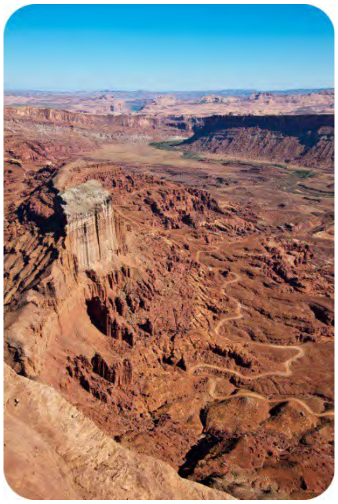


Figure 97: (a) Horsts and grabens. (b) Mountains in Nevada are of classic basin-and-range form. The photographer is in the Nopah Range and is looking across a basin to the Kingston Range beyond.

This is a very quick animation of movement of blocks in a basin-and-range setting:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Horst+%26amp%3B+Graben&flash_file=horstandgraben&flash_width=380&flash_height=210**.



Can you see the anticline at Anticline Overlook?

Moving around the desert Southwest, we see a lot of folds. This view is from the Anticline Overlook at Canyonlands National Park. Look up what an anticline is below and then see if you can spot this one. Remember you may only be able to see part of it in the photo. All of the folds (not the basin) pictured below are found in the arid Southwest.

Folds

Rocks deforming plastically under compressive stresses crumple into **folds**. They do not return to their original shape. If the rocks experience more stress, they may undergo more folding or even fracture.

Monocline

A **monocline** is a simple bend in the rock layers so that they are no longer horizontal (see **Figure 98** for an example).

Figure 98: At Utah's Cockscomb, the rocks plunge downward in a monocline.

What you see in the image appears to be a monocline. Are you certain it is a monocline? What else might it be? What would you have to do to figure it out?

Anticline

Anticline: An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (Figure 99). The oldest rocks are at the center of an anticline and the youngest are draped over them.

Figure 99: Anticlines are formations that have folded rocks upward.

When rocks arch upward to form a circular structure, that structure is called a **dome**. If the top of the dome is sliced off, where are the oldest rocks located?

Syncline

A **syncline** is a fold that bends downward. The youngest rocks are at the center and the oldest are at the outside (Figure 100).

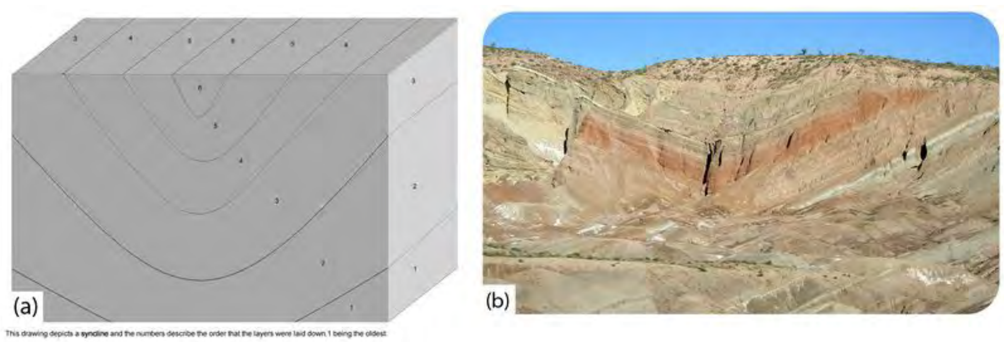


Figure 100: (a) Schematic of a syncline. (b) This syncline is in Rainbow Basin, California.

When rocks bend downward in a circular structure, that structure is called a **basin** (Figure 101). If the rocks are exposed at the surface, where are the oldest rocks located?

Figure 101: Basins can be enormous. This is a geologic map of the Michigan Basin, which is centered in the state of Michigan but extends into four other states and a Canadian province.

Figure 102: Some folding can be fairly complicated. What do you see in the photo above?

Types of Volcanoes

What does an active volcano look like?

Climbing up Mount St. Helens and looking into the crater at the steaming dome is an incredible experience. The slope is steep and the landscape is like something from another planet. Nothing's alive up there, except maybe a bird. When you're standing on the top you can see off to others of the Cascades volcanoes: Mt. Adams, Rainier, Hood, Jefferson, and sometimes more.

Volcanoes

A volcano is a vent through which molten rock and gas escape from a magma chamber. Volcanoes differ in many features, such as height, shape, and slope steepness. Some volcanoes are tall cones and others are just cracks in the ground (Figure 103). As you might expect, the shape of a volcano is related to the composition of its magma.

Composite Volcanoes

Composite volcanoes are constructed of felsic to intermediate rock. The viscosity of the lava means that eruptions at these volcanoes are often explosive.

Figure 103: Mt. Fuji in Japan is one of the world's most easily recognized composite volcanoes.

Figure 104: Mount St. Helens was a beautiful, classic, cone-shaped volcano. In May 1980 the volcano blew its top off in an explosive eruption, losing 1,300 feet off its summit.

Eruptions at Composite Volcanoes

Viscous lava cannot travel far down the sides of the volcano before it solidifies, which creates the steep slopes of a composite volcano. In some eruptions the pressure builds up so much that the material explodes as ash and small rocks. The volcano is constructed layer by layer, as ash and lava solidify, one upon the other (Figure 105). The result is the classic cone shape of composite volcanoes.

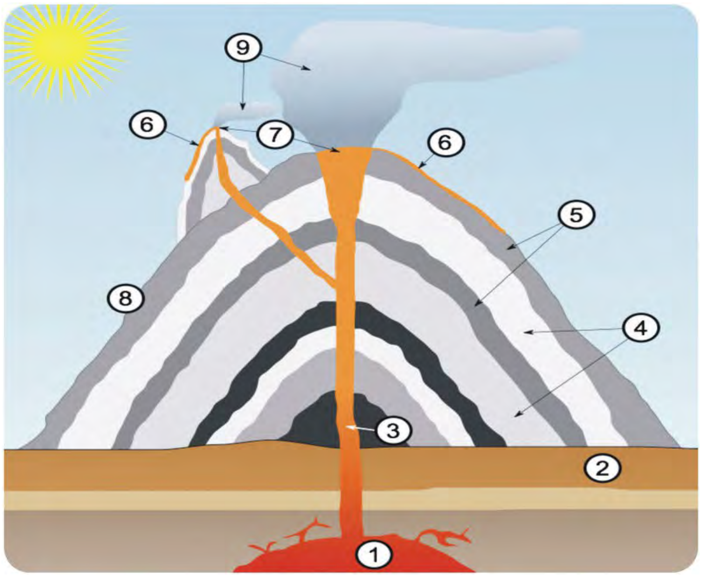


Figure 105: A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption

Shield Volcanoes

Shield volcanoes get their name from their shape. Although shield volcanoes are not steep, they may be very large. Shield volcanoes are common at spreading centers or intraplate hot spots (Figure 106). Hawaii has some spectacular shield volcanoes including Mauna Kea, which is the largest mountain on Earth from base to top. The mountain stands 33,500 ft. high, about 4,000 feet greater than the tallest mountain above sea level, Mt. Everest.

Figure 106: Mauna Kea on the Big Island of Hawaii is a classic shield volcano.

Eruptions at Shield Volcanoes

The lava that creates shield volcanoes is fluid and flows easily. The spreading lava creates the shield shape. Shield volcanoes are built by many layers over time and the layers are usually of very similar composition. The low viscosity also means that shield eruptions are non-explosive.

This "Volcanoes 101" video from National Geographic discusses where volcanoes are found and what their properties come from **(3e)**:

- **http://www.youtube.com/watch?feature=player_profilepage&v=uZp1dNybgfc** (3:05)

Cinder Cones

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

Eruptions at Cinder Cones

Cinder cones are composed of small fragments of rock, such as pumice, piled on top of one another. The rock shoots up in the air and doesn't fall far from the vent. The exact composition of a cinder cone depends on the composition of the lava ejected from the volcano. Cinder cones usually have a crater at the summit. Most cinder cones are active only for a single eruption.

Figure 107: A lava fountain erupts from Pu'u O'o, a cinder cone on Kilauea.

Volcanoes at plate boundaries

Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If both are continental they will smash together and form a mountain range. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes.

In Concept Plate Tectonics we moved up western North America to visit the different types of plate boundaries there. Locations with converging in which at least one plate is oceanic at the boundary have volcanoes.

Melting

Melting at convergent plate boundaries has many causes. The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. As the sediments subduct, the water rises into the overlying mantle material and lowers its melting point. Melting in the mantle above the subducting plate leads to volcanoes within an island or continental arc.

Figure 108: The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

Pacific Rim

Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in the previous lesson, Volcanoes I: What is a Volcano?

The Cascades are a chain of volcanoes at a convergent boundary where an oceanic plate is subducting beneath a continental plate. Specifically the volcanoes are the result of subduction of the Juan de Fuca, Gorda, and Explorer Plates beneath North America. The volcanoes are located just above where the subducting plate is at the right mantle depth for melting.

Figure 109: Mt. Baker, Washington.

The Cascades have been active for 27 million years, although the current peaks are no more than 2 million years old. The volcanoes are far enough north and are in a region where storms are common, so many are covered by glaciers.

The Cascades are shown on this interactive map with photos and descriptions of each of the volcanoes:

- **http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/6.Volcanoes4Rollover.swf**.

Divergent plate boundaries

At divergent plate boundaries hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock convects upward it rises higher in the mantle. The rock is under lower pressure; this lowers the melting temperature of the rock and so it melts. Lava erupts through long cracks in the ground, or **fissures.**

Figure 110: A volcanic eruption at Surtsey, a small island near Iceland.

Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (Figure 110).

Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in Figure 111 are in the East African Rift between the African and Arabian plates. Remember from Concept Plate Tectonics that Baja California is being broken apart from mainland Mexico as another example of continental rifting.

Figure 111: Mount Gahinga and Mount Muhabura in the East African Rift valley.

Geologic Stresses

Causes and Types of Stress

Stress is the force applied to an object. In geology, stress is the force per unit area that is placed on a rock. Four types of stresses act on materials.

Figure 112: Stress caused these rocks to fracture.

Figure 113: Shearing in rocks. The white quartz vein has been elongated by shear.

- A deeply buried rock is pushed down by the weight of all the material above it. Since the rock cannot move, it cannot deform. This is called **confining stress.**
- **Compression** squeezes rocks together, causing rocks to fold or fracture (break) (Figure 112). 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** (Figure 113). Shear stress is the most common stress at transform plate boundaries.

When stress causes a material to change shape, it has undergone **strain** or **deformation**. Deformed rocks are common in geologically active areas.

A rock's response to stress depends on the rock type, the surrounding temperature, the pressure conditions the rock is under, the length of time the rock is under stress, and the type of stress.

Responses to Stress

Rocks have three possible responses to increasing stress (illustrated in Figure 114):

- **elastic deformation**: the rock returns to its original shape when the stress is removed.
- **plastic deformation**: the rock does not return to its original shape when the stress is removed.
- **fracture**: the rock breaks.

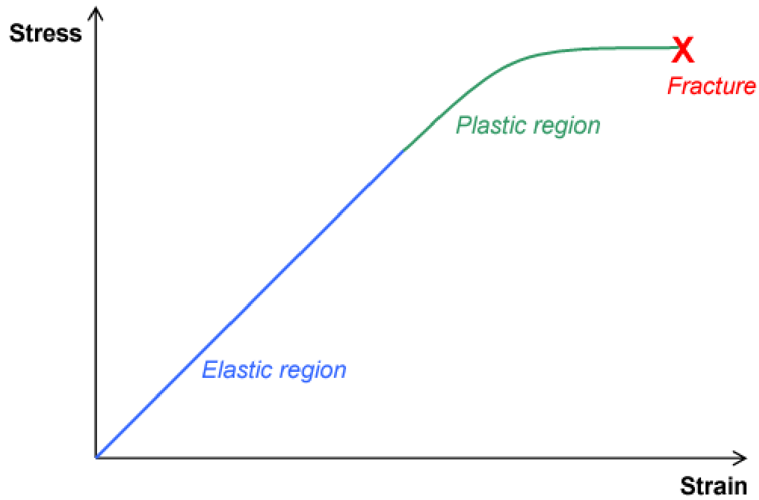


Figure 114: With increasing stress, the rock undergoes: (1) elastic deformation, (2) plastic deformation, and (3) fracture.

Under what conditions do you think a rock is more likely to fracture? Is it more likely to break deep within Earth's crust or at the surface? What if the stress applied is sharp rather than gradual?

- At the Earth's surface, rocks usually break quite quickly, but deeper in the crust, where temperatures and pressures are higher, rocks are more likely to deform plastically.
- Sudden stress, such as a hit with a hammer, is more likely to make a rock break. Stress applied over time often leads to plastic deformation.

Faults

Figure 115: The San Andreas Fault in California

Why is this called a fault?

The word "fault" refers to a defect. There may be no greater defect than the scar of the San Andreas Fault across California. Rocks on either side of the fault are estimated to have originated in locations about 350 miles apart! We're still in the arid western United States, but now our searching for geological features is more dangerous!

Fractures

A rock under enough stress will fracture. There may or may not be movement along the fracture.

Joints

If there is no movement on either side of a fracture, the fracture is called a **joint**. Granite rocks in Joshua Tree National Park show horizontal and vertical jointing. These joints formed when the confining stress was removed from the granite as shown in (Figure 116).

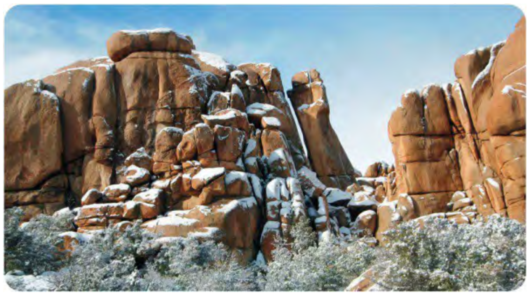


Figure 116: Joints in granite rocks at Joshua Tree National Park, in California.

Faults

If the blocks of rock on one or both sides of a fracture move, the fracture is called a **fault** (Figure 117). Sudden motions along faults cause rocks to break and move suddenly. The energy released is an earthquake.

Figure 117: Faults are easy to recognize as they cut across bedded rocks.

How do you know there's a fault in this rock? Try to line up the same type of rock on either side of the lines that cut across them. One side moved relative to the other side, so you know the lines are a fault.

Slip is the distance rocks move along a fault. Slip can be up or down the fault plane. Slip is relative, because there is usually no way to know whether both sides moved or only one. Faults lie at an **angle** to the horizontal surface of the Earth. That angle is called the fault's **dip.** The dip defines which of two basic types a fault is. If the fault's dip is inclined relative to the horizontal, the fault is a **dip-slip fault** (Figure 118**).**

Dip-Slip Faults

There are two types of dip-slip faults. In a **normal fault**, the hanging wall drops down relative to the footwall. In a **reverse fault**, the footwall drops down relative to the hanging wall.

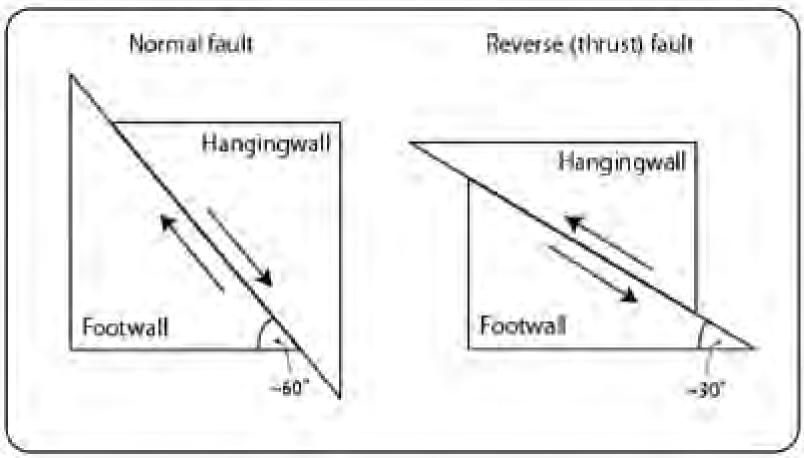


Figure 118: This diagram illustrates the two types of dip-slip faults: normal faults and reverse faults. Imagine miners extracting a resource along a fault. The hanging wall is where miners would have hung their lanterns. The footwall is where they would have walked.

An animation of a normal fault is seen here:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Normal+Fault&flash_file=normalfault&flash_width=220&flash_height=320**.

A **thrust fault** is a type of reverse fault in which the fault plane angle is nearly horizontal. Rocks can slip many miles along thrust faults (Figure 119).

An animation of a thrust fault is seen here:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Thrust+Fault&flash_file=thrustfault&flash_width=220&flash_height=320**.

Figure 119: At Chief Mountain in Montana, the upper rocks at the Lewis Overthrust are more than 1 billion years older than the lower rocks. How could this happen?

Normal faults can be huge. They are responsible for uplifting mountain ranges in regions experiencing tensional stress (Figure 120).

Figure 120: The rocks are different on each side of a normal fault.

Strike-Slip Faults

A **strike-slip fault** is a dip-slip fault in which the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. Imagine placing one foot on either side of a strike-slip fault. One block moves toward you. If that block moves toward your right foot, the fault is a right-lateral strike-slip fault; if that block moves toward your left foot, the fault is a left-lateral strike-slip fault **(Figure 121**).

California's San Andreas Fault is the world's most famous strike-slip fault. It is a right-lateral strike slip fault (Figure 115).

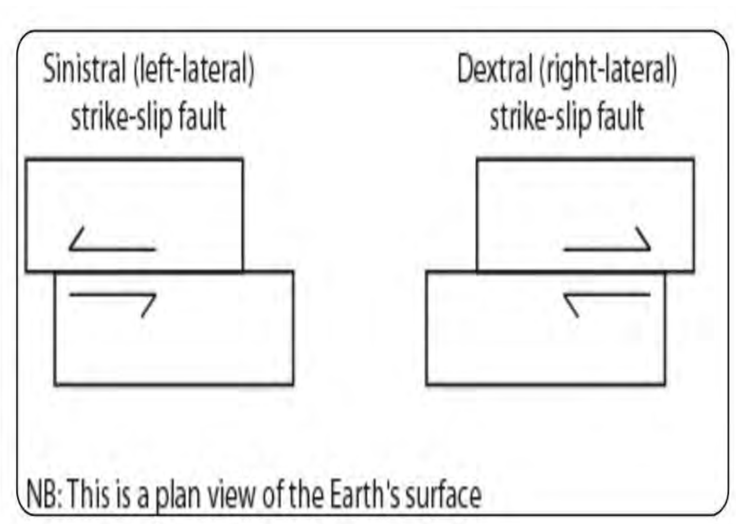


Figure 121: A strike slip vault

A strike-slip fault animation:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Strike-Slip+Fault&flash_file=strikeslip&flash_width=240&flash_height=310**.

People sometimes say that California will fall into the ocean someday, which is not true. This animation shows movement on the San Andreas into the future:

- **http://visearth.ucsd.edu/VisE_Int/aralsea/bigone.html**.

Does ground shaking cause the greatest damage in an earthquake?

This photo shows the Mission District of San Francisco burning after the 1906 earthquake. The greatest damage in earthquakes is often not from the ground shaking but from the effects of that shaking. In this earthquake, the shaking broke the gas mains and the water pipes so that when the gas caught fire there was no way to put it out. Do you wonder why the people standing in the street are looking toward the fire rather than running in the opposite direction?

Earthquake!

An earthquake is sudden ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Earthquakes can be so small they go completely unnoticed, or so large that it can take years for a region to recover.

Elastic Rebound Theory

The description of how earthquakes occur is called elastic rebound theory (Figure 122).

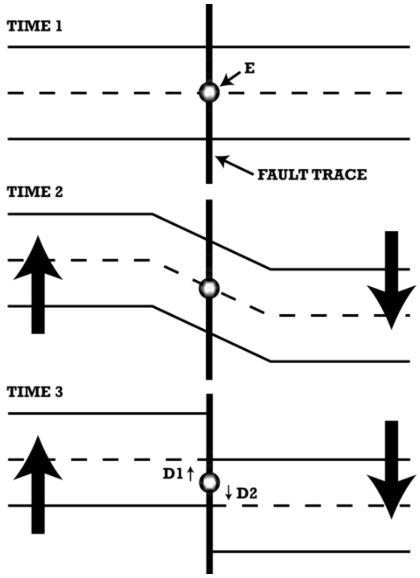


Figure 122: Elastic rebound theory. Stresses build on both sides of a fault, causing the rocks to deform plastically (Time 2). When the stresses become too great, the rocks break and end up in a different location (Time 3). This releases the built up energy and creates an earthquake.

Elastic rebound theory in an animation:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Elastic+Rebound&flash_file=elasticrebound&flash_width=300&flash_height=350**.

Focus and Epicenter

In an earthquake, the initial point where the rocks rupture in the crust is called the **focus**. The **epicenter** is the point on the land surface that is directly above the focus (Figure 123).

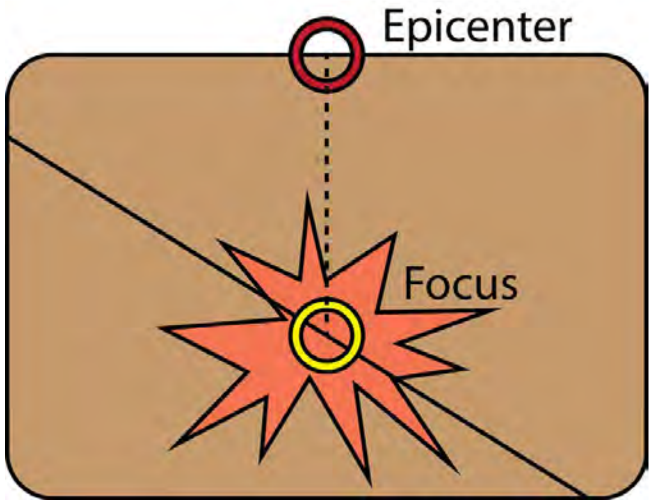


Figure 123: In the vertical cross section of crust, there are two features labeled - the focus and the epicenter, which is directly above the focus.

In about 75% of earthquakes, the focus is in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage because the focus is near where people live. However, it is the epicenter of an earthquake that is reported by scientists and the media.

Waves

Energy is transmitted in waves. Every wave has a high point called a crest and a low point called a trough. The height of a wave from the centerline to its crest is its amplitude. The distance between waves from crest to crest (or trough to trough) is its wavelength. The parts of a wave are illustrated in Figure 124.

Earthquake Waves

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

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

Body Waves

P-waves and S-waves are known as **body waves** because they move through the solid body of the Earth. P-waves travel through solids, liquids, and gases. S-waves only move through solids (Figure 124). Surface waves only travel along Earth's surface. In an earthquake, body waves produce sharp jolts. They do less damage than surface waves.

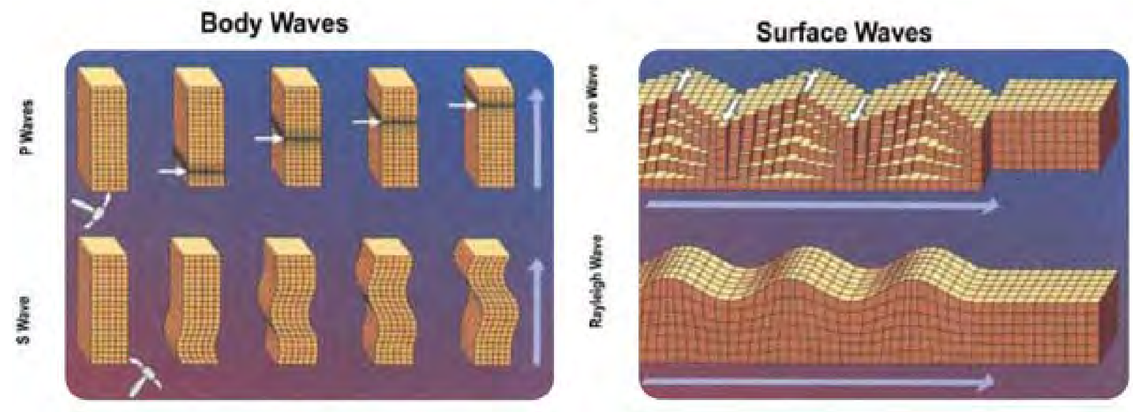


Figure 124: Body waves and surface waves

- **P-waves** (primary waves) are fastest, traveling at about 6 to 7 kilometers (about 4 miles) per second, so they arrive first at the seismometer. P-waves move in a **compression**/expansion type motion, squeezing and unsqueezing Earth materials as they travel. This produces a change in volume for the material. P-waves bend slightly when they travel from one layer into another. Seismic waves move faster through denser or more rigid material. As P-waves encounter the liquid outer core, which is less rigid than the mantle, they slow down. This makes the P-waves arrive later and further away than would be expected. The result is a P-wave **shadow zone**. No P-waves are picked up at seismographs 104º to 140º from the earthquakes focus (Figure 125).

- **S-waves** (secondary waves) are about half as fast as P-waves, traveling at about 3.5 km (2 miles) per second, and arrive second at seismographs. S-waves move in an up and down motion perpendicular to the direction of wave travel. This produces a change in shape for the Earth materials they move through. Only solids resist a change in shape, so S-waves are only able to propagate through solids. S-waves cannot travel through liquid.

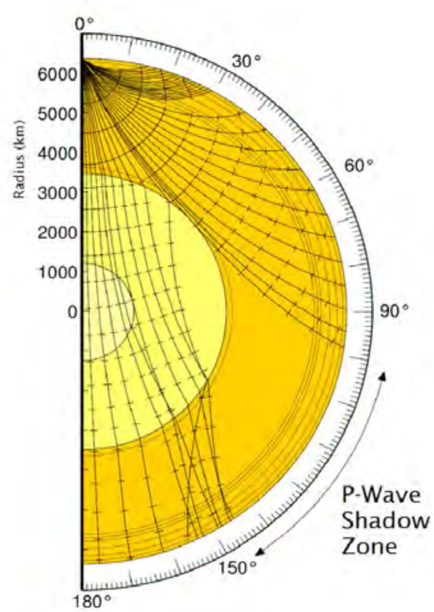


Figure 125: How P-waves travel through Earth's interior.

Earth's Interior
By tracking seismic waves, scientists have learned what makes up the planet's interior (Figure 126).

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

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

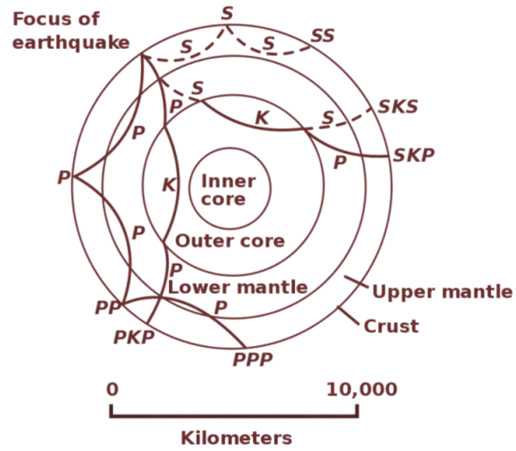


Figure 126: Letters describe the path of an individual P-wave or S-wave. Waves traveling through the core take on the letter K.

National Geographic has some interesting earthquake videos. They can be accessed at National Geopgraphic Videos -> Environment Video -> Natural Disasters -> Earthquakes:

- **http://video.nationalgeographic.com/video/player/environment/**.

Titles include: "Earthquake 101."

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

This animation shows a seismic wave shadow zone:

- **http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Shadow+Zone&flash_file=shadowzone&flash_width=220&flash_height=320**.

Practice and Review

1. Describe how plate interactions create mountain ranges like the Himalayas.

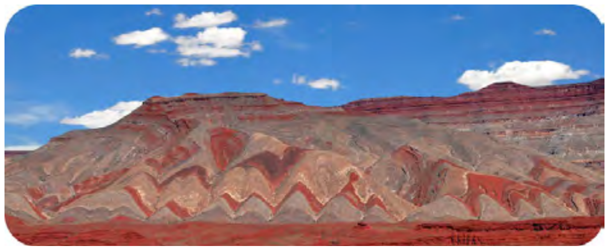
2. Diagram how pulling apart continental crust could create mountains and basins. What are the mountains and basins called?

3. How are the Andes Mountains similar to the Aleutian Islands? How are they different?

4. Draw a picture to show how compressive stresses lead to the formation of anticlines and synclines.

5. Do you think that anticlines and synclines are ordinarily found separately or adjacent to each other?

6. If you found a bulls-eye of rock on the flat ground with no structure to guide you, how could you tell if the structure had been a syncline or an anticline?



7. What folds can you find in this photo of Monument Valley in Arizona? Notice the rock layers at the top of the ridge. What is the geologic history of this region?

8. Why do mafic lavas produce shield-shaped volcanoes and felsic lavas produce cone-shaped volcanoes?

9. From what does a composite volcano get its name?

10. Describe how a cinder cone forms.

11. What causes melting at convergent plate boundaries?

12. Why are there so many volcanoes around the Pacific Ocean basin?

13. What causes melting at divergent plate boundaries?

14. How does a rifting within a continent lead to seafloor spreading?

15. What type of stress would you find at a transform fault? At a subduction zone? What type of stress at a continental rift zone?

16. Compare and contrast fracture, plastic deformation, and elastic deformation.

17. What do you think happens with stressed rocks in an earthquake zone?

18. Imagine you're looking at an outcrop. What features would you see to indicate a fault?

19. If the San Andreas Fault has had 350 miles of displacement, where did the rocks in San Francisco (on the west side of the fault) originate? How do scientists know?

20. How do you imagine the Grand Teton mountain range rose? In one earthquake? Along one fault? Or is there a more complex geological history?

21. What are the properties of P-waves?

22. What are the properties of S-waves?

23. How do scientists use seismic waves to learn about Earth's interior?

Practice Test Physical Geology

Principle of Uniformitarianism

1) Uniformitarianism is the processes that happen today,

a) Has major inconsistencies

b) Can never happen again

c) Is not reliable

d) Has operated the same way in the past

2) The idea of uniformitarianism was recognized by

a) Harry Hess

b) Alfred Wegener

c) James Hutton

d) Jacques Cousteau

3) Navajo sandstone is rock formed from

a) Rivers

b) Waves

c) Ancient sand dunes

d) Tornadoes

4) Ripples in the dunes at Death Valley National Park is caused by

a) Wind

b) Water

c) Hurricanes

d) Earthquakes

5) True or false. Alfred Wegener came up with the principle of uniformitarianism.

a) True

b) False

6) True or false. James Hutton came up with the idea that the present is the key to the past.

a) True

b) False

7) Rock can be formed from

a) Volcanoes

b) Oceans

c) Rivers

d) All of the above

8) True or false. Navajo sandstone is made from volcanoes.

a) True

b) False

9) True or false. Dunes are formed by wind.

a) True

b) False

10) True or false. The idea that the present is the key to the past is called the principle of geology.

a) True

b) False

Chemical Bonding

1) The main type(s) of chemical bonding:

a) Ionic bond

b) Covalent bond

c) Hydrogen bond

d) All of the above

2) An atom that shares one or more electrons with another atom is:

a) Ionic Bond

b) Covalent Bond

c) Hydrogen Bond

d) None of the above

3) True or false. Water is an example of a polar molecule.

a) True

b) False

4) A molecule of water is an example of this type of bonding.

a) Ionic bonding

b) Covalent bonding

c) Hydrogen bonding

d) All of the above

5) True or false. Table salt is an example of hydrogen bonding.

a) True

b) False

6) True or false. Covalent bonds are weak and do not take a lot of energy to take them apart.

a) True

b) False

7) The compound methane is an example of this type of bonding.

a) Ionic bonding

b) Covalent bonding

c) Hydrogen bonding

d) None of the above

8) When a lithium ion and a fluorine ion combine

a) Lithium gains a cation

b) Fluorine loses an anion

c) None of the above

d) Both a and b

9) True or false. A hydrogen bond is a strong bond.

a) True

b) False

10) True or false. A hydrogen bond is a bond between two oppositely charged sides of two or more molecules.

a) True

b) False

Minerals

1) Minerals must possess which of the following qualities:

a) Must be a solid

b) Naturally occurring

c) Inorganic

d) All of the above

2) Which of these is not a mineral characteristic?

a) Color

b) Solid

c) Naturally occurring

d) Specific chemical compound

3) True or false. A crystal is a solid in which atoms are arranged in a regular, repeating pattern.

a) True

b) False

4) True or false. Inorganic means that minerals are made by a natural process.

a) True

b) False

5) Which of these is a physical property for minerals?

a) Color

b) Density

c) Cleavage

d) All of the above

6) True or false. A fracture or cleavage describes the way a mineral breaks.

a) True

b) False

7) Which of these minerals is organic?

a) Coal

b) Diamond

c) Gold

d) Silver

8) Mass per volume

a) Fracture

b) Density

c) Luster

d) Streak

9) True or false. A chemical compound is two or more elements combined together.

a) True

b) False

10) True or false. Color is the best way to identify a mineral.

a) True

b) False

Mineral Formation

1) Minerals can form by

a) Precipitation from ions in solution

b) Crystallization from magma

c) Biological activity

d) All of the above

2) Which of these is not a way that minerals can form?

a) Precipitation from vapor

b) A change to more a stable state as in metamorphism

c) Biological activity

d) All of the above are ways that minerals can form

3) True or false. Magma is melted rock outside of Earth.

a) True

b) False

4) True or false. Lava cools much more rapidly than magma.

a) True

b) False

5) True or false. Crystals that form inside Earth are larger than when they form outside.

a) True

b) False

6) True or false. Amethysts form when large crystals grow in open spaces inside rock.

a) True

b) False

7) This type of mineral is formed from evaporated water.

a) Gold

b) Silver

c) Halite

d) Diamond

8) This is a graph, which plots the stability of phases of a compound as a function of pressure and temperature.

a) Cartesian graph

b) Line Graph

c) Phase diagram

d) Phase transition

9) True or false. Minerals form when the concentration of ions gets too great in a fluid.

a) True

b) False

10) True or false. The highest pressure structure of ice is orthorhombic.

a) True

b) False

Rock Cycle

1) Crystallization occurs when small pieces of rock are moved from one place to another by wind, water, and glaciers.

a) True

b) False

2) The magma cools down to form igneous rock.

a) True

b) False

3) How many types of igneous rocks are known?

a) Around 500

b) Below 500

c) Around 700

d) Above 1000

4) Which of the following rocks take part in the rock cycle?

a) Igneous, sandstone, and basalt

b) Igneous, sedimentary, and spondaic

c) Igneous, sedimentary, and metamorphic

d) None of these

5) Which of the following is a process of the rock cycle?

a) Weathering

b) Crystallization

c) Metamorphosis

d) All of these

6) A rock is heated so much that it melts. What type of rock will it become?

a) Igneous

b) Metamorphic

c) Sedimentary

d) Fossil

7) Use the rock cycle diagram to create two pathways that an igneous rock can turn into a sedimentary rock.

8) ____________________ and ______________________ are needed to form a metamorphic rock.

9) In crystallization, slower cooling form smaller crystals.

a) True

b) False

10) _________________ is a solid substance that separates out of a liquid to form a solid, usually when the liquid evaporates.

a) Weathering

b) Erosion

c) Sediment

d) Precipitate

11) Compare and contrast the way igneous and metamorphic rocks form.

Intrusive and Extrusive Igneous Rocks

1) Igneous rocks that cool below Earth's surface.

a) Intrusive rock

b) Extrusive rock

c) Sedimentary rock

d) Metamorphic rock

2) Which of these is not a type of extrusive rock?

a) Granite

b) Pumice

c) Obsidian

d) Basalt

3) True or false. Intrusive rock cool and solidify above Earth's surface.

a) True

c) False

4) True or false. Pluton is a type of igneous rock that cooled inside the crust.

a) True

b) False

5) A rock texture that indicate the presence of gas bubbles.

a) Porphyritic

b) Vesicular

c) Intrusive

d) Extrusive

6) Rock texture that in which visible crystals are found in a matrix of tiny crystals.

a) Porphyritic

b) Vesicular

c) Intrusive

d) Extrusive

7) Which of these igneous rocks have cooled so quickly that crystals do not form creating a natural glassy look?

a) Pumice

b) Basalt

c) Granite

d) Obsidian

8) Which of these igneous rocks have a vesicular texture?

a) Pumice

b) Basalt

c) Granite

d) Obsidian

9) True or false. Basalt is an intrusive rock.

a) True

b) False

10) True or false. Lava that cool extremely rapidly may have a glassy texture.

a) True

b) False

Igneous rock Classification

1) Which of these minerals is not felsic?

a) Quartz

b) Orthoclase feldspar

c) Olivine

d) Granite

2) What are the properties of mafic rock?

a) High density

b) Dark color

c) Both a and b

d) None of the above

3) True or false. Ultramafic igneous rock contains more than 45% of silica.

a) True

b) False

4) True or false. Ultramafic igneous rock is light in color and has a low density.

a) True

b) False

5) True or false. Quartz has an ultramafic composition.

a) True

b) False

6) True or false. Granite is a type of felsic rock.

a) True

b) False

7) Which of these rocks are ultramafic?

a) Komatiite

b) Olivine

c) Peridotite

d) All of the above

8) What are some characteristics of igneous rock?

a) Color

b) Texture

c) Density

d) All of the above

9) True or false. Gabbro and basalt has the same composition but different texture.

a) True

b) False

10) True or false. Granite and andesite have the same composition but different texture.

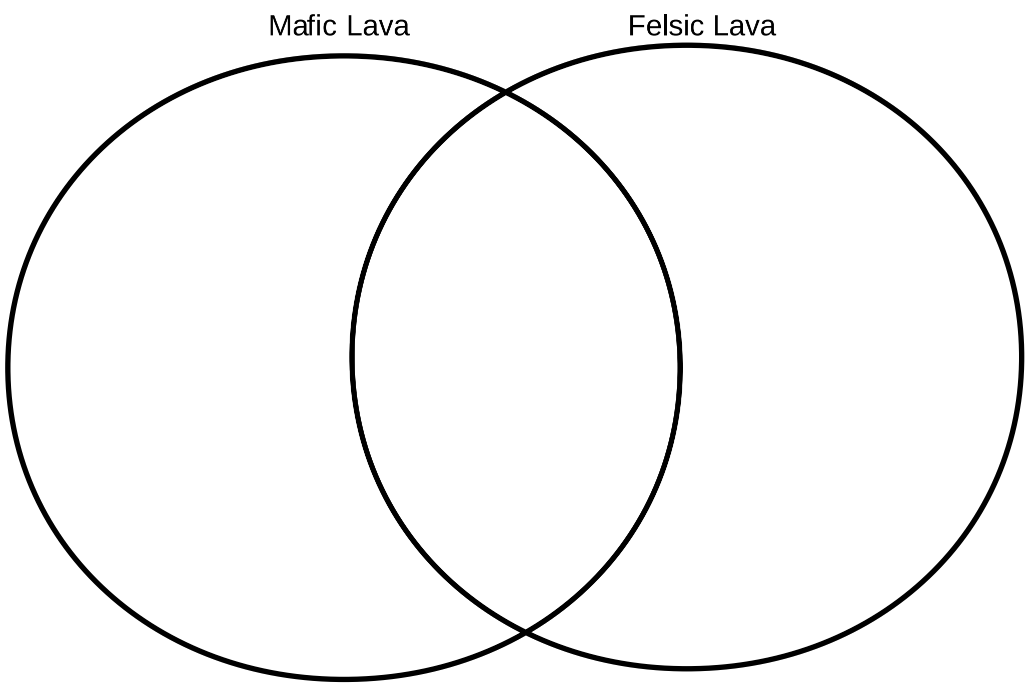
a) True

b) False

Magma Composition

1) What is more viscous, water or honey and why?

2) Fill in the Venn diagram to compare and contrast mafic and felsic lava.



3) Knowing the magma composition will determine

a) Eruption style

b) Type of volcanic cone that will form

c) Composition of rock found at the volcano

d) All of the above

4) ___________________ lava is low in silica, less viscous, and erupt effusively.

5) Felsic lava is less viscous and erupt effusively.

a) True

b) False

6) ___________________ is the thickness of a liquid or its resistance to flow.

7) This is a region below a volcano where magma and gases collect.

a) Magma chamber

b) Vent

c) Pipe

d) Crater

8) If magma is high in silica and more viscous, what type of eruption will form?

a) Effusive

b) Explosive

c) Alternate

d) Pahoehoe

9) What type of rocks form at volcanoes?

a) Metamorphic

b) Sedimentary

c) Fossil

d) Igneous

10) What happens to dissolved gases when magma is thick?

Sedimentary Rocks

1) Sedimentary rocks are made from

a) Fragments of other rocks

b) Organic materials

c) Chemical precipitates

d) All of the above

2) Which of these is not a way sedimentary rock is made?

a) From fragments of other rocks

b) Cooled magma

c) Chemical precipitates

d) Organic materials

3) True or false. Darker sediments form when the environment is oxygen rich.

a) True

b) False

4) Red rocks are formed when this element is present.

a) Nitrogen

b) Carbon

c) Silica

d) Oxygen

5) True or false. Organic materials are made from the remains of once-living organisms.

a) True

b) False

6) True or false. Erosion is the process in which sediments are removed and transported by water, wind, ice, or gravity.

a) True

b) False

7) Sediments can be moved by

a) Water

b) Wind

c) Ice

d) All of the above

8) Landslides dropping large piles of sediment can be caused by this.

a) Wind

b) Ice

c) Gravity

d) Oxygen

9) True or false. Chemical precipitates are made by fragments of other worn down rocks.

a) True

b) False

10) True or false. Mechanical weathering dissolves less stable minerals.

a) True

b) False

Sedimentary Rock Classification

1) Conglomerate rocks are made from

a) Jagged, angular rocks

b) Round rocks

c) Sand

d) Clay

2) Shale is made from

a) Jagged, angular rocks

b) Round rocks

c) Sand

d) Clay

3) True or false. Biochemical sedimentary rocks from in oceans or salt lakes.

a) True

b) False

4) Which of these rocks are NOT clastic?

a) Conglomerate

b) Sandstone

c) Coal

d) Shale

5) True or false. Clastic rocks are made from the fragments of non-organic sediments.

a) True

b) False

6) True or false. Rock salt is a clastic rock.

a) True

b) False

7) Which of these sedimentary rocks is organic?

a) Coal

b) Gypsum

c) Sandstone

d) Breccia

8) Sedimentary rocks are made by

a) Rock fragments

b) Precipitate from fluids

c) Precipitation from living organisms

d) All of the above

9) Which of these rocks are made from chemical precipitates?

a) Gypsum

b) Rock salt

c) Coal

d) A and B only

10) True or false. Sedimentary rocks are classified by

a) How they form

b) Size of sediments

c) Made from living things

d) All of the above

Weathering and Erosion

1) The process that changes solid rock into sediments.

a) Erosion

b) Weathering

c) Dissolution

d) Fracture

2) The process that moves sediments.

a) Erosion

b) Weathering

c) Dissolution

d) Fracture

3) True or false. Weathering is a quick process.

a) True

b) False

4) Compare and contrast mechanical and chemical weathering.

5) True or false. The Appalachians were once as tall as the Himalayas and have since weathered.

a) True

b) False

6) What can cause erosion?

a) Water

b) Wind

c) Ice

d) All of the above

7) What can cause chemical weathering?

a) Acid rain

b) Oxygen

c) Gravity

d) Both a and b

8) True or false. Weathering and erosion can change land over time.

a) True

b) False

9) True or false. Weathering can also change roads and sidewalks.

a) True

b) False

10) What causes mechanical weathering?

a) Animals

b) Wind

c) Roots

d) All of the above

Metamorphic Rocks

1) Which of these rocks can become a metamorphic rock?

a) Igneous

b) Sedimentary

c) Metamorphic

d) All of the above

2) Flat layers the form in rocks as the rocks are squeezed by pressure.

a) Felsic

b) Mafic

c) Foliated

d) Morphed

3) True or false. What is needed for metamorphic rocks to be made is heat and pressure.

a) True

b) False

4) True or false. Foliated rocks have flat layers that are formed by pressure.

a) True

b) False

5) Which of these metamorphic rocks is foliated?

a) Quartzite

b) Gneiss

c) Limestone

d) Sandstone

6) True or false. Quartzite is a metamorphic rock that is foliated.

a) True

b) False

7) The type of metamorphism occurs over a large area.

a) Contact metamorphism

b) Local metamorphism

c) Geological metamorphism

d) Regional metamorphism

8) Metamorphism changes

a) Physical makeup

b) Chemical make up

c) Nothing

d) Both a and b

9) True or false. Changes in a rock that is in contact with magma is regional metamorphism.

a) True

b) False

10) Which of these rocks are metamorphic?

a) Gneiss

b) Limestone

c) Quartzite

d) Only a and c

Metamorphic Rock Classification

1) Slate is a metamorphic rock made from

a) Granite

b) Limestone

c) Shale

d) Sandstone

2) Which of these rocks are foliated?

a) Slate

b) Phyllite

c) Gneiss

d) All of the above

3) True or false. Marble is foliated.

a) True

b) False

4) True or false. The more extreme the amount of metamorphism, the easier it is to tell what the original rock was.

a) True

b) False

5) Quartzite is a metamorphic rock made from this rock.

a) Shale

b) Sandstone

c) Limestone

d) Granite

6) True or false. Marble is a metamorphic rock made from sandstone.

a) True

b) False

7) Which of these rocks are non-foliated?

a) Metaconglomerate

b) Gneiss

c) Schist

d) Slate

8) Metamorphism of limestone turns into this rock.

a) Gneiss

b) Hornfels

c) Quartzite

d) Marble

9) True or false. Metaconglomerate is non-foliated.

a) True

b) False

10) This metamorphic rock derived from clay.

a) Slate

b) Phyllite

c) Schist

d) All of the above

Introduction to Plates

1) Draw and label how convection currents move pates under the mid-ocean ridge.

2) If two plates are sliding past each other, what type of boundary does it make?

a) Divergent

b) Transform

c) Convergent

d) Normal

3) Fill in the Chart

Type of Boundary	Plate Movement
Divergent	
	Moves toward each other
Transform	

4) ________________________ is the point on the Earth's surface directly above the focus of the earthquake.

5) A divergent boundary is where two lithospheric plates come together.

a) True

b) False

6) When two continental crusts move apart, it makes this.

a) the mid-ocean ridge

b) mountains

c) a fault

d) volcanoes

7) Where can earthquakes occur?

a) At the mid-ocean ridge

b) Trenches

c) Faults

d) All of the above

8) Earthquakes occur wherever this is plate movement.

a) True

b) False

9) A single plate can only be made by either continental or oceanic crust.

a) True

b) False

10) Plates move at a rate of a few __________________ a year.

a) Millimeters

b) Centimeters

c) Meters

d) Kilometers

Seafloor Spreading

1) The Gilbert reverse magnetic period was

a) 2.48 to 3.4 million years ago

b) 730,000 years ago to 2.48 million years ago

c) 3.4 to 5.3 million years ago

d) present to 730,000 years ago

2) What is true about the seafloor near mid-ocean ridge?

a) Rocks are younger closer to the ridge

b) The crust is thinner near the ridge

c) The magnetic stripes are the same on both sides of the ridge

d) All of the above are true

3) True or false. Submarines during WWII discovered the magnetic patterns on the seafloor.

a) True

b) False

4) True or false. The magnetic stripes on either side of the mid-ocean ridge are opposite.

a) True

b) False

5) True or false. Rocks are older closer to the ridge.

a) True

b) False

6) True or false. The Matuyama reverse was 2.48 to 3.4 million years ago.

a) True

b) False

7) What is not true about the magnetic stripes on the ocean floor?

a) Stripes alternate across the ocean floor.

b) Stripes mirror each other on either side of the mid-ocean ridge

c) Stripes do not alternate across the ocean floor.

d) Stripes end abruptly at the edge of continents.

8) Navy ships use these to search for enemy submarines, but accidently discovered the magnetic polarity of the seafloor.

a) Bar magnet

b) Electromagnets

c) Magnetometers

d) None of the above

9) True or false. It is crust is thicker at the mid-ocean ridge.

a) True

b) False

10) True or false. The ridge is hotter and is cooler going away from the ridge.

a) True

b) False

Mountain Building

1) This mountain range is a continental volcanic arc.

a) The Cascades

b) Appalachians

c) Himalayas

d) The Alps

2) This type of boundary creates the world's largest mountain range.

a) Divergent

b) Transform

c) Convergent

d) None of the above

3) Stresses from uplift cause

a) Folds

b) Faults

c) Mountains

d) All of the above

4) The Indian Plate and Eurasian Plate converge to make this mountain range.

a) The Cascades

b) Appalachians

c) Himalayas

d) The Alps

5) Compare and contrast how the Cascades and the Himalayas are made.

6) This process creates volcanic arcs.

a) Shearing

b) Subduction

c) Tension

d) Compression

7) Tension creates

a) Normal faults

b) Valleys

c) Fault-block mountains

d) All of the above

8) The Andes Mountains are made by

a) Shearing

b) Subduction

c) Tension

d) Compression

9) True or false. In basin-and-range, blocks that are uplifted form ranges, also known grabens.

a) True

b) False

10) Horsts are

a) Down-dropped rock that form basins

b) Uplifted rock that form ranges

c) Mountains

d) Valleys

Volcanic Types

1) Compare and contrast composite and shield volcanoes using a Venn diagram.

2) Draw and label parts of a composite volcano.

3) Draw a shield and cinder cone volcano and label the differences between them.

4) Mafic lavas produce cinder cone volcanoes.

a) True

b) False

5) Which of these are characteristics of cinder-cone volcanoes

a) Steep slope

b) Felsic lava

c) Smaller than composite volcanoes

d) All of the above

6) __________________ are alternating layers of felsic and mafic lava.

7) This determines both eruption type and volcano type.

a) Magma composition

b) Location

c) Boundary

d) Rock

8) Shield volcanoes are common at intraplate hot spots.

a) True

b) False

9) This is the largest shield volcano on earth.

a) Mt. Everest

b) Mauna Koa

c) Mt. Shasta

d) Mt. Fuji

10) Mt. Fuji is this type of volcano.

a) Cinder-cone

b) Shield

c) Composite

d) Dormant

Faults

1) This famous fault is found in California.

a) San Andreas Fault

b) Wasatch Fault

c) Alpine Fault

d) Allegheny Fault

2) If there is no movement on either side of a fracture, the fracture is called this.

a) A joint

b) A fault

c) A slip

d) A dip

3) This is a dip-slip fault.

a) Strike-slip fault

b) Reverse fault

c) Normal fault

d) Both b and c

4) The San Andreas Fault is a

a) Normal Fault

b) Reverse Fault

c) Strike-slip Fault

d) None of the above

5) True or false. Strike-slip faults have horizontal motions due to shear stress.

a) True

b) False

6) Strike-slip faults are made by this type of stress.

a) Shearing

b) Tension

c) Compression

d) Friction

7) Strike slip faults move

a) Downward

b) Diagonally

c) Vertically

d) Horizontally

8) This type of reverse fault has a plane angle that is nearly horizontal.

a) Normal fault

b) Thrust fault

c) Strike-slip fault

d) Dip-slip fault

9) Normal faults and reverse faults are similar in that they have

a) A hanging wall

b) A footwall

c) Fractured at an angle

d) All of the above

10) True or false. In a normal fault, the hanging wall goes up and the footwall goes down.

a) True

b) False

Earthquakes

1) The high point of a wave.

a) Trough

b) Amplitude

c) Crest

d) Length

2) The height of a wave from the center line to its crest.

a) Trough

b) Amplitude

c) Crest

d) Length

3) True or false. The distance between waves from crest to crest is its amplitude.

a) True

b) False

4) Which of these is not a seismic wave?

a) Primary Wave

b) Surface wave

c) Secondary Wave

d) Sharp Wave

5) True or false. S-waves can move through solids and liquids.

a) True

b) False

6) Which of these statements is not true about S-waves?

a) S-waves are secondary waves

b) S-waves move up and down or side to side

c) S-waves cannot travel through liquids

d) S-waves compress and expand

7) Which of these statements is true about surface waves?

a) Surface waves travel along the ground.

b) Surface waves are the slowest of all seismic waves.

c) There are two types of surface waves.

d) All of the above are true.

8) The lowest point of a wave.

a) Crest

b) Body

c) Amplitude

d) Trough

9) True or false. P-waves speed up at the mantle core boundary.

a) True

b) False

10) True or false. Scientists can learn about Earth interior by using seismic waves.

a) True

b) False

Historical Geology

The Geologic Time Scale

To be able to discuss Earth history, scientists needed some way to refer to the time periods in which events happened and organisms lived. With the information they collected from fossil evidence and using Steno's principles, they created a listing of rock layers from oldest to youngest. Then they divided Earth's history into blocks of time with each block separated by important events, such as the disappearance of a species of fossil from the rock record. Since many of the scientists who first assigned names to times in Earth's history were from Europe, they named the blocks of time from towns or other local places where the rock layers that represented that time were found.

From these blocks of time the scientists created the **geologic time scale** (Figure 127). In the geologic time scale the youngest ages are on the top and the oldest on the bottom. Why do you think that the more recent time periods are divided more finely? Do you think the divisions in the scale below are proportional to the amount of time each time period represented in Earth history?

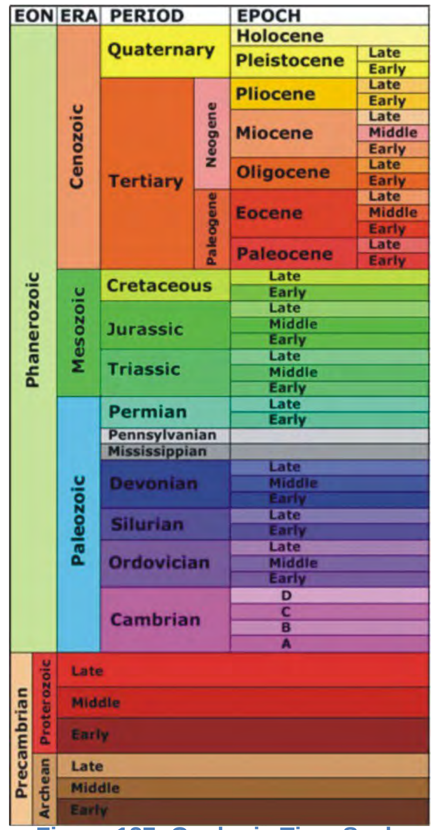


Figure 127: Geologic Time Scale

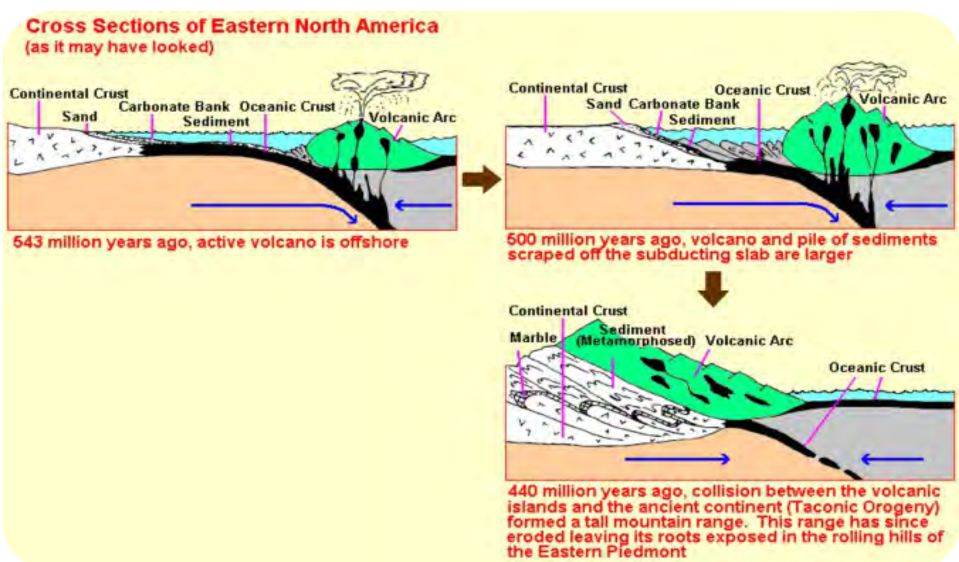


Figure 128: The Taconic Orogeny is an example of a collision between a continent and a volcanic island arc.

The Paleozoic Era

The Paleozoic is the earliest era of the Phanerozoic. The Paleozoic was also the longest era of the Phanerozoic. But the Paleozoic was relatively recent. It began only 570 million years ago. At the start of the Paleozoic, there was a supercontinent called Rodinia. The supercontinent broke apart during the early part of the Paleozoic.

The Phanerozoic is recent history compared with the Precambrian. This is one reason that the Paleozoic is much better known than the Precambrian. Another reason is that Paleozoic organisms had hard parts, and they fossilized better.

Formation of Pangaea

A mountain-building event is called an **orogeny**. Orogenies take place over tens or hundreds of millions of years. Continents smash into each other. Microcontinents and island arcs smash into continents. All of these events cause mountains to rise.

When Pangaea came together there were orogenies all along the collision zones. Geologists find much evidence of these orogenies. For example, Laurentia collided with the Taconic Island Arc during the Taconic Orogeny (Figure 128). The remnants of this mountain range make up the Taconic Mountains in New York.

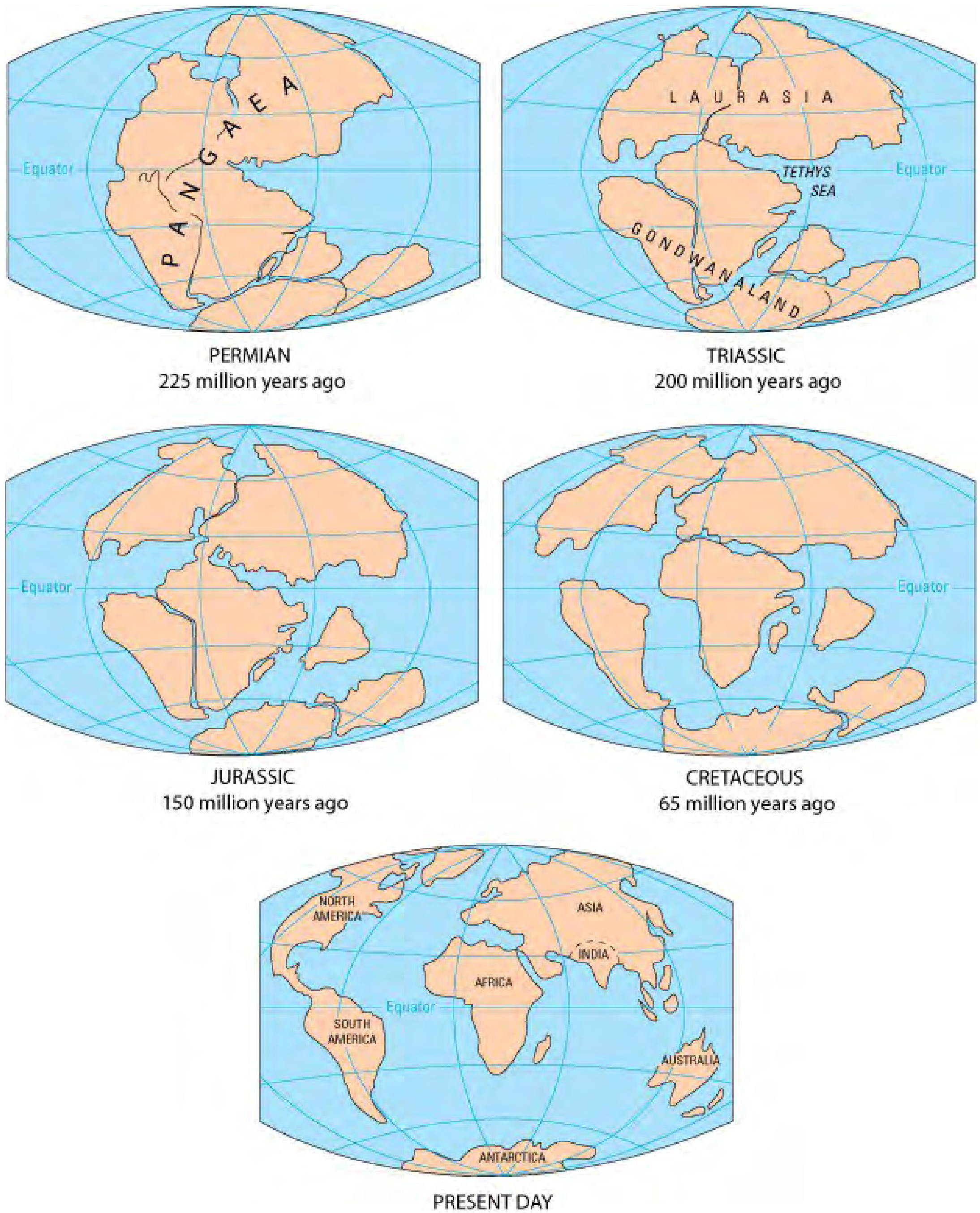
Laurentia experienced other orogenies as it collided with the northern continents. The southern continents came together to form Gondwana. When Laurentia and Gondwana collided to create Pangaea, the Appalachians rose. Geologists think the Appalachians were once higher than the Himalayas are now.

Pangaea

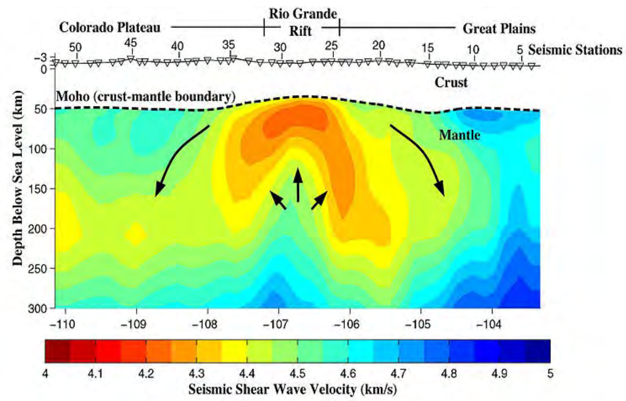
Pangaea was the last supercontinent on Earth. Evidence for the existence of Pangaea was what Alfred Wegener used to create his continental drift hypothesis. Continental drift was described in Concept Plate Tectonics.

As the continents move, the shape of the oceans changes too. At the time of Pangaea, most of Earth’s water was collected in a huge ocean. This ocean was called Panthalassa (Figure 129).

Figure 129: Pangea was the sole landform 250 million years ago. The rest of the planet was a huge ocean called Panthalassa, along with a few smaller seas.



Why would a supercontinent break up?



A continent is like a giant blanket that traps heat. Heat from the mantle comes up but cannot escape through the continent. This image shows hot material beneath New Mexico. The heat is trapped beneath the North American plate. The hot material is causing rifting to begin. This is known as the Rio Grande Rift.

Supercontinent Breakup

Why would a supercontinent break up? Remember that Earth's interior is hot. Heat builds up beneath the supercontinent. This causes the continent to buoy upward. Continental rifting begins. Basalt lava fills in the rift. This could lead to seafloor spreading and the formation of a new ocean basin. This basalt province is where Africa is splitting apart and generating basalt lava (Figure 130**).**

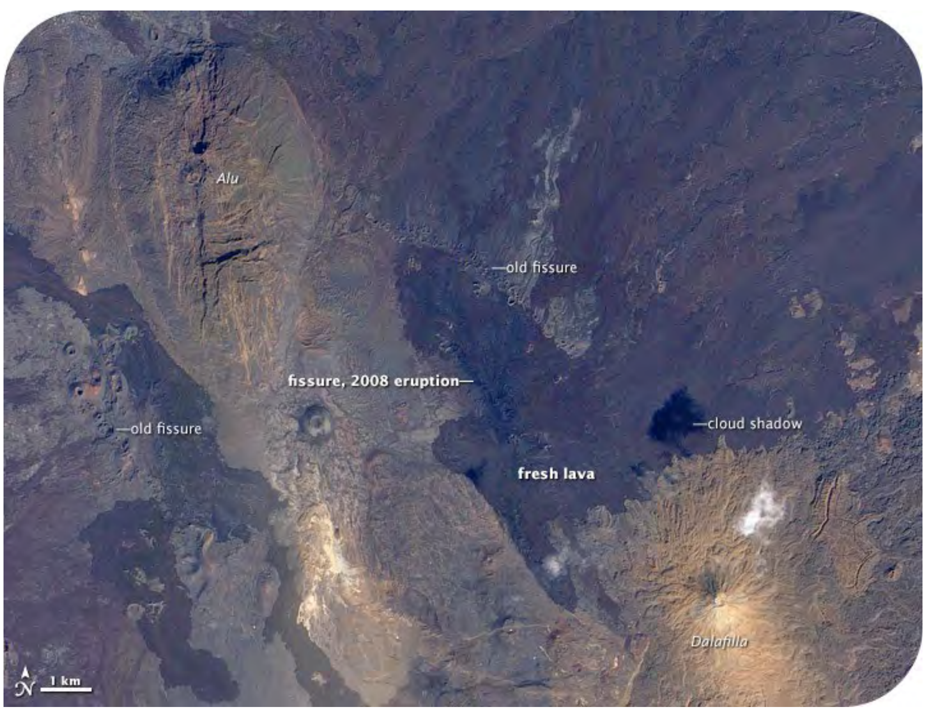


Figure 130: In the Afar Region of Ethiopia, Africa is splitting apart. Three plates are pulling away from a central point.

The Breakup of Pangaea

At the end of the Paleozoic, there was one continent and one ocean. Then Pangaea began to break apart about 180 million years ago. The Panthalassa Ocean separated into the individual but interconnected oceans that we see today on Earth.

Continental rifting and then seafloor spreading pushed Africa and South America. The Atlantic Ocean basin formed in between the continents. Seafloor spreading continues to enlarge the Atlantic Ocean (Figure 131).

Growth of Continents

The moving continents collided with island arcs and microcontinents. Mountain ranges grew near the continents' edges. The oceanic Farallon plate subducted beneath western North America during the late Jurassic and early Cretaceous. This activity produced igneous intrusions and other structures. The intrusions have since been uplifted. They are exposed in the Sierra Nevada Mountains (Figure 131).

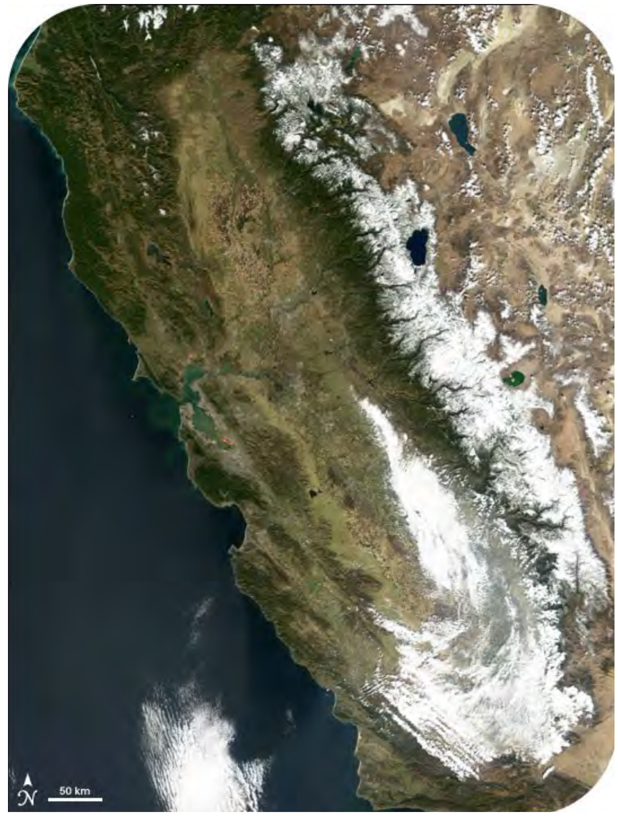


Figure 131: The snow-covered Sierra Nevada is seen striking SE to NW across the eastern third of the image. The mountain range is a line of uplifted batholiths from Mesozoic subduction.

The Cenozoic Era

The Cenozoic began around 65.5 million years ago and continues today. Although it accounts for only about 1.5% of the Earth's total history, as the most recent era it is the one scientists know the most about. Much of what has been discussed elsewhere in Concepts Earth Science describes the geological situation of the Cenozoic. A few highlights are mentioned here.

Plate Tectonics

The paleogeography of the era was very much like it is today. Early in the Cenozoic, blocks of crust uplifted to form the Rocky Mountains, which were later eroded away and then uplifted again. Subduction off of the Pacific Northwest formed the Cascades volcanic arc. The Basin and Range province that centers on Nevada is where crust is being pulled apart.

Evolution of the San Andreas Fault

The San Andreas Fault has grown where the Pacific and North American plates meet. The plate tectonic evolution of that plate boundary is complex and interesting (Figure 132). The Farallon Plate was subducting beneath the North American Plate 30 Ma. By 20 Ma the Pacific Plate and East Pacific Rise spreading center had started to subduct, splitting the Farallon Plate into two smaller plates. Transform motion where the Pacific and North American plates meet formed the San Andreas Fault. The fault moved inland and, at present, small sea-floor spreading basins, along with the transform motion of the San Andreas, are splitting Baja California from mainland Mexico. Although most plate tectonic activity involves continents moving apart, smaller regions are coming together. Africa collided with Eurasia to create the Alps. India crashed into Asia to form the Himalayas.

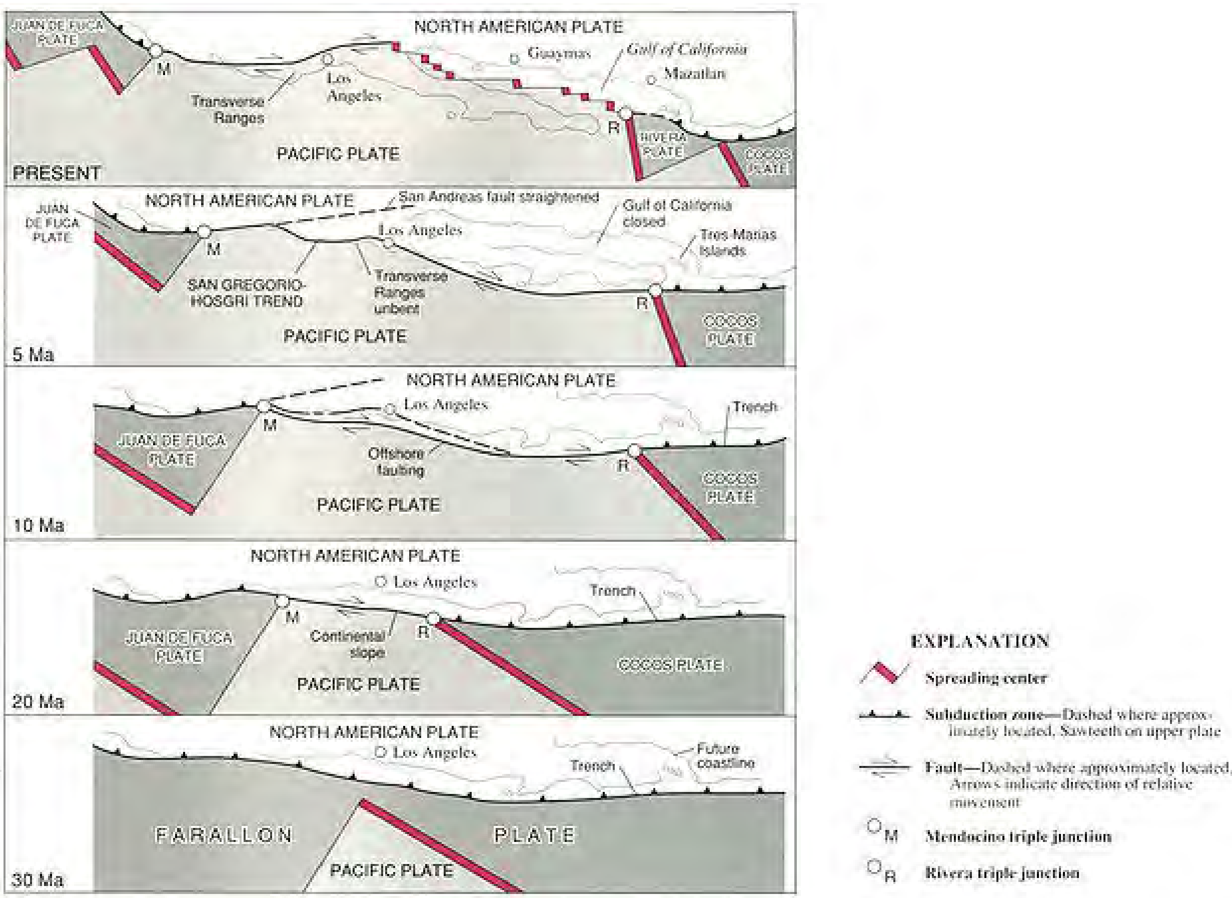


Figure 132: This figure shows the evolution of the San Andreas Fault zone from 30 million years ago (bottom) to present (top).

Ice Ages

As the continents moved apart, climate began to cool. When Australia and Antarctica separated, the Circumpolar Current could then move the frigid water around Antarctica and spread it more widely around the planet.

Antarctica drifted over the south polar region and the continent began to grow a permanent ice cap in the Oligocene. The climate warmed in the early Miocene but then began to cool again in the late Miocene and Pliocene when glaciers began to form. During the Pleistocene ice ages, which began 2.6 million years ago, glaciers advanced and retreated four times (Figure 133). During the retreats, the climate was often warmer than it is today.

Figure 133: Glacial ice at its maximum during the Pleistocene.

Practice / Review

1. When did Rodinia form?
2. What does Rodinia mean?
3. How long was Rodinia the dominant land form?
4. Describe the atmosphere at this time.
5. What coastline emerged when Rodinia broke apart?
6. When did Pangaea form?
7. What does Pangaea mean?
8. What happens to create an orogeny? How are plate tectonics processes related to orogenies?
9. How did Pangaea come together?
10. How is the creation of Pangaea related to events like the Taconic orogeny?
11. What creates the heat inside Earth?
12. What are plate tectonics?
13. Explain why Pangaea broke apart.
14. Is Pangaea still breaking up? Why or why not?

15. How do continents break up?

16. How did the Sierra Nevada mountains form?

17. What are the two divisions of the Cenozoic era?

18. What mountains formed during this time?

19. What was carved out of the Colorado Basin?

20. How much of the land was covered in ice?

21. How did animal populations change?

22. What is the history of the advance and retreat of ice during the Pleistocene?

Relative Age Dating

Where's a good place to see geology?

The Southwestern United States is a fantastic place to see geology. The arid climate means that that the rocks are not covered by vegetation. In many places, especially the national parks, the formations are fantastic. The rocks themselves are very interesting. The principles discussed below are easily seen around the Southwest.

> **Key Vocabulary:**
>
> **relative age**: Age of something relative to the age of something else; one rock is older than another rock, for example.
>
> **stratigraphy**: Study of rock strata.

Early geologists had no way to determine the absolute age of a geological material. If they didn't see it form, they couldn't know if a rock was one hundred years or 100 million years old. What they could do was determine the ages of materials relative to each other. Using sensible principles they could say whether one rock was older than another. They could also determine when a process occurred relative to those rocks.

Laws of Stratigraphy

The study of rock strata is called **stratigraphy**. The laws of stratigraphy can help scientists understand Earth's past. The laws of stratigraphy are usually credited to a geologist from Denmark named Nicolas Steno. He lived in the 1600s. The laws are illustrated below (Figure 135); refer to the figure as you read about Steno's laws below.

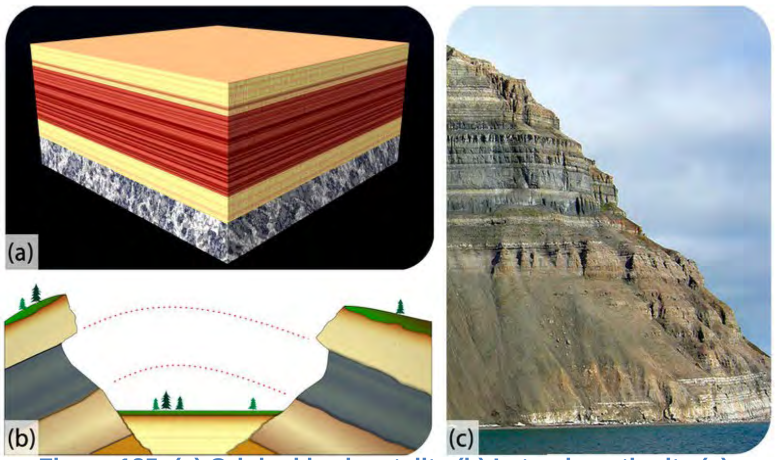


Figure 135: (a) Original horizontality (b) Lateral continuity (c) Superposition

Figure 134: Superposition. The rock layers at the bottom of this cliff are much older than those at the top. What force eroded the rocks and exposed the layers?

Law of Superposition

Superposition refers to the position of rock layers and their relative ages (Figure 134). **Relative age** means age in comparison with other rocks, either younger or older. The relative ages of rocks are important for understanding Earth's history. New rock layers are always deposited on top of existing rock layers. Therefore, deeper layers must be older than layers closer to the surface. This is the law of superposition.

Law of Lateral Continuity

Rock layers extend laterally, or out to the sides. They may cover very broad areas, especially if they formed at the bottom of ancient seas. Erosion may have worn away some of the rock, but layers on either side of eroded areas will still "match up." The Grand Canyon (Figure 136) is a good example of lateral continuity. You can clearly see the same rock layers on opposite sides of the canyon. The matching rock layers were deposited at the same time, so they are the same age.

Figure 136: Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

Law of Original Horizontality

Sediments were deposited in ancient seas in horizontal, or flat, layers. If sedimentary rock layers are tilted, they must have moved after they were deposited.

Law of Cross-Cutting Relationships

Rock layers may have another rock cutting across them, like the igneous rock pictured below (Figure 137). Which rock is older? To determine this, we use the law of cross-cutting relationships. The cut rock layers are older than the rock that cuts across them.

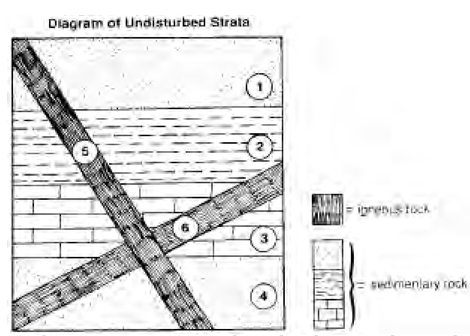
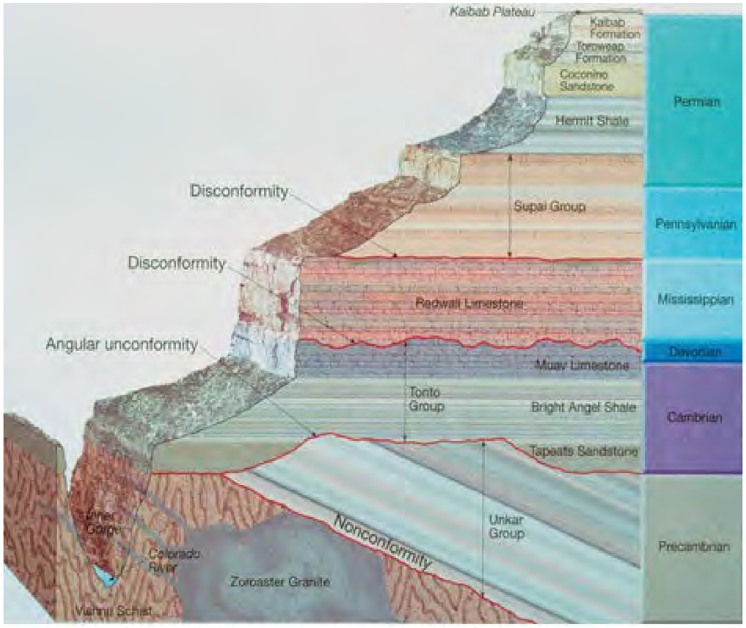


Figure 137: Organize the layers based on your understanding of Relative age dating.

Unconformities

Geologists can learn a lot about Earth's history by studying sedimentary rock layers. But in some places, there's a gap in time when no rock layers are present. A gap in the sequence of rock layers is called an **unconformity**.

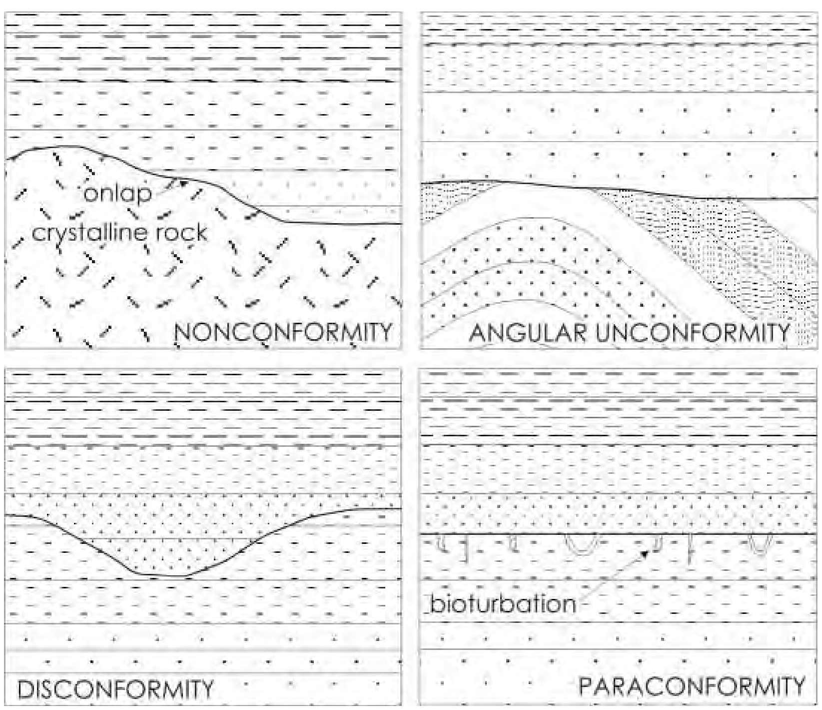


University of Iowa Department of Geoscience

Figure 138: Unconformities within the stratigraphic succession comprising the wall rocks of the Grand Canyon, Arizona

Look at the rock layers pictured below (Figure 138) they show a feature called Hutton's unconformity. James Hutton discovered the unconformity in the 1700s. Hutton saw that the lower rock layers are very old. The upper layers are much younger. There are no layers in between the ancient and recent layers. Hutton thought that the intermediate rock layers eroded away before the more recent rock layers were deposited.

Hutton's discovery was a very important event in geology! Hutton determined that the rocks were deposited over time. Some were eroded away. Hutton knew that deposition and erosion are very slow. He realized that for both to occur would take an extremely long time. This made him realize that Earth must be much older than people thought. This was a really big discovery! It meant there was enough time for life to evolve gradually.



Determining Relative Age

What are the relative ages of these rocks?

This photo shows rock layers and a fault—the fault is the large diagonal crack running through this rock. These features can tell us several things about relative age. Unless the rock was turned over somehow, we can assume that the layers on top are younger than the layers on the bottom. Since the fault separates the layers, we can tell that the fault occurred after all the layers were deposited.

Steno's principles are essential for determining the relative ages of rocks and rock layers. Remember that in **relative dating**, scientists do not determine the exact age of a fossil or rock. They look at a sequence of rocks to try to decipher when an event occurred relative to the other events represented in that sequence. The **relative age** of a rock, then, is its age in comparison with other rocks. (1) Do you know which rock is older and which is younger? (2) Do you know how old the rock's layers are in years? For relative ages, you know #1 but not #2.

An interactive website on relative ages and geologic time is found here:

- **http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/gtpage1.html**

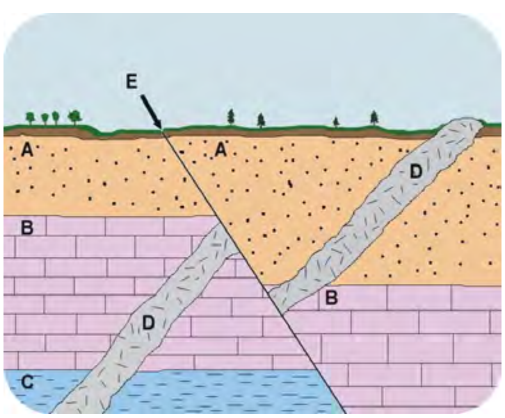


Figure 139: A geologic cross section: Sedimentary rocks (A-C), igneous intrusion (D), fault (E).

In some cases, it is very tricky to determine the sequence of events that leads to a certain formation. In Figure 139, can you figure out what happened and in what order? Write it down and then check the following paragraphs.

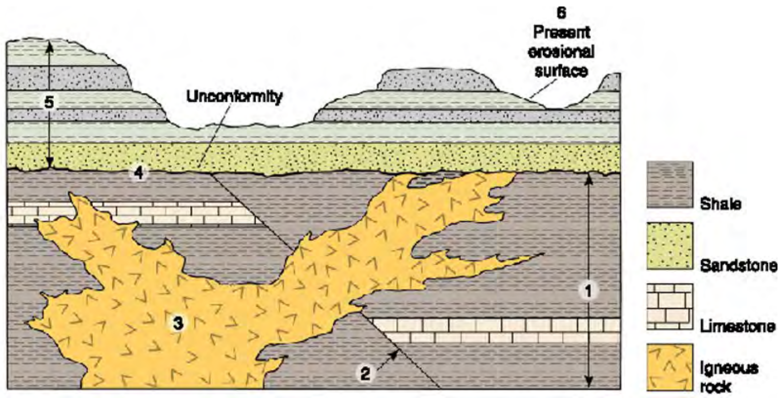
The principle of cross-cutting relationships states that a fault or intrusion is younger than the rocks that it cuts through. The fault cuts through all three sedimentary rock layers (A, B, and C) and also the intrusion (D). So the fault must be the youngest feature. The intrusion (D) cuts through the three sedimentary rock layers, so it must be younger than those layers. By the law of superposition, C is the oldest sedimentary rock, B is younger and A is still younger.

The full sequence of events is:

1. Layer C formed.
2. Layer B formed.
3. Layer A formed.
4. After layers A-B-C were present, intrusion D cut across all three.
5. Fault E formed, shifting rocks A through C and intrusion D.
6. Weathering and erosion created a layer of soil on top of layer A.

Practice / Review

1. What is superposition?



2. How can the age of the layers be determined?
3. Why does the principle of lateral continuity work?
4. How could you recognize the existence of an unconformity?
5. Write a complete story for one of the exampled unconformities above.
6. What is relative dating?
7. What is the problem with relative dating?
8. Describe the law of supposition.
9. What is relative age? How does it differ from absolute age?
10. Why do the principles of relative dating not indicate the absolute age of a rock unit?

11. Under what circumstances would a rock unit with an older fossil be above a rock until with a younger fossil?

12. Using image provided discuss why the sequence presented is correct (use terms from this chapter to explain).

Absolute Age Dating

Radioactive Decay

Radioactive decay is the breakdown of unstable elements into stable elements. To understand this process, recall that the atoms of all elements contain the particles protons, neutrons, and electrons.

Isotopes

An element is defined by the number of protons it contains. All atoms of a given element contain the same number of protons. The number of neutrons in an element may vary. Atoms of an element with different numbers of neutrons are called **isotopes**.

Consider carbon as an example. Two isotopes of carbon are shown below (Figure 140). Compare their protons and neutrons. Both contain six protons. But carbon-12 has six neutrons and carbon-14 has eight neutrons.

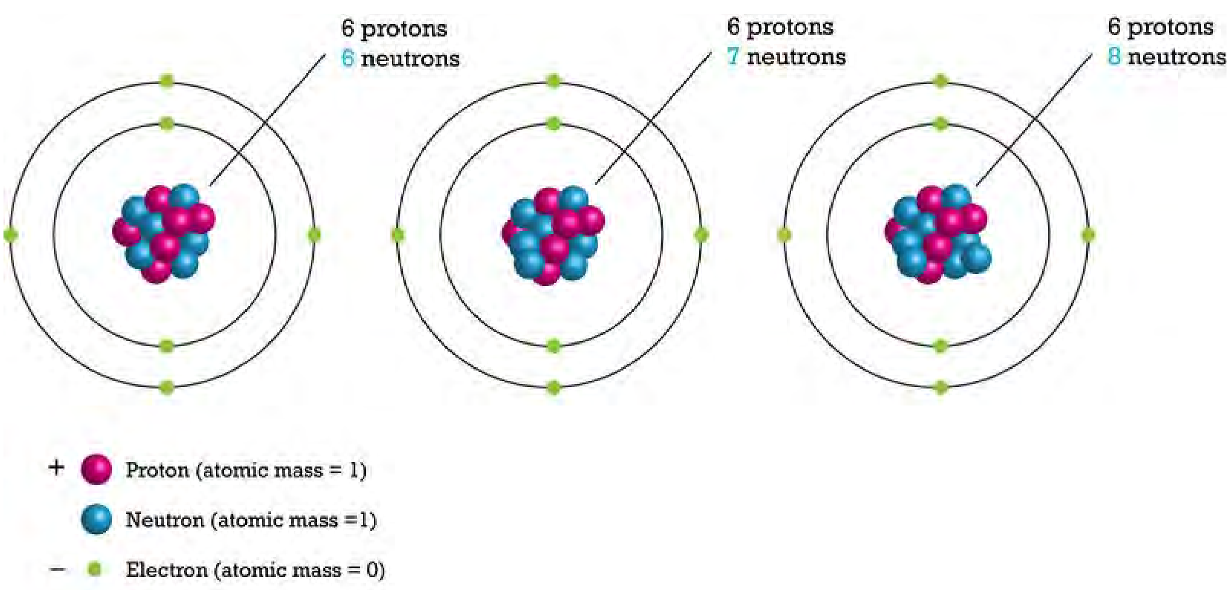


Figure 140: Isotopes are named for their number of protons plus neutrons. If a carbon atom had seven neutrons, what would it be named?

Almost all carbon atoms are carbon-12. This is a stable isotope of carbon. Only a tiny percentage of carbon atoms are carbon-14. carbon-14 is unstable. It is a **radioactive isotope** of carbon. Pictured below is carbon dioxide (Figure 141), which forms in the atmosphere from carbon-14 and oxygen. Neutrons in cosmic rays strike nitrogen atoms in the atmosphere. The nitrogen forms carbon-14. Carbon in the atmosphere combines with oxygen to form carbon dioxide. Plants take in carbon dioxide during photosynthesis. In this way, carbon-14 enters food chains.

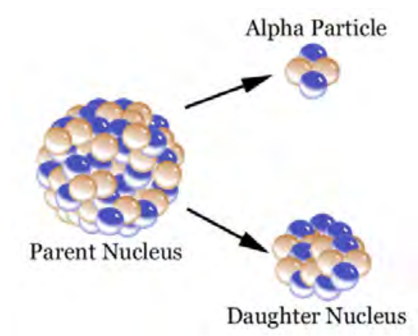


Figure 141: Unstable isotopes, such as carbon-14, decay by losing atomic particles. They form different, stable elements when they decay. In this case, the daughter is nitrogen-14.

Decay of Unstable Isotopes

Like other unstable isotopes, carbon-14 breaks down, or decays. The original atoms are called the **parent isotopes**. For carbon-14 decay, each carbon-14 atom loses an alpha particle. It changes to a stable atom of nitrogen-14. The stable atom at the end is the **daughter product** (Figure 141).

The decay of an unstable isotope to a stable element occurs at a constant rate. This rate is different for each parent-daughter isotope pair. The decay rate is measured in a unit called the half-life. The **half-life** is the time it takes for half of a given amount of an isotope to decay. For example, the half-life of carbon-14 is 5,730 years. Imagine that you start out with 100 grams of carbon-14. In 5,730 years, half of it decays. This leaves 50 grams of carbon-14. Over the next 5,730 years, half of the remaining amount will decay. Now there are 25 grams of carbon-14. How many grams will there be in another 5,730 years? The figure below graphs the rate of decay of a substance (Figure 142).

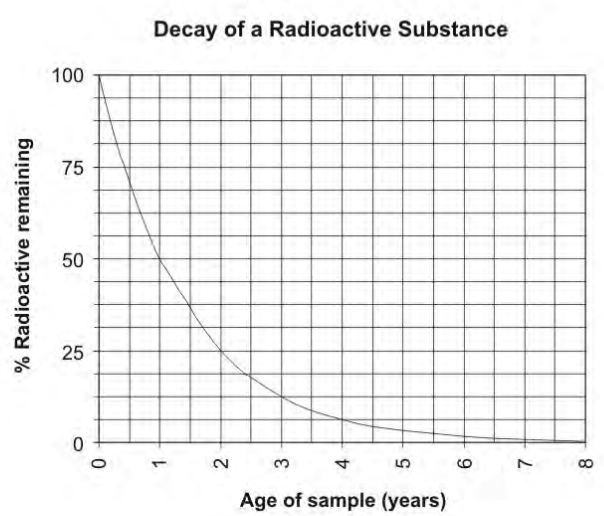


Figure 142: The decay of a radioactive substance is constant over time.

Radiometric Dating of Rocks

Figure 143: Carbon isotopes from the black material in these cave paintings places their creating at about 26,000 to 27,000 years BP (before present).

Radiometric dating is the process of using the concentrations of radioactive substances and daughter products to estimate the age of a material. Different isotopes are used to date materials of different ages. Using more than one isotope helps scientists to check the accuracy of the ages that they calculate.

Radiocarbon Dating

Radiocarbon dating is used to find the age of once-living materials between 100 and 50,000 years old. This range is especially useful for determining ages of human fossils and habitation sites (Figure 143).

The atmosphere contains three isotopes of carbon: carbon-12, carbon-13 and carbon-14. Only carbon-14 is radioactive; it has a half-life of 5,730 years. The amount of carbon-14 in the atmosphere is tiny and has been relatively stable through time.

Plants remove all three isotopes of carbon from the atmosphere during photosynthesis. Animals consume this carbon when they eat plants or other animals that have eaten plants. After the organism's death, the carbon-14 decays to stable nitrogen-14 by releasing a beta particle. The nitrogen atoms are lost to the atmosphere, but the amount of carbon-14 that has decayed can be estimated by measuring the proportion of radioactive carbon-14 to stable carbon-12. As time passes, the amount of carbon-14 decreases relative to the amount of carbon-12.

A video of carbon-14 decay is seen here:

- **http://www.youtube.com/watch?v=81dWTeregEA**;

a longer explanation is here:

- **http://www.youtube.com/watch?v=udkQwW6aLik&feature=related**.

Potassium-Argon Dating

Potassium-40 decays to argon-40 with a half-life of 1.26 billion years. Argon is a gas so it can escape from molten magma, meaning that any argon that is found in an igneous crystal probably formed as a result of the decay of potassium-40. Measuring the ratio of potassium-40 to argon-40 yields a good estimate of the age of that crystal.

Potassium is common in many minerals, such as feldspar, mica, and amphibole. With its half-life, the technique is used to date rocks from 100,000 years to over a billion years old. The technique has been useful for dating fairly young geological materials and deposits containing the bones of human ancestors.

Uranium-Lead Dating

Two uranium isotopes are used for radiometric dating.

- Uranium-238 decays to lead-206 with a half-life of 4.47 billion years.
- Uranium-235 decays to form lead-207 with a half-life of 704 million years.

Uranium-lead dating is usually performed on zircon crystals (Figure 144). When zircon forms in an igneous rock, the crystals readily accept atoms of uranium but reject atoms of lead. If any lead is found in a zircon crystal, it can be assumed that it was produced from the decay of uranium.

Figure 144: Zircon crystal.

Uranium-lead dating is useful for dating igneous rocks from 1 million years to around 4.6 billion years old. Zircon crystals from Australia are 4.4 billion years old, among the oldest rocks on the planet.

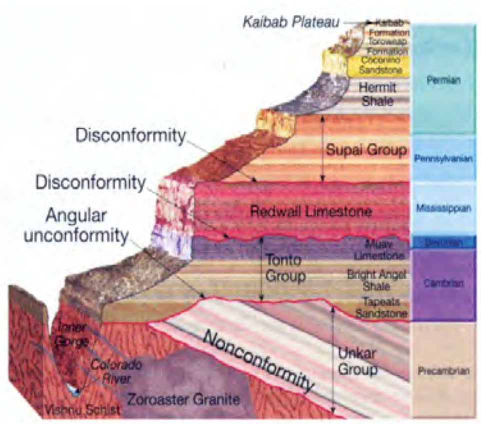
Limitations of Radiometric Dating

Radiometric dating is a very useful tool for dating geological materials but it does have limits:

1. The material being dated must have measurable amounts of the parent and/or the daughter isotopes. Ideally, different radiometric techniques are used to date the same sample; if the calculated ages agree, they are thought to be accurate.
2. Radiometric dating is not very useful for determining the age of sedimentary rocks. To estimate the age of a sedimentary rock, geologists find nearby igneous rocks that can be dated and use relative dating to constrain the age of the sedimentary rock.

Using Radiometric Ages to Date Other Materials

As you've learned, radiometric dating can only be done on certain materials. But these important numbers can still be used to get the ages of other materials! How would you do this? One way is to constrain a material that cannot be dated by one or more that can. For example, if sedimentary rock A is below volcanic rock B and the age of volcanic rock B is 2.0 million years, then you know that sedimentary rock A is older than 2.0 million years. If sedimentary rock A is above volcanic rock C and its age is 2.5 million years then you know that sedimentary rock A is between 2.0 and 2.5 million years. In this way, geologists can figure out the approximate ages of many different rock formations.



The picture starts to come together…

With relative and absolute age dating methods along with an understanding of unconformities a complete picture of the Grand Canyon can become a complete story of Earth's history.

Hypothesize what was used to determine a layer in the canyon's age. Use complete sentences and the terms discussed thus far in this class to discuss how geologist might have determined the age of a specific layer in the Grand Canyon.

Key Vocabulary

- **daughter product**: Product of the radioactive decay of a parent isotope.
- **half-life**: Amount of time required for half of the atoms of a radioactive substance to decay to the daughter product.
- **isotope**: Atoms of an element that have a different number of neutrons.
- **parent isotope**: Unstable isotope that will undergo radioactive decay.
- **radioactive decay**: Emission of high-energy particles by unstable isotopes.
- **radioactive isotope**: Substance that is unstable and likely to decay into another isotope.

Practice and Review

1. What is an isotope?

2. Describe carbon-14.

3. What is radioactive decay?

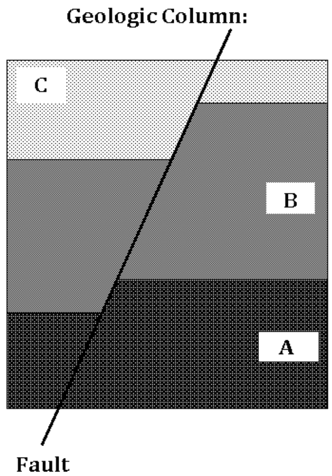
4. What is carbon dating?

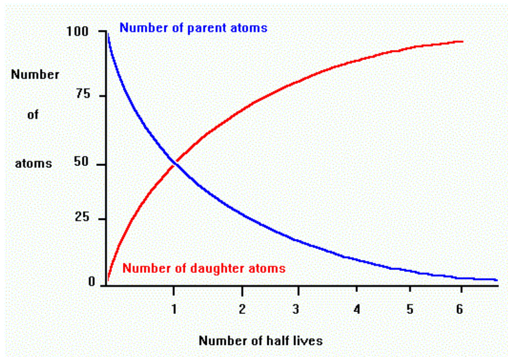
5. What makes an isotope radioactive? Are all isotopes radioactive?

6. What is a parent isotope and a daughter product?

7. Describe half-life. Use an example.

8. Looking at the geologic column provided and the graph determine the age of layer B and Fault. Information: an Isotope was found in layer A that has a half-life of 50 million years and shows a ratio of 1 parent product to 3 daughter product, layer C also was found to have an isotope in the layer, its half-life was determined to be 25 million years and a ratio of 1 parent to 1 daughter product. What is the range in age for layer B? What geologic era and period does this correspond to? What is the approximate age of the Fault and what geologic period might this be associated with?





Fossil Creation

Fossils were Parts of Living Organisms

It wasn't always known that fossils were parts of living organisms. In 1666, a young doctor named Nicholas Steno dissected the head of an enormous great white shark that had been caught by fisherman near Florence, Italy. Steno was struck by the resemblance of the shark's teeth to fossils found in inland mountains and hills (Figure 145).

Figure 145: Fossil Shark Tooth (left) and Modern Shark Tooth (right).

Most people at the time did not believe that fossils were once part of living creatures. Authors in that day thought that the fossils of marine animals found in tall mountains, miles from any ocean could be explained in one of two ways:

- The shells were washed up during the Biblical flood. (This explanation could not account for the fact that fossils were not only found on mountains, but also within mountains, in rocks that had been quarried from deep below Earth's surface.)
- The fossils formed within the rocks as a result of mysterious forces.

But for Steno, the close resemblance between fossils and modern organisms was impossible to ignore. Instead of invoking supernatural forces, Steno concluded that fossils were once parts of living creatures.

How Fossils Form

A fossil is any remains or traces of an ancient organism. Fossils include **body fossils**, left behind when the soft parts have decayed away, and **trace fossils**, such as burrows, tracks, or fossilized coprolites (feces) as seen above. Collections of fossils are known as fossil assemblages.

Fossilization is Rare

Becoming a fossil isn't easy. Only a tiny percentage of the organisms that have ever lived become fossils.

Figure 146: Hyenas eating an antelope. Will the antelope in this photo become a fossil?

Why do you think only a tiny percentage of living organisms become fossils after death? Think about an antelope that dies on the African plain (Figure 146).

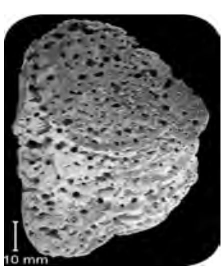


Figure 147: Fossil shell that has been attacked by a boring sponge.

Hyenas and other scavengers eat most of its body and insects and bacteria devour the remaining flesh. Only bones are left behind. As the years go by, the bones are scattered and fragmented into small pieces, eventually turning into dust. The remaining nutrients return to the soil. This antelope will not be preserved as a fossil.

Is it more likely that a marine organism will become a fossil? When clams, oysters, and other shellfish die, the soft parts quickly decay, and the shells are scattered. In shallow water, wave action grinds them into sand-sized pieces. The shells are also attacked by worms, sponges, and other animals (Figure 147).

How about a soft bodied organism? Will a creature without hard shells or bones become a fossil? There is virtually no fossil record of soft bodied organisms such as jellyfish, worms, or slugs. Insects, which are by far the most common land animals, are only rarely found as fossils.

Conditions that Create Fossils

Despite these problems, there is a rich fossil record. How does an organism become fossilized?


Figure 148: This fish was quickly buried in sediment to become a fossil.

Hard Parts

Usually it's only the hard parts that are fossilized. The fossil record consists almost entirely of the shells, bones, or other hard parts of animals. Mammal teeth are much more resistant than other bones, so a large portion of the mammal fossil record consists of teeth. The shells of marine creatures are common also.

Quick Burial

Quick burial is essential because most decay and fragmentation occurs at the surface. Marine animals that die near a river delta may be rapidly buried by river sediments. A storm at sea may shift sediment on the ocean floor, covering a body and helping to preserve its skeletal remains (Figure 148).

Quick burial is rare on land, so fossils of land animals and plants are less common than marine fossils. Land organisms can be buried by mudslides, volcanic ash, or covered by sand in a sandstorm. Skeletons can be covered by mud in lakes, swamps, or bogs.

Unusual Circumstances

Unusual circumstances may lead to the preservation of a variety of fossils, as at the La Brea Tar Pits in Los Angeles, California. Although the animals trapped in the La Brea Tar Pits probably suffered a slow, miserable death, their bones were preserved perfectly by the sticky tar (Figure 149).


Figure 149: Artists concept of animals surrounding the La Brea Tar Pits.

In spite of the difficulties of preservation, billions of fossils have been discovered, examined, and identified by thousands of scientists. The fossil record is our best clue to the history of life on Earth, and an important indicator of past climates and geological conditions as well.

Exceptional Preservation

Some rock beds contain exceptional fossils or fossil assemblages. Two of the most famous examples of soft organism preservation are from the 505 million-year-old Burgess Shale in Canada (Figure 150). The 145 million-year-old Solnhofen Limestone in Germany has fossils of soft body parts that are not normally preserved (Figure 150**).**

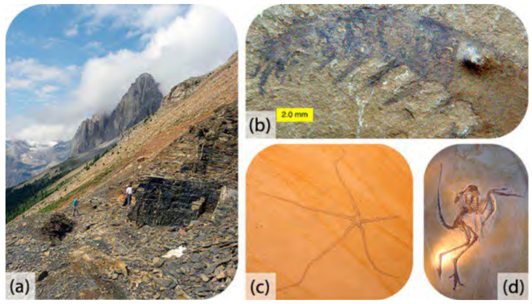


Figure 150: (a) The Burgess shale contains soft-bodied fossils. (b) Anomalocaris, meaning “abnormal shrimp” is now extinct. The image is of a fossil. (c) A brittle star from the Solnhofen Limestone. (d) The famous Archeopteryx fossil from the Solnhofen Limestone has distinct feathers and is possibly the earliest bird?

Types of Fossilization

Most fossils are preserved by one of five processes outlined below (Figure 151):

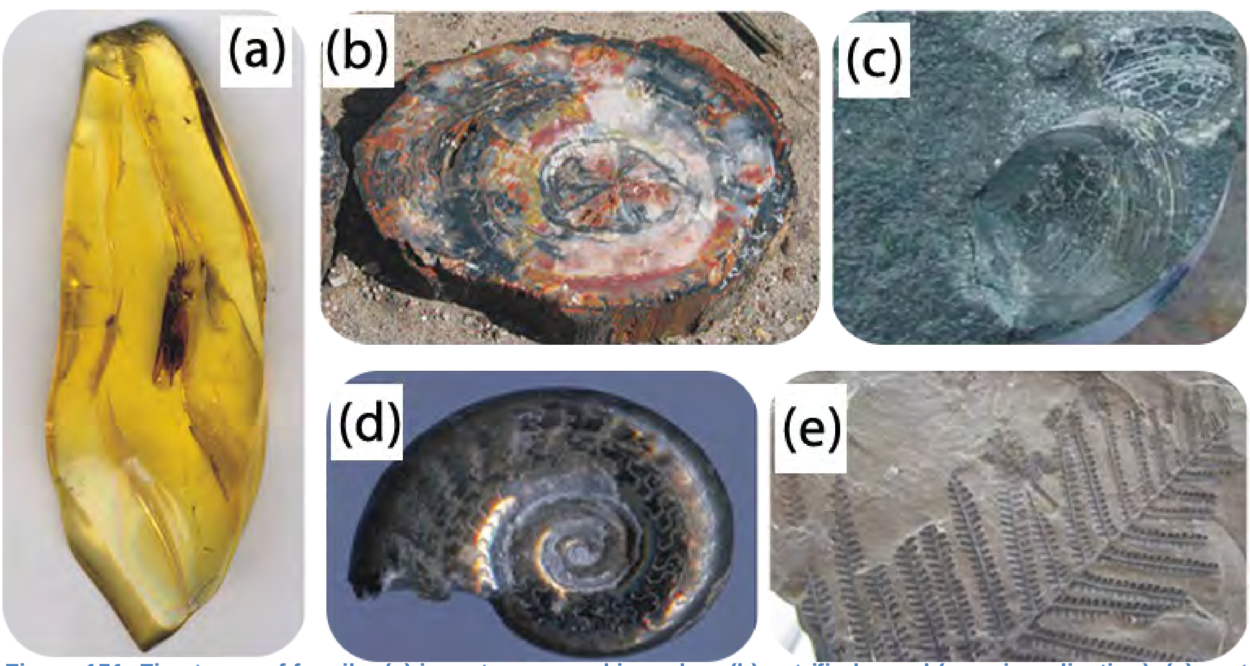


Figure 151: Five types of fossils: (a) insect preserved in amber, (b) petrified wood (permineralization), (c) cast and mold of a clam shell, (d) pyritized ammonite, and (e) compression fossil of a fern.

Preserved Remains

Most uncommon is the preservation of soft-tissue original material. Insects have been preserved perfectly in **amber**, which is ancient tree sap. Mammoths and a Neanderthal hunter were frozen in glaciers, allowing scientists the rare opportunity to examine their skin, hair, and organs. Scientists collect DNA from these remains and compare the DNA sequences to those of modern counterparts.

Permineralization

The most common method of fossilization is **permineralization**. After a bone, wood fragment, or shell is buried in sediment, mineral-rich water moves through the sediment. This water deposits minerals into empty spaces and produces a fossil. Fossil dinosaur bones, petrified wood, and many marine fossils were formed by permineralization.

Molds and Casts

When the original bone or shell dissolves and leaves behind an empty space in the shape of the material, the depression is called a **mold**. The space is later filled with other sediments to form a matching **cast** within the mold that is the shape of the original organism or part. Many mollusks (clams, snails, octopi, and squid) are found as molds and casts because their shells dissolve easily.

Replacement

The original shell or bone dissolves and is replaced by a different mineral. For example, calcite shells may be replaced by dolomite, quartz, or pyrite. If a fossil that has been replace by quartz is surrounded by a calcite matrix, mildly acidic water may dissolve the calcite and leave behind an exquisitely preserved quartz fossil.

Compression

Some fossils form when their remains are compressed by high pressure, leaving behind a dark imprint. Compression is most common for fossils of leaves and ferns, but can occur with other organisms.

Seashells at 20,000 feet!

On his voyage on the Beagle, Charles Darwin noticed many things besides just the Galapagos finches that made him famous. Another important discovery was shell beds high in the Andes Mountains. How did they get there? He determined that they must mean that mountains rise slowly above the ocean, an idea that was being championed at the time by Charles Lyell. If this is the case, Darwin reasoned, the mountains and Earth must be extremely old.

Clues from Fossils

Fossils are our best form of evidence about Earth history, including the history of life. Along with other geological evidence from rocks and structures, fossils even give us clues about past climates, the motions of plates, and other major geological events. Since the present is the key to the past, what we know about a type of organism that lives today can be applied to past environments.

History of Life on Earth

That life on Earth has changed over time is well illustrated by the fossil record. Fossils in relatively young rocks resemble animals and plants that are living today. In general, fossils in older rocks are less similar to modern organisms. We would know very little about the organisms that came before us if there were no fossils. Modern technology has allowed scientists to reconstruct images and learn about the biology of extinct animals like dinosaurs!

- **http://www.youtube.com/watch?feature=player_embedded&v=6IKM9vmU5DE**

Environment of Deposition

By knowing something about the type of organism the fossil was, geologists can determine whether the region was terrestrial (on land) or marine (underwater) or even if the water was shallow or deep. The rock may give clues to whether the rate of sedimentation was slow or rapid. The amount of wear and fragmentation of a fossil allows scientists to learn about what happened to the region after the organism died; for example, whether it was exposed to wave action.

Geologic History

The presence of marine organisms in a rock indicates that the region where the rock was deposited was once marine. Sometimes fossils of marine organisms are found on tall mountains indicating that rocks that formed on the seabed were uplifted.

Climate

By knowing something about the climate a type of organism lives in now, geologists can use fossils to decipher the climate at the time the fossil was deposited. For example, coal beds form in tropical environments but ancient coal beds are found in Antarctica. Geologists know that at that time the climate on the Antarctic continent was much warmer. Recall from Concept Plate Tectonics that Wegener used the presence of coal beds in Antarctica as one of the lines of evidence for continental drift.

Index Fossils

An **index fossil** can be used to identify a specific period of time. Organisms that make good index fossils are distinctive, widespread, and lived briefly. Their presence in a rock layer can be used to identify rocks that were deposited at that period of time over a large area.

The fossil of a juvenile mammoth found near downtown San Jose California reveals an enormous amount about these majestic creatures: what they looked like, how they lived, and what the environment of the Bay Area was like so long ago.

Find out more at:

- **http://science.kqed.org/quest/video/science-on-the-spot-lupe-the-mammoth-comes-to-life/.**

Key Vocabulary

- **Body fossil**: The remains of an ancient organism. Examples include shells, bones, teeth, and leaves.
- **Trace fossil**: Evidence of the activity of an ancient organism; e.g. tracks, tubes, and bite marks.
- **Index fossil**: can be used to identify a specific period of time. Organisms that make good index fossils are distinctive, widespread, and lived briefly. Their presence in a rock layer can be used to identify rocks that were deposited at that period of time over a large area.

Practice and Review

1. Give three examples of body fossils and trace fossils.

2. Under what conditions do fossils form?

3. Why are more fossils of marine organisms than of land organisms?

4. Why are there so few fossils of soft parts?

5. If a snail shell is buried in mud and then infused with mineral rich water what type of fossilization has occurred?

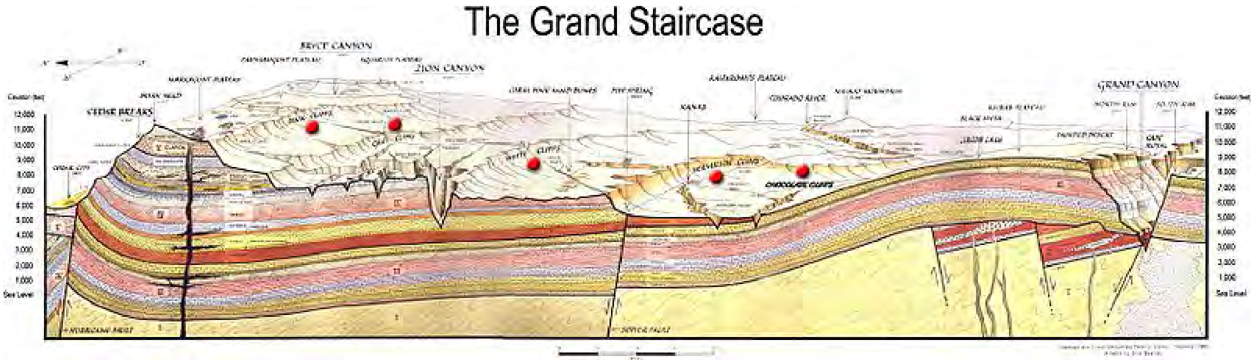
6. What types of fossils are most likely to form by compression and why?

7. How does a single fossil or set of fossils help geologists to decipher the geological history of an area?

8. How is an index fossil used to identify a time period?

9. Why are the fossils of marine organisms sometimes found in rock units at the tops of high mountains? What evidence would you look for to determine if this reason is plausible?

Geologic Correlation



Rock Matching

If we want to understand the geological history of a location we need to look at the rocks in that location. But if we want to understand a region, we need to correlate the rocks between different locations so that we can meld the individual histories of the different locations into one regional history.

Matching Up Rock Layers

Superposition and cross-cutting are helpful when rocks are touching one another and lateral continuity helps match up rock layers that are nearby. To match up rocks that are further apart we need the process of **correlation**. How do geologists correlate rock layers that are separated by greater distances? There are three kinds of clues:

Distinctive Rock Formations

Distinctive rock formations may be recognizable across large regions (Figure 152).

Figure 152: The famous White Cliffs of Dover in southwest England can be matched to similar white cliffs in Denmark and Germany.

Index Fossils

Two separated rock units with the same index fossil are of very similar age. What traits do you think an index fossil should have? To become an index fossil the organism must have (1) been widespread so that it is useful for identifying rock layers over large areas and (2) existed for a relatively brief period of time so that the approximate age of the rock layer is immediately known.

Many fossils may qualify as index fossils (Figure 153). Ammonites, trilobites, and graptolites are often used as index fossils.

Figure 153: Mucrospirifer mucronatus is an index fossil that indicates that a rock was laid down from 416 to 359 million years ago.

Microfossils, which are fossils of microscopic organisms, are also useful index fossils. Fossils of animals that drifted in the upper layers of the ocean are particularly useful as index fossils, since they may be distributed over very large areas.

A biostratigraphic unit, or biozone, is a geological rock layer that is defined by a single index fossil or a fossil assemblage. A biozone can also be used to identify rock layers across distances.

Key Beds

A key bed can be used like an index fossil since a key bed is a distinctive layer of rock that can be recognized across a large area. A volcanic ash unit could be a good key bed. One famous key bed is the clay layer at the boundary between the Cretaceous Period and the Tertiary Period, the time that the dinosaurs went extinct (Figure 154). This widespread thin clay contains a high concentration of iridium, an element that is rare on Earth but common in asteroids. In 1980, the father-son team of Luis and Walter Alvarez proposed that a huge asteroid struck Earth 66 million years ago and caused the mass extinction.

Figure 154: The white clay is a key bed that marks the Cretaceous-Tertiary Boundary.

Practice and Review

1. What features must the iridium layer that dates to around 66 million years ago have to be a key bed?
2. Why are microfossils especially useful as index fossils?
3. What is the process of correlation?

Create a Geologic Column

Here are 6 geologic layers with information about each. Using information provided about each layer build a column following the laws and principles of geology.

Layer F

- Type of rock Sandstone
- Isotope ratio 1:7
- Half-life = 10.5 million years

Layer X:

- Type of rock is a gravel
- Isotope ratio 1:3 or 3 non-radioactive element to 1 radioactive element
- Half-life = 25,000 years

Layer Z

- Type of rock Dolomite
- 3 fossils found
    - Fossil A – record indicates 248 – 144 million years
    - Fossil B – record indicates 290 – 206 million years
    - Fossil C – record indicates 323 – 144 million years

Layer C

- Type of rock Limestone
- Isotope ration 1:7
- Half-life = 50 million years

For each layer

1. Identify in millions of years the age of the layer
2. Identify the geologic Era and period of each layer
3. Give each rock type its own pattern or color key
4. Create a geologic column showing the correct sequence of rock
    a. Label the name of the layer
    b. Color or provide a pattern for each layer
    c. Identify the period for each layer

Questions:

1. Where is the unconformity in this column and how long does the unconformity last?
2. Which layer would you expect to find fossils of Dinosaurs in?
3. Which layers would you not expect to find fossils of Dinosaurs in and why?

Practice Test Historical Geology:

Geologic Time Scale

1) Scientists used evidence from fossils and ________ to create a listing of rock layers from oldest to youngest.

a) Climate history

b) Steno's principles

c) Sediment

d) Atmosphere readings

2) The Earth's history was divided into blocks of time, scientists refer this as the

a) Geological time scale

b) Geological calendar

c) Geological time line

d) Geological story

3) We live in the Holocene epoch, as well as the

a) Quaternary period

b) Cenozoic Era

c) Phanerozoic Era

d) All of the above

4) True or false. If Earth history was condensed into one calendar year, 3 months into the year the oldest dated rock date is equal to 3.8 million years ago.

a) True

b) False

5) True or false. The first fossil evidence of cells with nuclei was discovered after the Cambrian Explosion.

a) True

b) False

6) True or false. Naming time periods makes it easier to talk about them.

a) True

b) False

7) True or false. Humans have been around the longest.

a) True

b) False

8) True or false. Many of the names of the time periods are from places in Europe.

a) True

b) False

9) True or false. Eons refer to larger amounts of time.

a) True

b) False

Principles of Relative Dating

1) This scientist determined that fossils represented parts of once-living organisms.

a) Alfred Wegener

b) William Smith

c) Nicholas Steno

d) Richard Leakey

2) True or false. Original horizontality is when sediments are deposited in continuous sheets.

a) True

b) False

3) Superpostion is when ______________________.

a) Sediments are deposited fairly flat, horizontal layers

b) Sediments are deposited in continuous sheets that span the body of water

c) Sedimentary rocks are deposited one on top of another

d) All of the above

4) The oldest rocks are found ___________________ of a sequence.

a) At the top

b) In the middle

c) At the bottom

d) None of the above

5) Sedimentary rocks found on either side of a valley are an example of ____________.

a) Original horizontality

b) Lateral continuity

c) Superposition

d) Vertical Position

6) This geologist identified the principle of faunal succession.

a) Alfred Wegener

b) William Smith

c) Nicholas Steno

d) Richard Leakey

7) True or false. Human ancestors can be found with dinosaur fossils.

a) True

b) False

8) The ____________________, found in Arizona and formed with the help of the Colorado river, is an excellent illustration of the principle of cross-cutting relationships.

9) Which of these statements are true.

a) Usually fossils are found clustered together with other fossils from different time periods

b) Older features are found at the top of layers of rock

c) Fossil species with features can be used to determine the age of rock layers quite precisely

d) All of the above are true

10) True or false. Feathered dinosaurs preceded birds in the fossil record.

a) True

b) False

Determining Relative Ages

1) Steno's and ________ principles are essential for determining the relative ages of rocks and rock layers.

a) Smith's

b) Cod's

c) Thomas'

d) Lee's

2) The _________ of a rock is its age in comparison with other rocks.

a) Relative age

b) Exact age

c) Approximate age

d) Fake age

3) True or false. The principle of cross-cutting relationships states that a fault or intrusion is younger than the rocks that it cuts through.

a) True

b) False

4) True or false. Older rocks lie above the younger rocks.

a) True

b) False

5) True or false. The law of superposition states, the older rock will be underneath younger rocks.

a) True

b) False

6) True or false. A fault can cut through three sedimentary rock layers.

a) True

b) False

7) True or false. An intrusion can cut through sedimentary rock layers.

a) True

b) False

8) According to Figure 1, the first event to happen is:

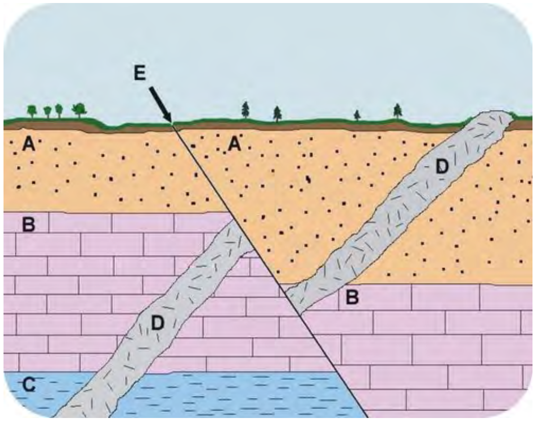


Figure 155: A Geological cross-section. A-C: Sedimentary Rocks, D: Intrusion, E: Fault

a) Layer C formed

b) Layer B formed

c) Layer A formed

d) Fault E formed

9) True or false. According to Figure 1, after layers A-B-C were present, intrusion D cut across all three.

a) True

b) False

Radioactive Decay

1) _________________ is the tendency of certain atoms to decay into lighter atoms.

2) Radioactive isotopes are unstable and spontaneously change by ____________.

a) Gaining particles

b) Losing particles

c) Both a and b

d) None of the above

3) The radioactive decay of a parent isotope leads to the formation of a stable _________.

a) Progeny

b) Daughter Product

c) Son Product

d) All of the above

4) The parent isotope emits this to create a daughter.

a) An alpha particle

b) A zeta particle

c) An omega particle

d) All of the above

5) If two half-lives have passed, this percent of the parent isotope remains.

a) 100%

b) 50%

c) 25%

d) 12.5%

6) If 75% of the daughter is produced, this many half-lives have passed.

a) 0

b) 1

c) 2

d) 3

7) True or false. With beta decay only three electrons are lost.

a) True

b) False

8) Radiometric decay

a) Is constant

b) Plateaus

c) Exponential

d) None of the above

9) This team of physicists discovered the spontaneous emission of particles from certain elements, which they called "radioactivity."

a) Steno and Sutton

b) Pierre and Marie Curie

c) Watson and Crick

d) All of the above

Radiometric Dating

1) Wood can be dated by

a) Counting the twigs

b) Tree rings

c) Feeling the bark

d) Counting the leaves

2) A process of using the concentrations of radioactive substances and daughter products to estimate the age of a material is called ______________.

a) Counting radioactivity

b) Celestial dating

c) Radiometric dating

d) Radio dating

3) True or false. Radiometric dating uses the rate of decay of unstable isotopes to estimate the absolute ages of fossils and rocks.

a) True

b) False

4) True or false. The worst known method of radiometric dating is carbon-14 dating.

a) True

b) False

5) True or false. Carbon-14 dating is done by measuring the amount of carbon-14 to carbon-12; and by knowing the rate of how fast carbon-14 decays, we can tell how long ago the organism died.

a) True

b) False

6) True or false. Radiocarbon dating is useful for specimens younger than 50,000 years old.

a) True

b) False

7) Which is an unstable isotope?

a) Potassium-40

b) Uranium-235

c) Uranium-238

d) All of the above

8) Which is a limitation of radiometric dating?

a) Radiometric dating can be done only on sedimentary rock and plant fossils.

b) There must be Carbon-12.

c) The material being dated must have measurable amounts of the parent and/or the daughter isotope.

d) None of the above

9) True or false. Potassium-argon dating is useful for dating fairly young geological materials and deposits containing the bones of human ancestors.

a) True

b) False

10) True or false. Uranium-lead dating is NOT usually performed on zircon crystals.

a) True

b) False

Types of Fossilization

1) There are _____ types of fossils.

a) 3

b) 5

c) 8

d) 50

2) Which is a type of fossil?

a) Petrified wood

b) Insect preserved in amber

c) Cast and mold of a clam shell

d) All of the above

3) True or false. Preservation of soft-tissue original material is the most uncommon.

a) True

b) False

4) True or false. Amber is an ancient tree sap that can perfectly preserve insects.

a) True

b) False

5) True or false. Permineralization is the most common method of fossilization.

a) True

b) False

6) True or false. Molds are the depression and casts are the filled spaces with sediments to match the mold.

a) True

b) False

7) When the original shell or bone dissolves and is replaced by a different mineral, this is called

a) Replacement
b) Molds and casts
c) Permineralization
d) None of the above

8) The most common type of fossil of leaves and ferns is

a) Replacement
b) Amber
c) Compression
d) All of the above

9) True or false. There are many fossils of bacteria and jellyfish.

a) True
b) False

Earth History and Clues

1) Charles Darwin discovered

a) The Galapagos Islands
b) Shell beds high in the Andes Mountains
c) Mountains and Earth must be extremely old
d) All of the above

2) Fossils help us learn more about

a) Earth history
b) Space
c) Water
d) Nothing

3) True or false. Fossils help us determine the past climates, the motions of plates, and other major geological events.

a) True

b) False

4) True or false. By knowing something about the type of organism the fossil was, geologists determine whether the region was terrestrial or marine or shallow or deep water.

a) True

b) False

5) True or false. Finding marine organisms in a rock may indicate that the region was once marine.

a) True

b) False

Correlation Using Relative Ages

1) __________________ of a rock is its age in comparison with other rocks.

2) True or false. The younger rocks lie above the older rocks.

a) True

b) False

3) Which principle describes when younger rock cuts through older rock.

a) The principle of cross-cutting relationship

b) The principle of sedimentary layers

c) The principle of young rock cutting

d) The principle of cutting across relationship

4) What is the geological time scale?

5) Which describes the process where the youngest rocks are at the top of the canyon and oldest are at the bottom?

a) Superposing

b) Superposition

c) Positioning

d) Superseding

6) _____________ and erosion create a layer of soil on the top layer.

Water, water everywhere. But how much of it is useful?

Earth is the water planet. From space, Earth is a blue ball, unlike any of the other planets in our solar system. Life, also unique to Earth of the planets in our solar system, depends on this water. While there's a lot of salt water, a surprisingly small amount of it is fresh water.

Distribution of Water

Earth's oceans contain 97% of the planet's water. That leaves just 3% as fresh water, water with low concentrations of salts (Figure 156). Most fresh water is trapped as ice in the vast glaciers and ice sheets of Greenland.

How is the 3% of fresh water divided into different reservoirs? How much of that water is useful for living creatures? How much for people?

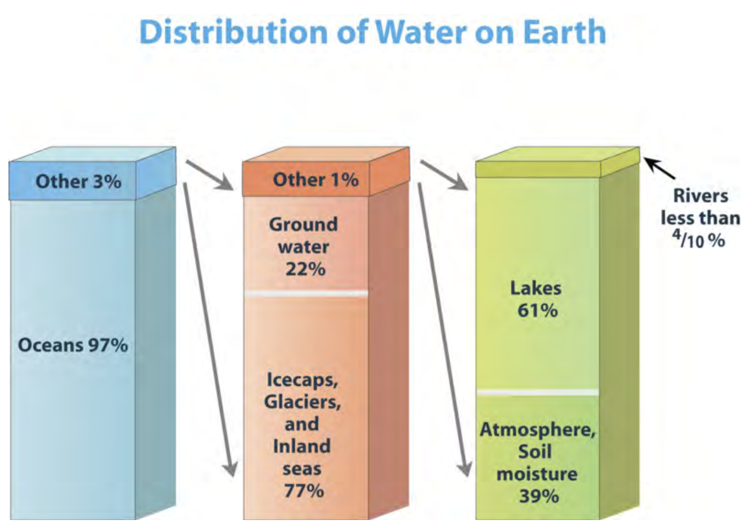


Figure 156: The distribution of Earth's water.

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**.

Where have these water molecules been?

Because of the unique properties of water, water molecules can cycle through almost anywhere on Earth. The water molecule found in your glass of water today could have erupted from a volcano early in Earth's history. In the intervening billions of years, the molecule probably spent time in a glacier or far below the ground. The molecule surely was high up in the atmosphere and maybe deep in the belly of a dinosaur. Where will that water molecule go next?

The Water Cycle

The movement of water around Earth's surface is the **hydrological (water) cycle** (Figure 157). Water inhabits reservoirs within the cycle, such as ponds, oceans, or the atmosphere. The molecules move between these reservoirs by certain processes, including condensation and precipitation. There are only so many water molecules and these molecules cycle around. If climate cools and glaciers and ice caps grow, there is less water for the oceans and sea level will fall. The reverse can also happen.

The following section looks at the reservoirs and the processes that move water between them.

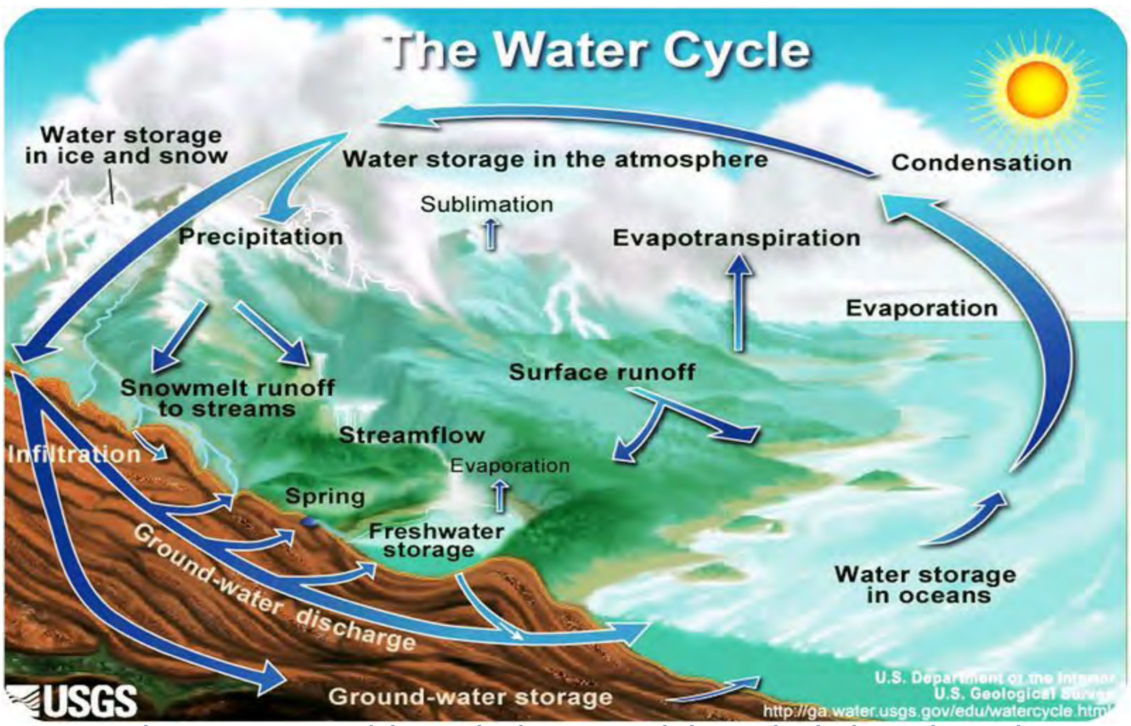


Figure 157: Because it is a cycle, the water cycle has no beginning and no end.

Solar Energy Drives the Hydrological 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, an essential part of the water cycle.

Oceans

Most of Earth's water is stored in the oceans, where it can remain for hundreds or thousands of years.

Oceans Moderate Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70^{o}C and others as hot as 55^{o}C, the range is only 125^{o}C. On Mercury, where no water exists, temperatures go from -180^{o}C to 430^{o}C, a range of 610^{o}C.

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the equator and then move that solar energy to more polar regions via ocean currents. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller in lands nearer the oceans than away from the oceans. Summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down.

Effect on Global Climate

Surface currents play an enormous role in Earth's climate. Even though the equator and poles have very different climates, these regions would have more extremely different climates if ocean currents did not transfer heat from the equatorial regions to the higher latitudes.

The Gulf Stream is a river of warm water in the Atlantic Ocean, about 160 kilometers wide and about a kilometer deep. Water that enters the Gulf Stream is heated as it travels along the equator. The warm water then flows up the east coast of North America and across the Atlantic Ocean to Europe. The energy the Gulf Stream transfers is enormous: more than 100 times the world's energy demand.

The Gulf Stream's warm waters raise temperatures in the North Sea, which raises the air temperatures over land between 3 to 6^{o}C (5 to 11^{o}F). London, U.K., for example, is at about six degrees further south than Quebec, Canada. However, London's average January temperature is 3.8^{o}C (38^{o}F), while Quebec's is only -12^{o}C (10^{o}F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on weather; they remain unchanged even in large storms because they depend on factors that do not change.

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

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

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time and are related to the unequal heating of Earth by the Sun — that is, more solar radiation strikes the equator than the polar regions — and the rotation of the Earth — that is, the **Coriolis effect**. Coriolis was described in "Concept Earth as a Planet." The causes of the global wind patterns will be described in detail in "Concept Atmospheric Processes."

Water in the surface currents is pushed in the direction of the major wind belts:

- trade winds: east to west between the equator and 30°N and 30°S
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50° and 60° north and south of the equator and the north and south pole

Shape of the Ocean Basins

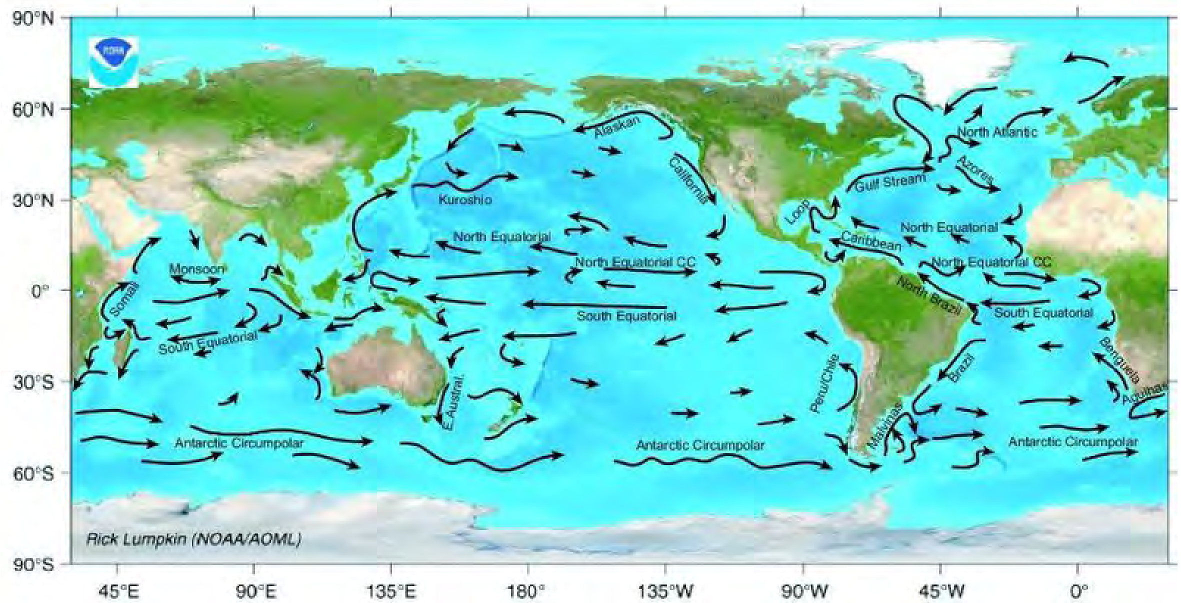


Figure 158: The major surface ocean currents.

When a surface current collides with land, the current must change direction (Figure 158). In the figure below, the Atlantic South Equatorial Current travels westward along the equator until it reaches South America. At Brazil, some of it goes north and some goes south. Because of Coriolis effect, the water goes right in the Northern Hemisphere and left in the Southern Hemisphere.

Gyres

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (Figure 159). The Antarctic Circumpolar Current is unique because it travels uninhibited around the globe. Why is it the only current to go all the way around?

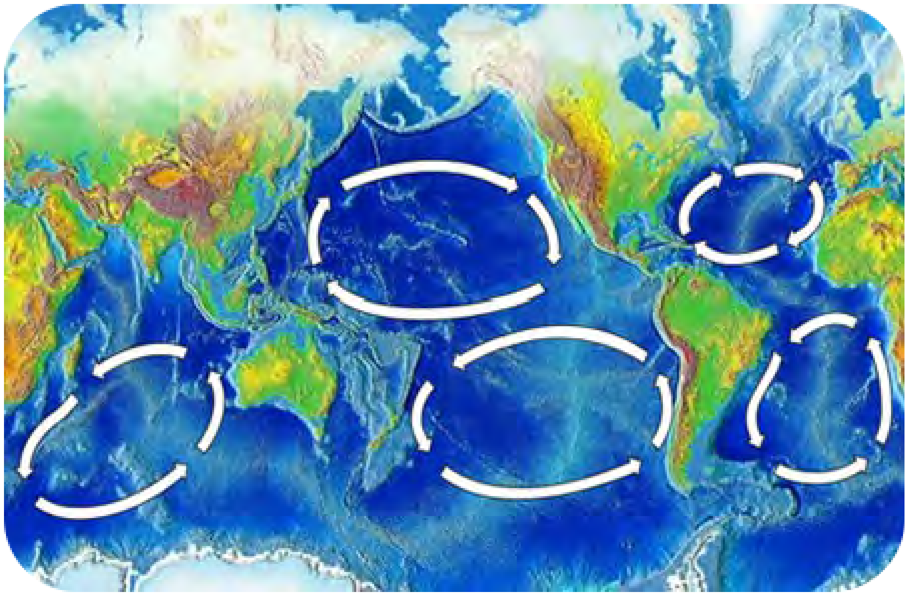


Figure 159: The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

Atmosphere
Water changes from a liquid to a gas by **evaporation** to become water vapor. The Sun's energy can evaporate water from the ocean surface or from lakes, streams, or puddles on land. Only the water molecules evaporate; the salts remain in the ocean or a fresh water reservoir.

The water vapor remains in the atmosphere until it undergoes **condensation** to become tiny droplets of liquid. The droplets gather in clouds, which are blown about the globe by wind. As the water droplets in the clouds collide and grow, they fall from the sky as precipitation. **Precipitation** can be rain, sleet, hail, or snow. Sometimes precipitation falls back into the ocean and sometimes it falls onto the land surface.

For a little fun, watch this video. This water cycle song focuses on the role of the sun in moving H_2O from one reservoir to another. The movement of all sorts of matter between reservoirs depends on Earth's internal or external sources of energy **(7c)**:

- **http://www.youtube.com/watch?v=Zx_1g5pGFLI&feature=related** (2:38).

Streams and Lakes
When water falls from the sky as rain it may enter streams and rivers that flow downward to oceans and lakes. Water that falls as snow may sit on a mountain for several months. Snow may become part of the ice in a glacier, where it may remain for hundreds or thousands of years. Snow and ice may go directly back into the air by sublimation, the process in which a solid changes directly into a gas without first becoming a liquid. Although you probably have not seen water vapor undergoing **sublimation** from a glacier, you may have seen dry ice sublimate in air.

Snow and ice slowly melt over time to become liquid water, which provides a steady flow of fresh water to streams, rivers, and lakes below. A water droplet falling as rain could also become part of a stream or a lake. At the surface, the water may eventually evaporate and reenter the atmosphere.

Soil
A significant amount of water infiltrates into the ground. Soil moisture is an important reservoir for water (Figure 160). Water trapped in soil is important for plants to grow.

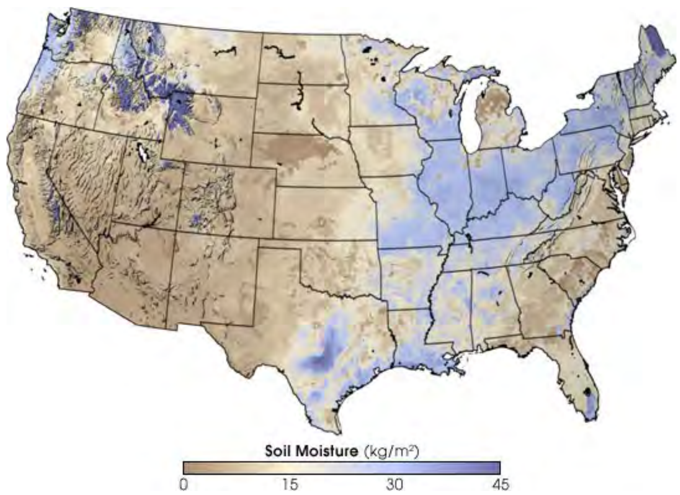


Figure 160: The moisture content of soil in the United States varies greatly.

Soil Formation
How well soil forms and what type of soil forms depends on several different factors, which are described below.

An animation of how weathering makes soil is found here:

- **http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/mineral_weathering.swf**.

Climate
Scientists know that climate is the most important factor determining soil type because, given enough time, different rock types in a given climate will produce a similar soil (Figure 161). Even the same rock type in different climates will not produce the same type of soil. This is true because most rocks on Earth are made of the same eight elements and when the rock breaks down to become soil, those elements dominate.

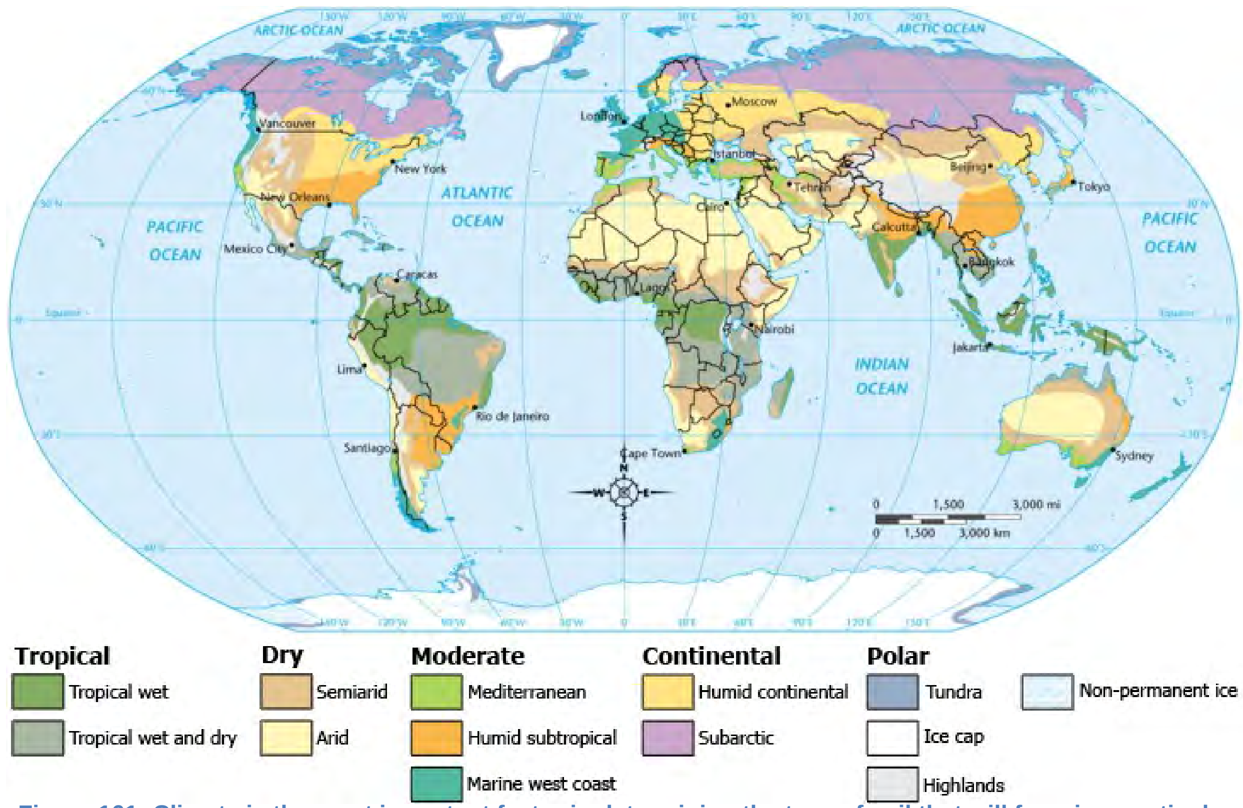


Figure 161: Climate is the most important factor in determining the type of soil that will form in a particular area.

The same factors that lead to increased weathering also lead to greater soil formation.

- More rain equals more chemical reactions to weather minerals and rocks. Those reactions are most efficient in the top layers of the soil, where the water is fresh and has not yet reacted with other materials.
- Increased rainfall increases the amount of rock that is dissolved as well as the amount of material that is carried away by moving water. As materials are carried away, new surfaces are exposed, which also increases the rate of weathering.
- Increased temperature increases the rate of chemical reactions, which also increases soil formation.
- In warmer regions, plants and bacteria grow faster, which helps to weather material and produce soils. In tropical regions, where temperature and precipitation are consistently high, thick soils form. Arid regions have thin soils because chemical weathering is limited by the lack of water.

Soil type also influences the type of vegetation that can grow in the region. We can identify climate types by the types of plants that grow there.

Rock Type

The original rock is the source of the inorganic portion of the soil. The minerals that are present in the rock determine the composition of the material that is available to make soil. Soils may form in place or from material that has been moved.

- **Residual soils** form in place. The underlying rock breaks down to form the layers of soil that reside above it. Only about one-third of the soils in the United States are residual.

- **Transported soils** have been transported in from somewhere else. Sediments can be transported into an area by glaciers, wind, water, or gravity. Soils form from the loose particles that have been transported to a new location and deposited.

Slope
The steeper the slope, the less likely material will be able to stay in place to form soil. Material on a steep slope is likely to go downhill. Materials will accumulate and soil will form where land areas are flat or gently undulating.

Time
Soils thicken as the amount of time available for weathering increases. The longer the amount of time that soil remains in a particular area, the greater the degree of alteration.

Biological Activity
The partial decay of plant material and animal remains produces the organic material and nutrients in soil. In soil, decomposing organisms breakdown the complex organic molecules of plant matter and animal remains to form simpler inorganic molecules that are soluble in water. Decomposing organisms also create organic acids that increase the rate of weathering and soil formation. Bacteria in the soil change atmospheric nitrogen into nitrates.

The decayed remains of plant and animal life are called **humus**, which is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that then hold the soil together, creating its structure. Humus increases the soil's porosity and water-holding capacity and helps to buffer rapid changes in soil acidity. Humus also helps the soil to hold its nutrients, increasing its fertility. Fertile soils are rich in nitrogen, contain a high percentage of organic materials, and are usually black or dark brown in color. Soils that are nitrogen poor and low in organic material might be gray or yellow or even red in color. Fertile soils are more easily cultivated.

An animation of how different types of weathering affect different minerals in soil:

- **http://courses.soil.ncsu.edu/resources/soil_classification_genesis/mineral_weathering/elemental_change.swf**.

Groundwater
Water may seep through dirt and rock below the soil and then through pores infiltrating the ground to go into Earth's groundwater system. Groundwater enters aquifers that may store fresh water for centuries. Alternatively, the water may come to the surface through springs or find its way back to the oceans.

Aquifer
Groundwater resides in **aquifers**, porous rock and sediment with water in between. Water is attracted to the soil particles, and **capillary action**, which describes how water moves through porous media, moves water from wet soil to dry areas.

Aquifers are found at different depths. Some are just below the surface and some are found much deeper below the land surface. A region may have more than one aquifer beneath it and even most deserts are above aquifers. The source region for an aquifer beneath a desert is likely to be far away, perhaps in a mountainous area.

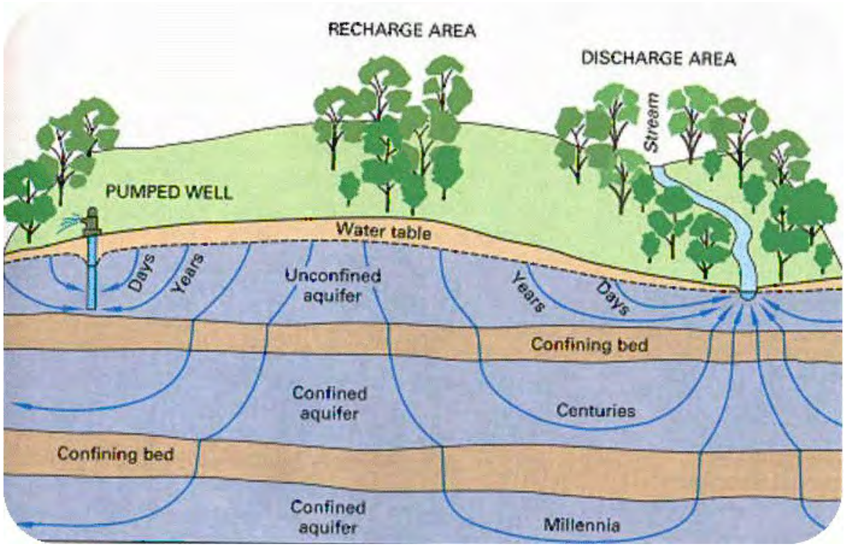


Figure 162: A diagram of groundwater flow through aquifers showing residence times. Deeper aquifers typically contain older "fossil water."

Recharge

The amount of water that is available to enter groundwater in a region, called **recharge**, is influenced by the local climate, the slope of the land, the type of rock found at the surface, the vegetation cover, land use in the area, and water retention, which is the amount of water that remains in the ground. More water goes into the ground where there is a lot of rain, flat land, porous rock, exposed soil, and where water is not already filling the soil and rock.

Fossil Water

The residence time of water in a groundwater aquifer can be from minutes to thousands of years. Groundwater is often called "fossil water" because it has remained in the ground for so long, often since the end of the ice ages.

Biosphere

Plants and animals depend on water to live. They also play a role in the water cycle. Plants take up water from the soil and release large amounts of water vapor into the air through their leaves (Figure 163), a process known as **transpiration**.

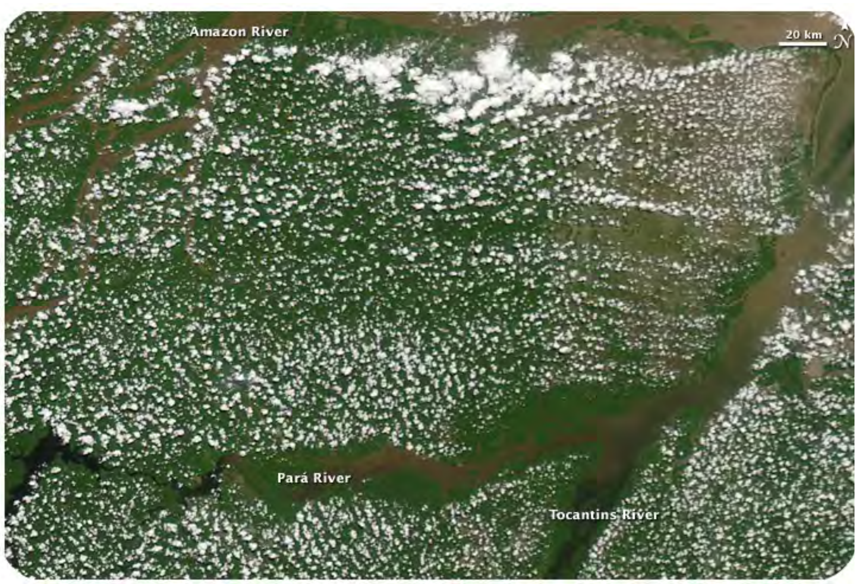


Figure 163: Clouds form above the Amazon Rainforest even in the dry season because of moisture from plant transpiration.

An online guide to the hydrologic cycle from the University of Illinois is found here:

- **http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hyd/home.rxml**.

How the water cycle works and how rising global temperatures will affect the water cycle, especially in California, are the topics of this Quest video.

Watch it at:

- **http://www.kqed.org/quest/television/tracking-raindrops/.**

Human Uses

People also depend on water as a natural resource. Not content to get water directly from streams or ponds, humans create canals, aqueducts, dams, and wells to collect water and direct it to where they want it (Figure 164).

Figure 164: Pont du Gard in France is an ancient aqueduct and bridge that was part of of a well-developed system that supplied water around the Roman empire.

Water Power

Water covers 70% of the planet's surface, and water power (hydroelectric power) is the most widely used form of renewable energy in the world. Hydroelectric power from streams provides almost one fifth of the world's electricity.

Hydroelectric Power

Remember that potential energy is the energy of an object waiting to fall. Water held behind a dam has a lot of potential energy.

In a hydroelectric plant, a dam across a riverbed holds a stream to create a reservoir. Instead of flowing down its normal channel, the water is allowed to flow into a large turbine. As the water moves, it has kinetic energy, which makes the turbine spin. The turbine is connected to a generator, which makes electricity (Figure 165).

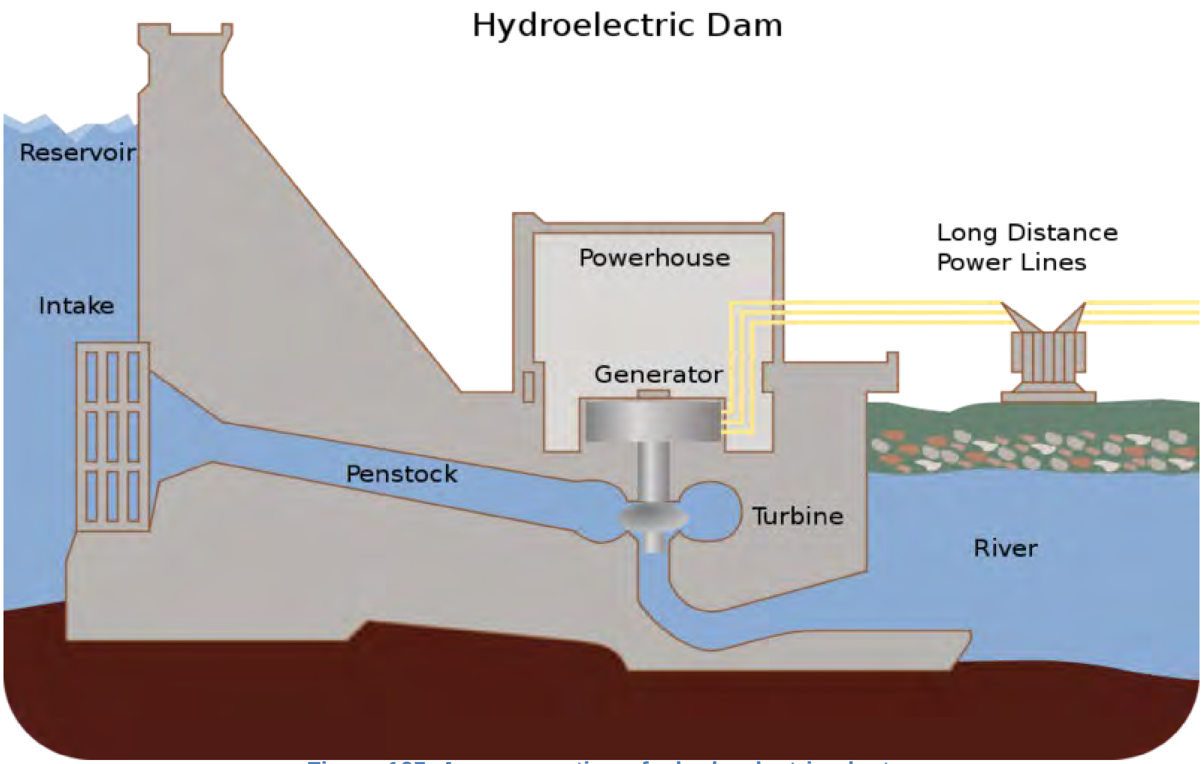


Figure 165: A cross-section of a hydroelectric plant.

Most of the streams in the United States and elsewhere in the developed world that are suitable for hydroelectric power have already been dammed. In California, about 14.5% of the total electricity comes from hydropower. The state's nearly 400 hydropower plants are mostly located in the eastern mountain ranges, where large streams descend down a steep grade.

Consequences of Water Power Use

The major benefit of hydropower is that it generates power without releasing any pollution. Hydropower is also a renewable resource since the stream will keep on flowing. However, there are a limited number of suitable dam sites. Hydropower also has environmental problems. When a large dam disrupts a river's flow, it changes the ecosystem upstream. As the land is flooded by rising water, plants and animals are displaced or killed. Many beautiful landscapes, villages, and archeological sites have been drowned by the water in a reservoir (Figure 166).

Figure 166: Glen Canyon Dam in Arizona created Lake Powell. The dam was controversial because it flooded Glen Canyon, a beautiful desert canyon.

The dam and turbines also change the downstream environment for fish and other living things. Dams slow the release of silt so that downstream deltas retreat and seaside cities become dangerously exposed to storms and rising sea levels.

Water Consumption

Humans use six times as much water today as they did 100 years ago. People living in developed countries use a far greater proportion of the world's water than people in less developed countries. What do people use all of that water for?

Human Uses of Water

Besides drinking and washing, people need water for agriculture, industry, household uses, and recreation (Figure 167). Recreational use and environmental use average 1% each.

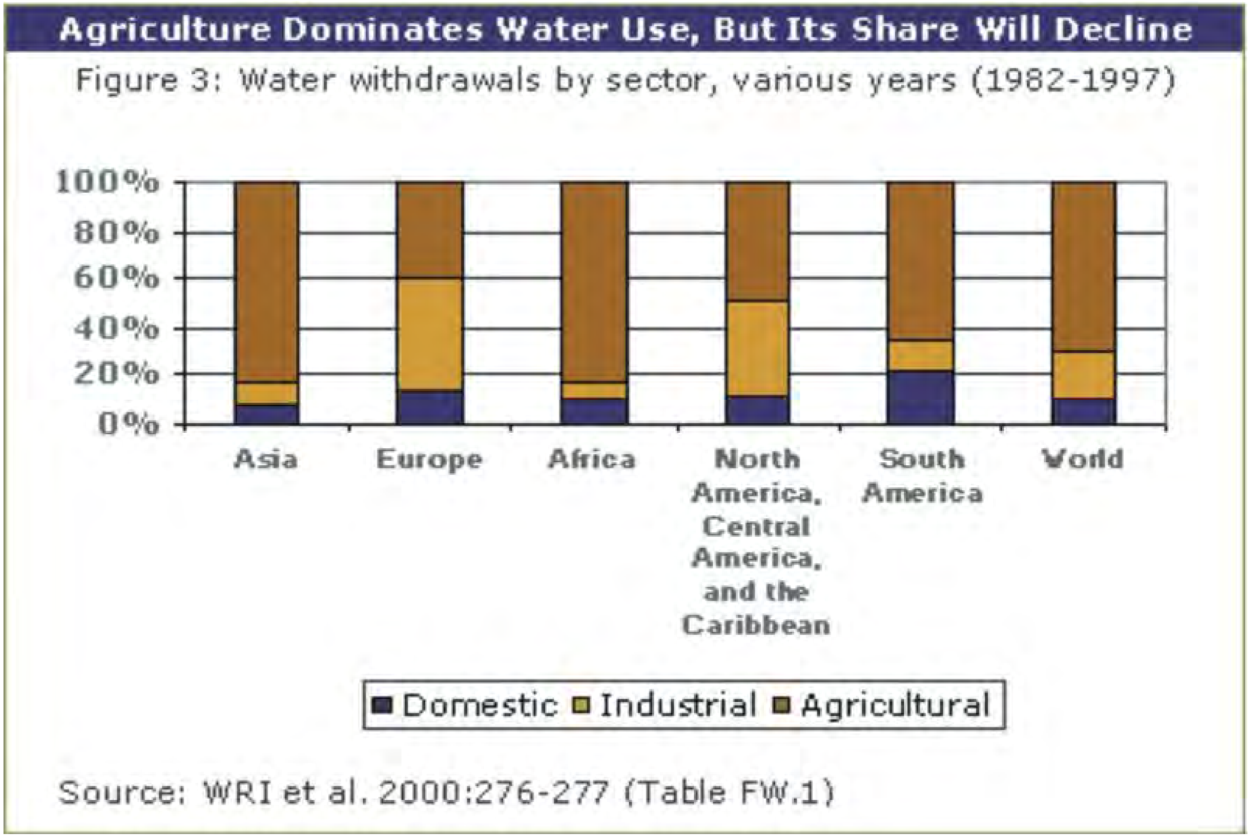


Figure 167: Water used for home, industrial, and agricultural purposes in different regions. Globally more than two-thirds of water is for agriculture.

Water use can be consumptive or non-consumptive, depending on whether the water is lost to the ecosystem.

- **Non-consumptive** water use includes water that can be recycled and reused. For example, the water that goes down the drain and enters the sewer system is purified and then redistributed for reuse. By recycling water, the overall water consumption is reduced.
- **Consumptive** water use takes the water out of the ecosystem. Can you name some examples of consumptive water use?

Agriculture

Some of the world's farmers still farm without irrigation by choosing crops that match the amount of rain that falls in their area. But some years are wet and others are dry. For farmers to avoid years in which they produce little or no food, many of the world's crops are produced using irrigation.

Wasteful Methods

Three popular irrigation methods are:

- Overhead sprinklers.
- Trench irrigation: canals carry water from a water source to the fields.
- Flood irrigation: fields are flooded with water.

All of these methods waste water. Between 15% and 36% percent of the water never reaches the crops because it evaporates or leaves the fields as runoff. Water that runs off a field often takes valuable soil with it.

Non-wasteful Methods

A much more efficient way to water crops is **drip irrigation** (Figure 168). With drip irrigation, pipes and tubes deliver small amounts of water directly to the soil at the roots of each plant or tree. The water is not sprayed into the air or over the ground, so nearly all of it goes directly into the soil and plant roots.

Figure 168: Drip irrigation delivers water to the base of each plant so little is lost to evaporation and runoff.

Why Not Change?

Why do farmers use wasteful irrigation methods when water-efficient methods are available? Many farmers and farming corporations have not switched to more efficient irrigation methods for two reasons:

1. Drip irrigation and other more efficient irrigation methods are more expensive than sprinklers, trenches, and flooding.

2. In the United States and some other countries, the government pays for much of the cost of the water that is used for agriculture. Because farmers do not pay the full cost of their water use, they do not have any financial incentive to use less water.

What ideas can you come up with to encourage farmers to use more efficient irrigation systems?

Aquaculture

Aquaculture is a different type of agriculture. Aquaculture is farming to raise fish, shellfish, algae, or aquatic plants (Figure 169). As the supplies of fish from lakes, rivers, and the oceans dwindle, people are getting more fish from aquaculture. Raising fish increases our food resources and is especially valuable where protein sources are limited. Farmed fish are becoming increasingly common in grocery stores all over the world. Growing fish in a large scale requires that the fish stocks are healthy and protected from predators. The species

Figure 169: Workers at a fish farm harvest fish they will sell to stores.

raised must be hearty, inexpensive to feed, and able to reproduce in captivity. Wastes must be flushed out to keep animals healthy. Raising shellfish at farms can also be successful.

Aquaculture Problems

For some species, aquaculture is very successful and environmental harm is minimal. But for other species, aquaculture can cause problems. Natural landscapes, such as mangroves, which are rich ecosystems and also protect coastlines from storm damage, may be lost to fish farms (Figure 170). For fish farmers, keeping costs down may be a problem since coastal land may be expensive and labor costs may be high. Large predatory fish at the 4th or 5th trophic level must eat a lot, so feeding large numbers of these fish is expensive and environmentally costly. Farmed fish are genetically different from wild stocks, and if they escape into the wild they may cause problems for native fish. Because the organisms live so close together, parasites are common and may also escape into the wild.

Figure 170: Shrimp farms on the coast of Ecuador are shown as blue rectangles. Mangrove forests, salt flats, and salt marshes have been converted to shrimp farms.

Industrial Water Use

Industrial water use accounts for an estimated 15% of worldwide water use, with a much greater percentage in developed nations. Industrial uses of water include power plants that use water to cool their equipment and oil refineries that use water for chemical processes. Manufacturing is also water intensive.

Household Use

Think about all the ways you use water in a day. You need to count the water you drink, cook with, bathe in, garden with, let run down the drain, or flush down the toilet. In developed countries, people use a lot of water, while in less developed countries people use much less. Globally, household or personal water use is estimated to account for 15% of world-wide water use.

Some household water uses are non-consumptive, because water is recaptured in sewer systems, treated, and returned to surface water supplies for reuse. Many things can be done to lower water consumption at home.

- Convert lawns and gardens to drip-irrigation systems.
- Install low-flow shower heads and low-flow toilets.

In what other ways can you use less water at home?

Recreational Use

People love water for swimming, fishing, boating, river rafting, and other activates. Even activities such as golf, where there may not be any standing water, require plenty of water to make the grass on the course green. Despite its value, the amount of water that most recreational activities use is low: less than 1% of all the water we use.

Many recreational water uses are non-consumptive including swimming, fishing, and boating. Golf courses are the biggest recreational water consumer since they require large amounts for irrigation, especially because many courses are located in warm, sunny, desert regions where water is scarce and evaporation is high.

This National Geographic video chronicles the conflict between conserving the Yangtze River for recreational uses versus damming it for the clean energy China needs so badly:

- **http://video.nationalgeographic.com/video/player/environment/energy-environment/energy-conservation.html**.

Environmental Use

Environmental use of water includes creating wildlife habitat. Lakes are built to create places for fish and water birds (Figure 171). Most environmental uses are non-consumptive and account for an even smaller percentage of water use than recreational uses. A shortage of this water is a leading cause of global biodiversity loss.

Figure 171: Wetlands and other environments depend on clean water to survive.

Practice and Review

1. If Earth is the water planet, why is water sometimes a scarce resource?

2. What are the reservoirs for water?

3. In which reservoirs does water have the longest residence times? The shortest?

4. Use this resource to answer the questions that follow (**http://ga.water.usgs.gov/edu/earthwherewater.html**)

    a. What percentage of Earth's water is usable for humans?

    b. How much of the Earth's water is ocean water?

    c. How much freshwater is in glaciers?

    d. How much freshwater is groundwater?

    e. How much freshwater is in lakes?

5. What is transpiration?

6. Describe when and how sublimation occurs.

7. What is the role of the major reservoirs in the water cycle?

8. Describe the motion of a water particle that is stuck in a gyre in the North Pacific.

9. What would happen if a major surface current did not run into a continent? Note that this is what happens with the Antarctic Circumpolar Current.

10. How does energy transition from one form to another as water moves from behind a dam to downstream of a dam?

11. Describe how hydroelectric energy is harnessed.

12. What are some of the downsides of using hydroelectric power?

13. Why do people use so much more water than they used to?

14. Why don't localities and people use water in the most efficient way, rather than sometimes in wasteful ways?

15. What is aquaculture and why is it going to be increasingly important in the future?

Seasons

Earth's Seasons, Weather, and Climate

A common misconception is that the Sun is closer to Earth in the summer and farther away from it during the winter. Instead, the seasons are caused by the 23.5^o tilt of Earth's axis of rotation relative to its plane of orbit around the Sun (Figure 172). **Solstice** refers to the position of the Sun when it is closest to one of the poles. At summer solstice, June 21 or 22, Earth's axis points toward the Sun and so the Sun is directly overhead at its furthest north point of the year, the Tropic of Cancer (23.5^o N).

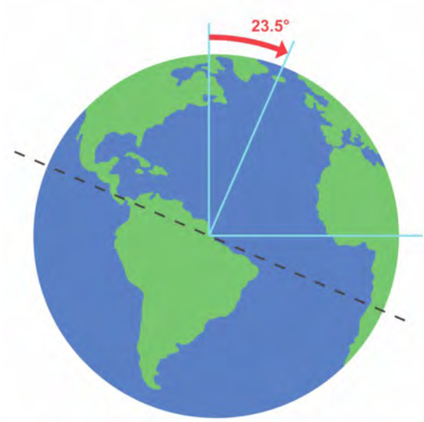


Figure 172: The Earth's tilt on its axis leads to one hemisphere facing the Sun more than the other hemisphere and gives rise to seasons.

During the summer, areas north of the equator experience longer days and shorter nights. In the Southern Hemisphere, the Sun is as far away as it will be and so it is their winter. Locations will have longer nights and shorter days. The opposite occurs on winter solstice, which begins on December 21. More about seasons can be found in the "Atmospheric Processes" concept.

Check out this video on why Earth has seasons to learn more:

- **http://www.youtube.com/watch?v=DuiQvPLWziQ&feature=related**.

Solar Radiation on Earth

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

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

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

Northern Hemisphere Summer

The North Pole is tilted towards the Sun and the Sun's rays strike the Northern Hemisphere more directly in summer (Figure 173). At the summer solstice, June 21 or 22, the Sun's rays hit the Earth most directly along the Tropic of Cancer (23.5^{o}N); that is, the angle of incidence of the sun's rays there is zero (the angle of incidence is the deviation in the angle of an incoming ray from straight on). When it is summer solstice in the Northern Hemisphere, it is winter solstice in the Southern Hemisphere.

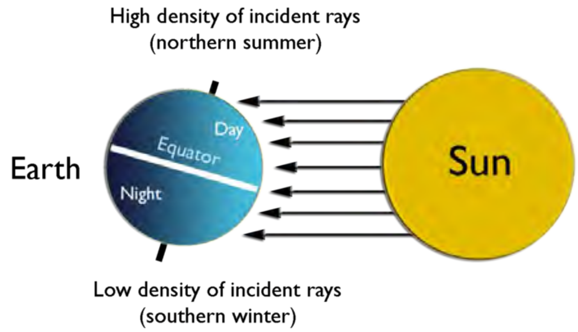


Figure 173: Summer solstice in the Northern Hemisphere.

Northern Hemisphere Winter

Winter solstice for the Northern Hemisphere happens on December 21 or 22. The tilt of Earth's axis points away from the Sun (Figure 174). Light from the Sun is spread out over a larger area, so that area isn't heated as much. With fewer daylight hours in winter, there is also less time for the Sun to warm the area. When it is winter in the Northern Hemisphere, it is summer in the Southern Hemisphere.

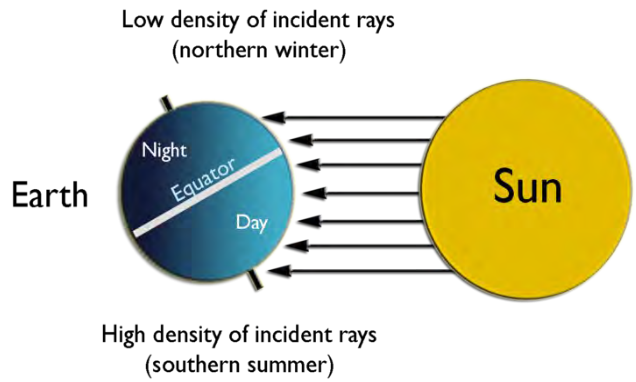


Figure 174: In Southern Hemisphere summer, the Sun's rays directly strike the Tropic of Capricorn (23.5oS). Sunlight is spread across a large area near the South Pole. No sunlight reaches the North Pole.

An animation of the seasons from the University of Illinois is seen here:

- **http://projects.astro.illinois.edu/data/Seasons/seasons.html**.

Notice the area of solar radiation, or insolation, in the lower right of the screen.

Equinox

Halfway between the two solstices, the Sun's rays shine most directly at the equator, called an **equinox** (Figure 174). The daylight and nighttime hours are exactly equal on an equinox. The autumnal equinox happens on September 22 or 23 and the vernal, or spring, equinox happens March 21 or 22 in the Northern Hemisphere.

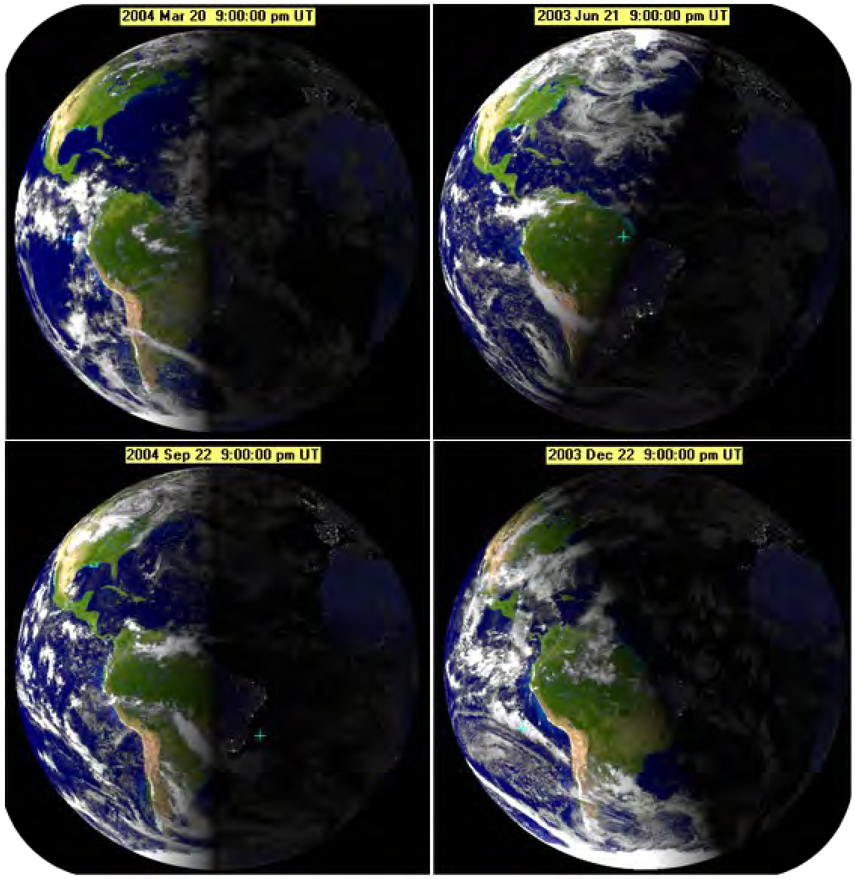


Figure 175: Where sunlight reaches on spring equinox, summer solstice, vernal equinox, and winter solstice. The time is 9:00 p.m. Universal Time, at Greenwich, England.

This is Antarctica. What season is this?

The sun is always up, even in the middle of the night. That's the photo on the left. In the day, the sun never gets too high in the sky. That's the photo on the right. So, this is summer. In the winter, it's just dark in Antarctica.

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight (Figure 176). The sun's rays strike Earth's surface most directly at the equator. This focuses the rays on a small area. Near the poles, the sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives, and the warmer it is.

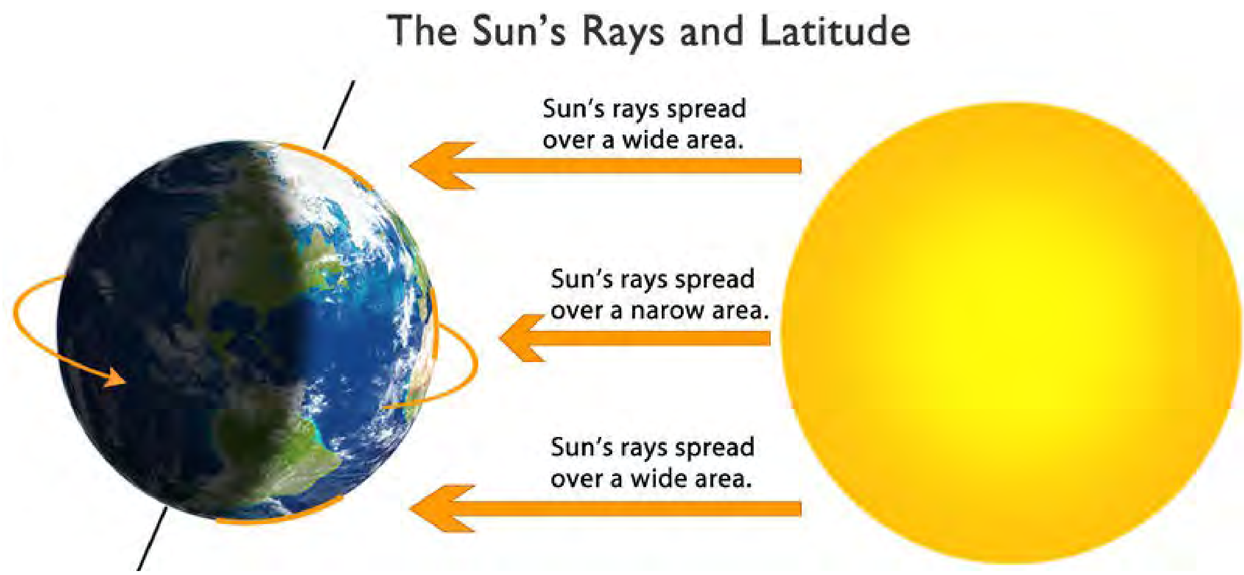


Figure 176: The lowest latitudes get the most energy from the sun. The highest latitudes get the least.

The difference in solar energy received at different latitudes drives atmospheric circulation. Places that get more solar energy have more heat. Places that get less solar energy have less heat. Warm air rise, and cool air sinks. These principles mean that air moves around the planet. The heat moves around the globe in certain ways. This determines the way the atmosphere moves.

Practice and Review

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

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

3. What are equinoxes and when do they come?

4. The North Pole receives sunlight 24 hours a day in the summer. Why does it receive less solar radiation than the equator?

5. What part of Earth receives the most solar radiation in a year?

6. What makes the atmosphere move the way it does?

7. Using the site provided place date at June 22 and make following observations:

   http://astro.unl.edu/classaction/animations/coordsmotion/daylighthoursexplorer.html

   a. What latitude is it the highest value?

   b. What latitude is it the lowest value?

      Explain each answer and include the globes position and the hours of day light or night in your answer.

Atmosphere

What Is the Atmosphere?

Earth's **atmosphere** is a thin blanket of gases and tiny particles — together called air. We are most aware of air when it moves and creates wind. Earth's atmosphere, along with the abundant liquid water at Earth's surface, is the keys to our planet's unique place in the solar system. Much of what makes Earth exceptional depends on the atmosphere. For example, all living things need some of the gases in air for life support. Without an atmosphere, Earth would likely be just another lifeless rock. Let's consider some of the reasons we are lucky to have an atmosphere.

Gases Indispensable for Life on Earth

Without the atmosphere, Earth would look a lot more like the Moon. Atmospheric gases, especially carbon dioxide (CO_2) and oxygen (O_2), are extremely important for living organisms. How does the atmosphere make life possible? How does life alter the atmosphere?

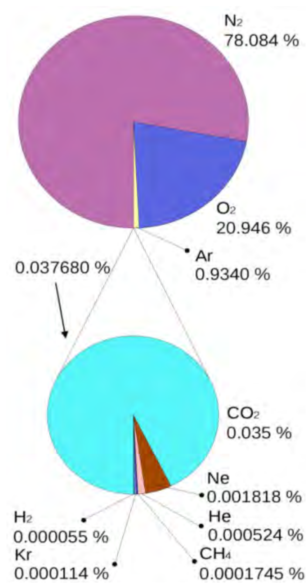


Figure 177: The composition of Earth's atmosphere.

Photosynthesis

In **photosynthesis**, plants use CO_2 and create O_2. Photosynthesis is responsible for nearly all of the oxygen currently found in the atmosphere.

The chemical reaction for photosynthesis is:

$6CO_2 + 6H_2O$ + solar energy $C_6H_{12}O_6$ (sugar) + $6O_2$

Respiration

By creating oxygen and food, plants have made an environment that is favorable for animals. In **respiration**, animals use oxygen to convert sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6O_2$ $6CO_2 + 6H_2O$ + useable energy

How is respiration similar to and different from photosynthesis? They are approximately the reverse of each other. In photosynthesis, CO_2 is converted to O_2 and in respiration, O_2 is converted to CO_2 (Figure 177).

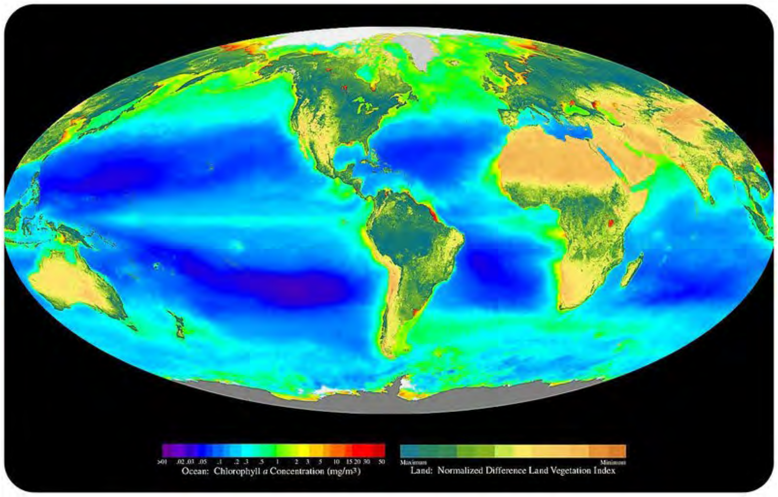


Figure 178: Chlorophyll indicates the presence of photosynthesizing plants as does the vegetation index.

Crucial Part of the Water Cycle

As part of the hydrologic cycle, water spends a lot of time in the atmosphere, mostly as water vapor. The atmosphere is an important reservoir for water.

Ozone Makes Life on Earth Possible

Ozone is a molecule composed of three oxygen atoms, (O_3). Ozone in the upper atmosphere absorbs high-energy **ultraviolet (UV) radiation** coming from the Sun. This protects living things on Earth's surface from the Sun's most harmful rays. Without ozone for protection, only the simplest life forms would be able to live on Earth. The highest concentration of ozone is in the ozone layer in the lower stratosphere.

Keeps Earth's Temperature Moderate

Along with the oceans, the atmosphere keeps Earth's temperatures within an acceptable range. Without an atmosphere, Earth's temperatures would be frigid at night and scorching during the day. If the 12-year-old in the scenario above asked why, she would find out. **Greenhouse gases** trap heat in the atmosphere. Important greenhouse gases include carbon dioxide, methane, water vapor, and ozone.

Provides the Substance for Waves to Travel Through

The atmosphere is made of gases that take up space and transmit energy. Sound waves are among the types of energy that travel though the atmosphere. Without an atmosphere, we could not hear a single sound. Earth would be as silent as outer space (explosions in movies about space should be silent). Of course, no insect, bird, or airplane would be able to fly, because there would be no atmosphere to hold it up.

Composition of Air

Several properties of the atmosphere change with altitude, but the composition of the natural gases does not. The proportions of gases in the atmosphere are everywhere the same, with one exception. At about 20 km to 40 km above the surface, there is a greater concentration of ozone molecules than in other portions of the atmosphere. This is called the **ozone layer**.

Nitrogen and Oxygen

Nitrogen and oxygen together make up 99% of the planet's atmosphere. Nitrogen makes up the bulk of the atmosphere, but is not involved in geological or biological processes in its gaseous form. Nitrogen fixing is described in "Concept Life on Earth." Oxygen is extremely important because animals need it for respiration. The rest of the gases are minor components but sometimes are very important.

Water Vapor

Humidity is the amount of water vapor in the air. Humidity varies from place to place and season to season. This fact is obvious if you compare a summer day in Atlanta, Georgia, where humidity is high, with a winter day in Phoenix, Arizona, where humidity is low. When the air is very humid, it feels heavy or sticky. Dry air usually feels more comfortable. When humidity is high, water vapor makes up only about 4% of the atmosphere.

Where around the globe is mean atmospheric water vapor higher and where is it lower (Figure 179)? 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.

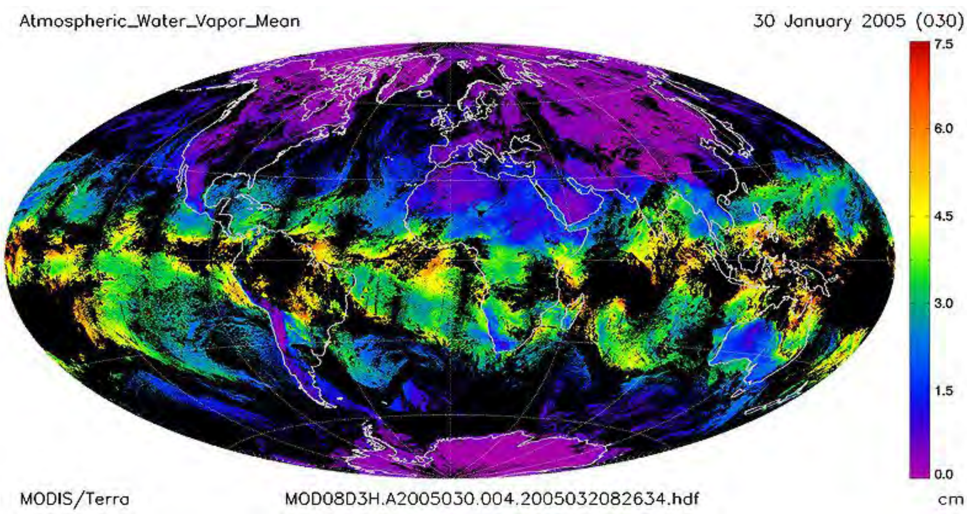


Figure 179: Mean winter atmospheric water vapor in the Northern Hemisphere when temperature and humidity are lower than they would be in summer.

Greenhouse Gases

Remember that greenhouse gases trap heat in the atmosphere. Important natural greenhouse gases include carbon dioxide, methane, water vapor, and ozone. CFCs and some other man-made compounds are also greenhouse gases.

Particulates

Some of what is in the atmosphere is not gas. Particles of dust, soil, fecal matter, metals, salt, smoke, ash, and other solids make up a small percentage of the atmosphere and are called **particulates**. Particles provide starting points (or nuclei) for water vapor to condense on and form raindrops. Some particles are pollutants.

Circulation in the Atmosphere

Temperature

Temperature is a measure of how fast the atoms in a material are vibrating. High temperature particles vibrate faster than low temperature particles. Rapidly vibrating atoms smash together, which generates heat. As a material cools down, the atoms vibrate more slowly and collide less frequently. As a result, they emit less heat. What is the difference between heat and temperature?

- Temperature measures how fast a material's atoms are vibrating.
- Heat measures the material's total energy.

Heat

Heat energy is transferred between physical entities. Heat is taken in or released when an object changes state, or changes from a gas to a liquid, or a liquid to a solid. This heat is called **latent heat**. When a substance changes state, latent heat is released or absorbed. A substance that is changing its state of matter does not change temperature. All of the energy that is released or absorbed goes toward changing the material's state.
For example, imagine a pot of boiling water on a stove burner: that water is at 100°C (212°F). If you increase the temperature of the burner, more heat enters the water. The water remains at its boiling temperature, but the additional energy goes into changing the water from liquid to gas. With more heat the water evaporates more rapidly. When water changes from a liquid to a gas it takes in heat. Since evaporation takes in heat, this is called evaporative cooling. Evaporative cooling is an inexpensive way to cool homes in hot, dry areas.

Substances also differ in their **specific heat**, the amount of energy needed to raise the temperature of one gram of the material by 1.0°C (1.8°F). Water has a very high specific heat, which means it takes a lot of energy to change the temperature of water. Let's compare a puddle and asphalt, for example. If you are walking barefoot on a sunny day, which would you rather walk across, the shallow puddle or an asphalt parking lot? Because of its high specific heat, the water stays cooler than the asphalt, even though it receives the same amount of solar radiation.

What could cause such a spectacular, swirling funnel of air?

For many people, this sight is unfamiliar. It is a tornado. Tornadoes happen when heat is rapidly transferred between layers in the atmosphere.

Heat Transfer in the Atmosphere

Heat moves in the atmosphere the same way it moves through the solid Earth or another medium. What follows is a review of the way heat flows, but applied to the atmosphere.

Radiation is the transfer of energy between two objects by electromagnetic waves. Heat radiates from the ground into the lower atmosphere.

In **conduction**, heat moves from areas of more heat to areas of less heat by direct contact. Warmer molecules vibrate rapidly and collide with other nearby molecules, transferring their energy. In the atmosphere, conduction is more effective at lower altitudes, where air density is higher. This transfers heat upward to where the molecules are spread further apart or transfers heat laterally from a warmer to a cooler spot, where the molecules are moving less vigorously.

Heat transfer by movement of heated materials is called **convection**. Heat that radiates from the ground initiates convection cells in the atmosphere (Figure 180).

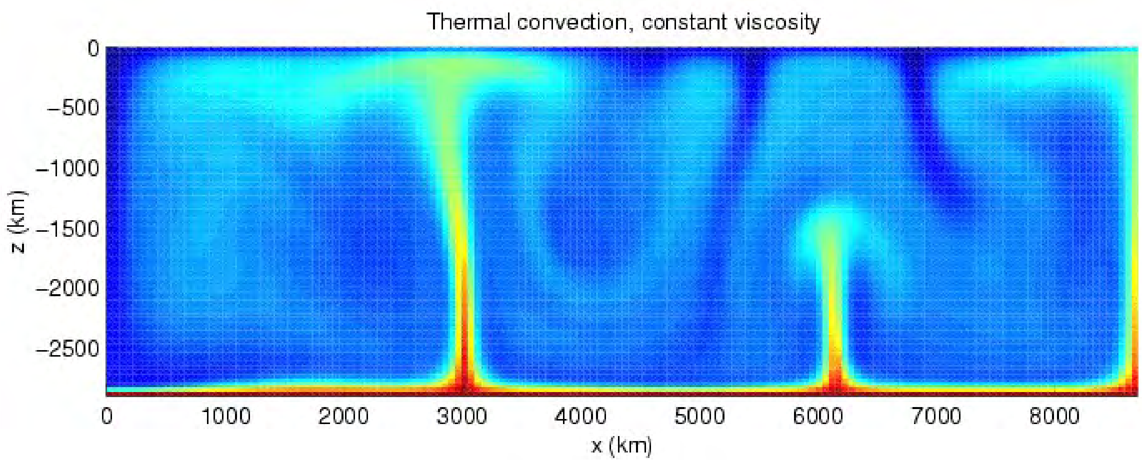


Figure 180: Thermal convection where the heat source is at the bottom and there *is* a ceiling at the top.

What Drives Atmospheric Circulation?

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

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

Heat at Earth's Surface

About half of the solar radiation that strikes the top of the atmosphere is filtered out before it reaches the ground. This energy can be absorbed by atmospheric gases, reflected by clouds, or scattered. Scattering occurs when a light wave strikes a particle and bounces off in some other direction.

About 3% of the energy that strikes the ground is reflected back into the atmosphere. The rest is absorbed by rocks, soil, and water and then radiated back into the air as heat. These infrared wavelengths can only be seen by infrared sensors.

The basics of Earth's annual heat budget are described in this video **(4b)**:

- **http://www.youtube.com/watch?v=mjj2i3hNQF0&feature=related** (5:40).

The Heat Budget

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

To say that the Earth's heat budget is balanced ignores an important point. The amount of incoming solar energy is different at different latitudes. Where do you think the most solar energy ends up and why? Where does the least solar energy end up and why? See Table 9**.**

Table 9: The Amount of Incoming Solar Energy				
	Day Length	**Sun Angle**	**Solar Radiation**	**Albedo**
Equatorial Region	Nearly the same all year	High	High	Low
Polar Regions	Night 6 months	Low	Low	High

Note: Colder temperatures mean more ice and snow cover the ground, making albedo relatively high.

This animation shows the average surface temperature across the planet as it changes through the year: Monthly Mean Temperatures:

- **http://upload.wikimedia.org/wikipedia/commons/b/b3/MonthlyMeanT.gif**

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

Why do we say Earth's temperature is moderate?

It may not look like it, but various processes work to moderate Earth's temperature across the latitudes. Atmospheric circulation brings warm equatorial air poleward and frigid polar air toward the equator. If the planet had an atmosphere that was stagnant, the difference in temperature between the two regions would be much greater.

Air Pressure Zones

Within the troposphere are convection cells (Figure 181). Air heated at the ground rises, creating a **low pressure zone**. Air from the surrounding area is sucked into the space left by the rising air. Air flows horizontally at top of the troposphere; horizontal flow is called **advection**. The air cools until it descends. When the air reaches the ground, it creates a **high pressure zone**. Air flowing from areas of high pressure to low pressure creates winds. The greater the pressure difference between the pressure zones, the faster the wind blows.

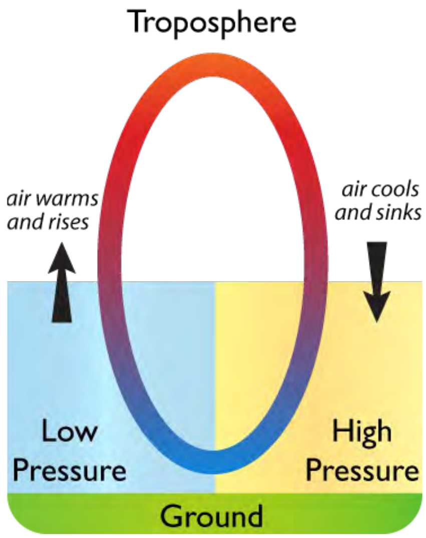


Figure 181: Warm air rises, creating a low pressure zone; cool air sinks, creating a high pressure zone.

Warm air can hold more moisture than cool air. When warm air rises and cools in a low pressure zone, it may not be able to hold all the water it contains as vapor. Some water vapor may condense to form clouds or precipitation. When cool air descends, it warms. Since it can then hold more moisture, the descending air will evaporate water on the ground.

Wind

Air moving between large high and low pressure systems at the bases of the three major convection cells creates the global wind belts. These planet-wide air circulation systems profoundly affect regional climate. Smaller pressure systems create localized winds that affect the weather and climate of a local area.

An online guide to air pressure and winds from the University of Illinois is found here:

- **http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/fw/home.rxml**.

Atmospheric Circulation

Two Convection Cells

Because more solar energy hits the equator, the air warms and forms a low pressure zone. At the top of the troposphere, half moves toward the North Pole and half toward the South Pole. As it moves along the top of the troposphere it cools. The cool air is dense, and when it reaches a high pressure zone it sinks to the ground. The air is sucked back toward the low pressure at the equator. This describes the convection cells north and south of the equator.

Plus Coriolis Effect

If the Earth did not rotate, there would be one convection cell in the northern hemisphere and one in the southern with the rising air at the equator and the sinking air at each pole. But because the planet does rotate, the situation is more complicated. The planet's rotation means that the Coriolis effect must be taken into account.

Let's look at atmospheric circulation in the Northern Hemisphere as a result of the Coriolis effect (Figure 182).

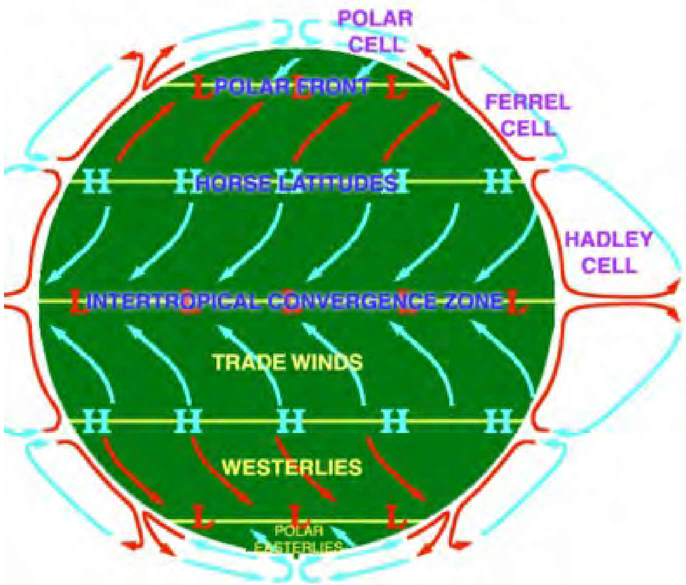


Figure 182: The atmospheric circulation cells, showing direction of winds at Earth's surface.

Air rises at the equator, but as it moves toward the pole at the top of the troposphere, it deflects to the right. (Remember that it just appears to deflect to the right because the ground beneath it moves.) At about 30°N latitude, the air from the equator meets air flowing toward the equator from the higher latitudes. This air is cool because it has come from higher latitudes. Both batches of air descend, creating a high pressure zone. Once on the ground, the air returns to the equator. This convection cell is called the Hadley Cell and is found between 0° and 30°N.

Equals Three Convection Cells

There are two more convection cells in the Northern Hemisphere. The Ferrell cell is between 30°N and 50° to 60°N. This cell shares its southern, descending side with the Hadley cell to its south. Its northern rising limb is shared with the Polar cell located between 50°N to 60°N and the North Pole, where cold air descends.

Plus Three in the Southern Hemisphere

There are three mirror image circulation cells in the Southern Hemisphere. In that hemisphere, the Coriolis effect makes objects appear to deflect to the left. The total number of atmospheric circulation cells around the globe is six.

Coriolis Effect

The **Coriolis effect** describes how Earth's rotation steers winds and surface ocean currents (Figure 183). Coriolis causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve. That's why it is incorrect to call Coriolis a force. It is not forcing anything to happen!

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

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

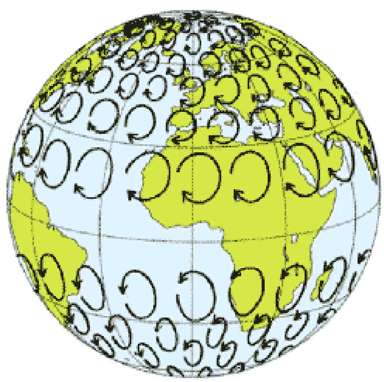


Figure 183: The Coriolis effect causes winds and currents to form circular patterns. The direction that they spin depends on the hemisphere that they are in.

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

The Greenhouse Effect

The exception to Earth's temperature being in balance is caused by greenhouse gases. But first the role of greenhouse gases in the atmosphere must be explained.

Greenhouse gases warm the atmosphere by trapping heat. Some of the heat that radiates out from the ground is trapped by greenhouse gases in the troposphere. Like a blanket on a sleeping person, greenhouse gases act as insulation for the planet. The warming of the atmosphere because of **insulation** by greenhouse gases is called the **greenhouse effect** (Figure 184). Greenhouse gases are the component of the atmosphere that moderate Earth's temperatures.

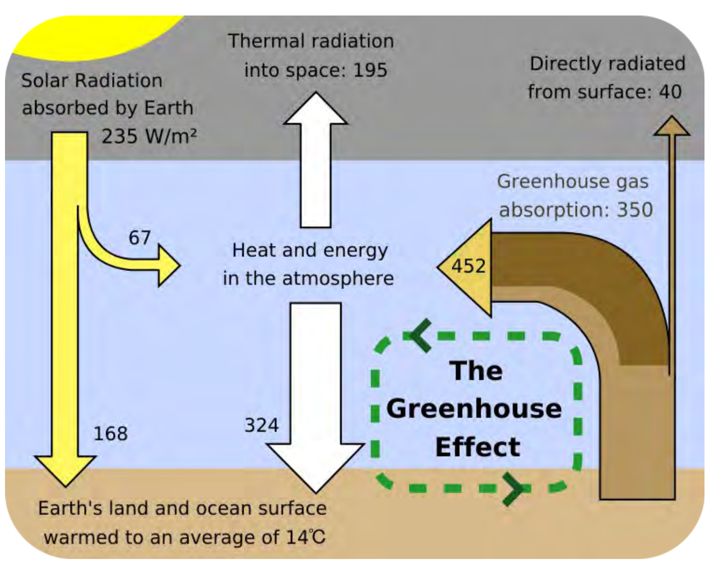


Figure 184: The Earth's heat budget shows the amount of energy coming into and going out of the Earth's system and the importance of the greenhouse effect. The numbers are the amount of energy that is found in one square meter of that location.

Greenhouse Gases

Greenhouse gases include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. Table 10 shows how each greenhouse gas naturally enters the atmosphere.

Table 10: Greenhouse Gas Entering the Atmosphere

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

Different greenhouse gases have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human Activity and Greenhouse Gas Levels

Human activity has significantly raised the levels of many of greenhouse gases in the atmosphere. Methane levels are about 2 1/2 times higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed.

What do you think happens as atmospheric greenhouse gas levels increase? More greenhouse gases trap more heat and warm the atmosphere. The increase or decrease of greenhouse gases in the atmosphere affect climate and weather the world over.

This PowerPoint review, *Atmospheric Energy and Global Temperatures*, looks at the movement of energy through the atmosphere **(6a)**: **http://www.youtube.com/watch?v=p6xMF_FFUU0** (8:17).

Practice and Review

1. What gases are used and expelled by photosynthesis and respiration?

2. Where is the largest concentration of ozone and what value does it have?

3. How does the atmosphere keep Earth's temperature moderate?

4. What are the two major atmospheric gases and what roles do they play?

5. What are the important greenhouse gases?

6. What is humidity?

7. How does evaporative cooling work? Why do you think it is only effective in hot, dry areas?

8. What happens to the temperature of a substance as it changes state from liquid to solid? What happens to its latent heat?

9. As a substance changes state from liquid to solid, what happens to the molecules that make it up?

10. What is moving in conduction? What is moving in convection?

11. The poles experience 24 hours of daylight in their summer. Why do poles receive less solar radiation than the equator?

12. What drives atmospheric circulation?

13. If the Sun suddenly started to emit more energy, what would happen to Earth's heat budget and the planet's temperature?

14. If more greenhouse gases were added to the atmosphere, what would happen to Earth's heat budget and the planet's temperature?

15. What happens to sunlight that strikes the ground?

16. Diagram and label the parts of a convection cell in the troposphere.

17. How many major atmospheric convection cells would there be without Coriolis effect? Where would they be?

18. How does Coriolis effect change atmospheric convection?

19. If an airplane flies from east to west in the Northern Hemisphere without changing latitude at all, in which direction will it appear to curve?

20. If an airplane flies from south to north in the Southern Hemisphere, in which direction will it appear to curve?

21. If freely moving objects are only appearing to curve their paths, why is this important?

22. If you were trying to keep down global temperature and you had a choice between adding 100 methane molecules or 1 CFC-12 molecule to the atmosphere, which would you choose?

23. What is the greenhouse effect?

24. How does Earth's atmosphere resemble a greenhouse?

Weather

What is Weather?

All **weather** takes place in the atmosphere, virtually all of it in the lower atmosphere. Weather describes what the atmosphere is like at a specific time and place. A location's weather depends on:

- air temperature
- air pressure
- fog
- humidity
- cloud cover
- precipitation
- wind speed and direction

All of these characteristics are directly related to the amount of energy that is in the system and where that energy is. Like the water cycle, the ultimate source of this energy is the Sun.

Weather is the change we experience from day to day. Weather can change rapidly.

What Causes Weather?

Weather occurs because of unequal heating of the atmosphere. The source of heat is the sun. The general principles behind weather can be stated simply:

- The sun heats Earth's surface more in some places than in others.
- Where it is warm, heat from the sun warms the air close to the surface. If there is water at the surface, it may cause some of the water to evaporate.
- Warm air is less dense, so it rises. When this happens, more dense air flows in to take its place. The flowing surface air is wind.
- The rising air cools as it goes higher in the atmosphere. If it is moist, the water vapor may condense. Clouds may form, and precipitation may fall.

What is Climate?

Although almost anything can happen with the weather, **climate** is more predictable. The weather on a particular winter day in San Diego may be colder than on the same day in Lake Tahoe, but, on average, Tahoe's winter climate is significantly colder than San Diego's (Figure 185).

Figure 185: Winter weather at Lake Tahoe doesn't much resemble winter weather in San Diego even though they're both in California.

Climate is the long-term average of weather in a particular spot. Good climate is why we choose to vacation in Hawaii in February, even though the weather is not guaranteed to be good! A location's climate can be described by its air temperature, humidity, wind speed and direction, and the type, quantity, and frequency of precipitation.

The climate for a particular place is steady, and changes only very slowly. Climate is determined by many factors, including the angle of the Sun, the likelihood of cloud cover, and the air pressure. All of these factors are related to the amount of energy that is found in that location over time.

The climate of a region depends on its position relative to many things. These factors are described in the next sections.

Precipitation

Precipitation (Figure 186) is an extremely important part of weather. Water vapor condenses and usually falls to create precipitation.

Dew and Frost

Some precipitation forms in place. **Dew** forms when moist air cools below its dew point on a cold surface. **Frost** is dew that forms when the air temperature is below freezing.

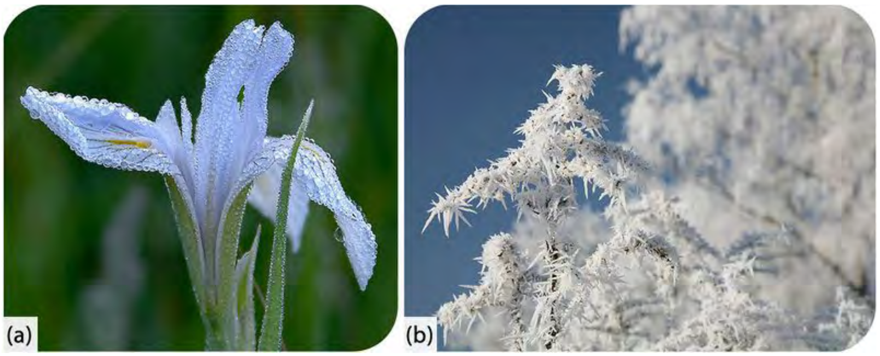


Figure 186: (a) Dew on a flower. (b) Hoar frost.

Precipitation From Clouds

The most common precipitation comes from clouds. **Rain** or snow droplets grow as they ride air currents in a cloud and collect other droplets (Figure 187). They fall when they become heavy enough to escape from the rising air currents that hold them up in the cloud. One million cloud droplets will combine to make only one rain drop! If temperatures are cold, the droplet will hit the ground as **snow**.

Figure 187: (a) Rain falls from clouds when the temperature is fairly warm. (b) Snow storm in Boston, Massachusetts.

Other less common types of precipitation are **sleet** (Figure 188). Sleet is rain that becomes ice as it hits a layer of freezing air near the ground. If a frigid raindrop freezes on the frigid ground, it forms **glaze**. **Hail** forms in cumulonimbus clouds with strong updrafts. An ice particle travels until it finally becomes too heavy and it drops.

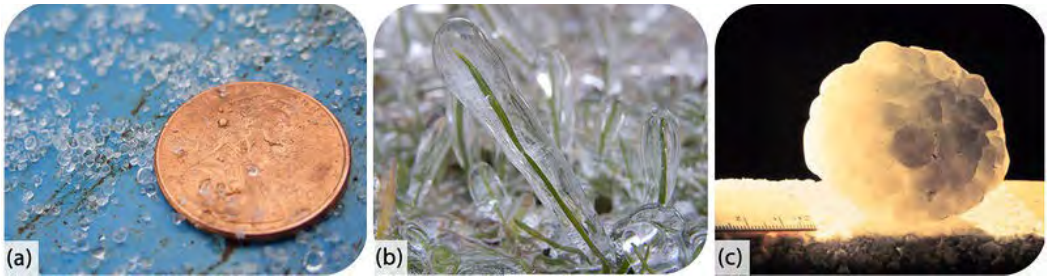


Figure 188: (a)Sleet. (b) Glaze. (c) Hail. This large hail stone is about 6 cm (2.5 inches) in diameter.

An online guide from the University of Illinois to different types of precipitation is seen here:

- **http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/cld/prcp/home.rxml**.

Would you rather spend a summer day in Phoenix or in Atlanta?

People who live in Phoenix, Arizona are told that summer isn't so bad because "it's a dry heat." What does that mean? Imagine that both Phoenix and Atlanta have a temperature of 90°F. In Phoenix, the relative humidity is 20%. In Atlanta, the relative humidity is 90%. So in Phoenix it feels like it's 90°. But in Atlanta it feels like it's 122! Of course in Phoenix in July, the average high temperature is 106°. That's hot, dry or not!

Humidity

Humidity is the amount of water vapor in the air. High humidity increases the chances of clouds and precipitation.

Relative Humidity

Humidity usually refers to **relative humidity**. This is the percent of water vapor in the air relative to the total amount the air can hold. How much water vapor can the air hold? That depends on temperature. Warm air can hold more water vapor than cool air (Figure 189).

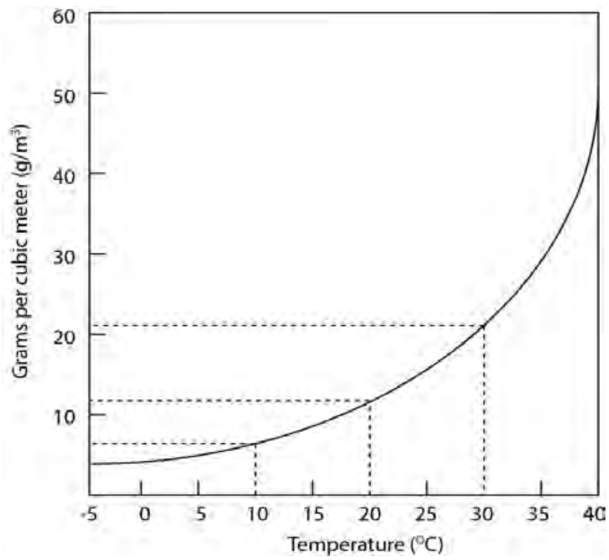


Figure 189: How much water vapor can the air hold when its temperature is 40° C?

Humidity and Heat

People often say, "It's not the heat but the humidity." Humidity can make a hot day feel even hotter. When sweat evaporates, it cools your body. But sweat can't evaporate when the air already contains as much water vapor as it can hold. The heat index (Figure 190) is a measure of what the temperature feels like because of the humidity.

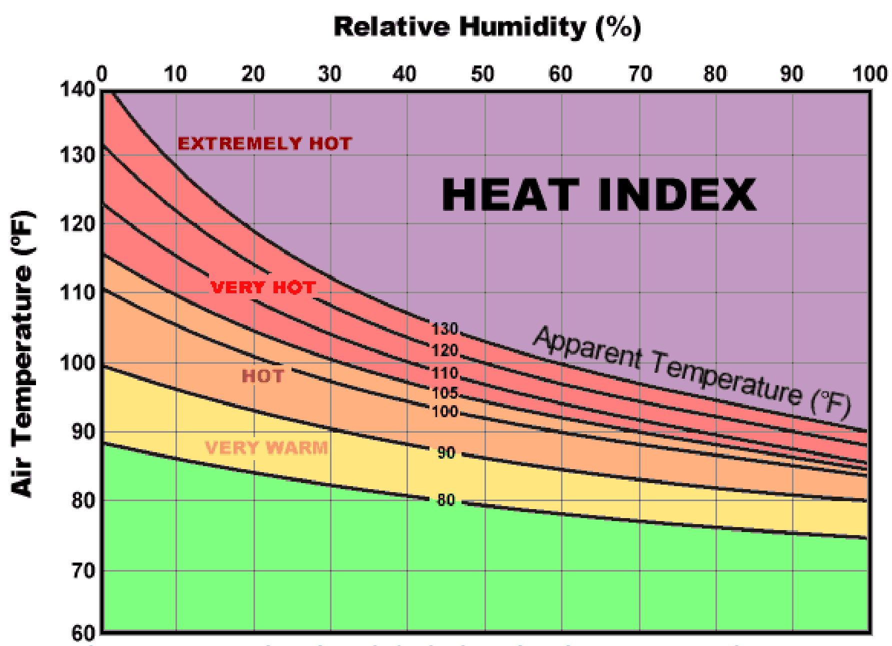


Figure 190: How hot does it feel when the air temperature is 90°F? It depends on the humidity.

Dew Point

You've probably noticed dew on the grass on a summer morning. Why does dew form?

Remember that the land heats up and cools down fairly readily. So when night comes, the land cools. Air that was warm and humid in the daytime also cools over night. As the air cools, it can hold less water vapor. Some of the water vapor condenses on the cool surfaces, such as blades of grass. The temperature at which water vapor condenses is called the **dew point**. If this temperature is below freezing, ice crystals of frost form instead of dew. As you can see below, the dew point occurs at 100 percent relative humidity (Figure 191). Can you explain why?

Figure 191: The grass on the left is covered with dew. The grass on the right is covered with frost. The difference is the temperature of the grass.

Fronts

Two air masses meet at a **front**. At a front, the two air masses have different densities and do not easily mix. One air mass is lifted above the other, creating a low pressure zone. If the lifted air is moist, there will be condensation and precipitation. Winds are common at a front. The greater the temperature difference between the two air masses, the stronger the winds will be. Fronts are the main cause of stormy weather.

There are four types of fronts, three moving and one stationary. With cold fronts and warm fronts, the air mass at the leading edge of the front gives the front its name. In other words, a cold front is right at the leading edge of moving cold air and a warm front marks the leading edge of moving warm air.

Stationary Front

At a **stationary front** the air masses do not move (Figure 192). A front may become stationary if an air mass is stopped by a barrier, such as a mountain range. A stationary front may bring days of rain, drizzle, and fog. Winds usually blow parallel to the front, but in opposite directions. After several days, the front will likely break apart.

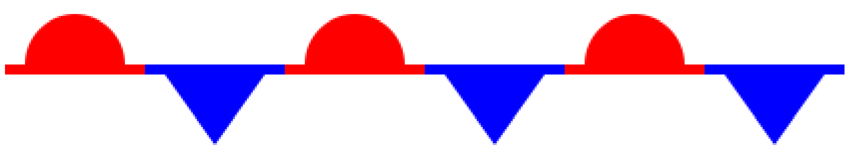


Figure 192: The map symbol for a stationary front has red domes for the warm air mass and blue triangles for the cold air mass.

Cold Fronts

When a cold air mass takes the place of a warm air mass, there is a **cold front** (Figure 193).

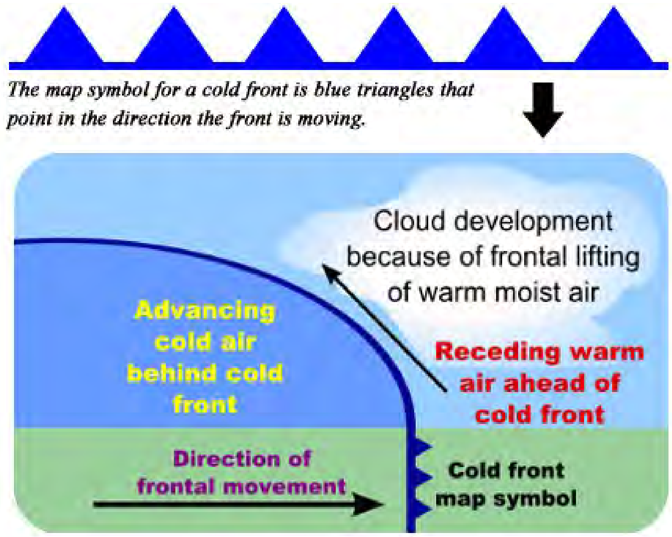


Figure 193: The cold air mass is dense, so it slides beneath the warm air mass and pushes it up.

Figure 194: A squall line.

Imagine that you are standing in one spot as a cold front approaches. Along the cold front, the denser, cold air pushes up the warm air, causing the air pressure to decrease (Figure 193). If the humidity is high enough, some types of cumulus clouds will grow. High in the atmosphere, winds blow ice crystals from the tops of these clouds to create cirrostratus and cirrus clouds. At the front, there will be a line of rain showers, snow showers, or thunderstorms with blustery winds (Figure 194). 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

At a **warm front**, a warm air mass slides over a cold air mass (Figure 195). When warm, less dense air moves over the colder, denser air, the atmosphere is relatively stable.

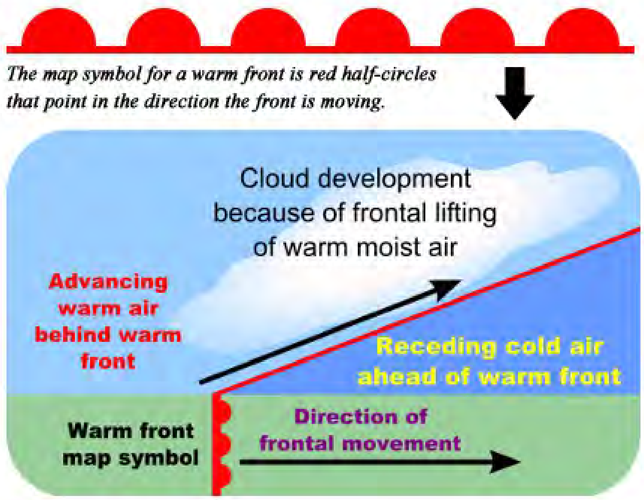


Figure 195: Warm air moves forward to take over the position of colder air.

Imagine that you are on the ground in the wintertime under a cold winter air mass with a warm front approaching. The transition from cold air to warm air takes place over a long distance, so the first signs of changing weather appear long before the front is actually over you. Initially, the air is cold: the cold air mass is above you and the warm air mass is above it. High cirrus clouds mark the transition from one air mass to the other.

Over time, cirrus clouds become thicker and cirrostratus clouds form. As the front approaches, altocumulus and altostratus clouds appear and the sky turns gray. Since it is winter, snowflakes fall. The clouds thicken and nimbostratus clouds form. Snowfall increases. Winds grow stronger as the low pressure approaches. As the front gets closer, the cold air mass is just above you but the warm air mass is not too far above that. The weather worsens. As the warm air mass approaches, temperatures rise and snow turns to sleet and freezing rain. Warm and cold air mix at the front, leading to the formation of stratus clouds and fog (Figure 196).

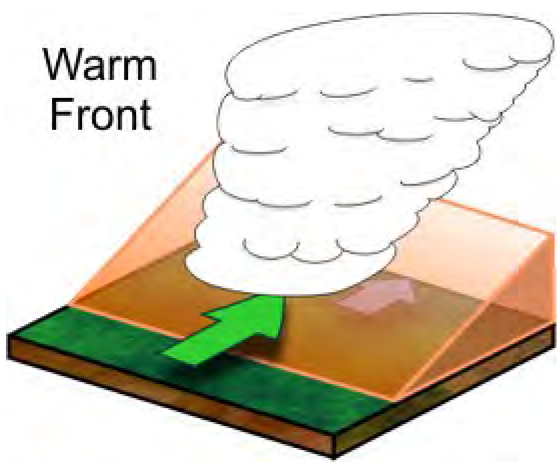


Figure 196: Cumulus clouds build at a warm front.

Occluded Front

An **occluded front** usually forms around a low pressure system (Figure 197). The occlusion starts when a cold front catches up to a warm front. The air masses, in order from front to back, are cold, warm, and then cold again.

Figure 197: The map symbol for an occluded front is mixed cold front triangles and warm front domes.

Coriolis effect curves the boundary where the two fronts meet towards the pole. If the air mass that arrives third is colder than either of the first two air masses, that air mass slip beneath them both. This is called a cold occlusion. If the air mass that arrives third is warm, that air mass rides over the other air mass. This is called a warm occlusion (Figure 198).

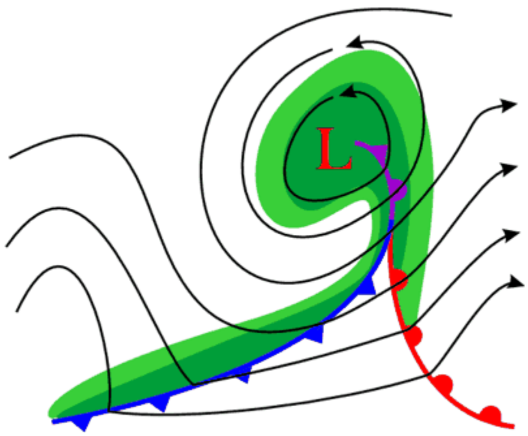


Figure 198: An occluded front with the air masses from front to rear in order as cold, warm, cold.

The weather at an occluded front is especially fierce right at the occlusion. Precipitation and shifting winds are typical. The Pacific Coast has frequent occluded fronts.

Thunderstorms

Thunderstorms are extremely common. Worldwide there are 14 million per year — that's 40,000 per day! Most drop a lot of rain on a small area quickly, but some are severe and highly damaging.

Thunderstorm Formation

Thunderstorms form when ground temperatures are high, ordinarily in the late afternoon or early evening in spring and summer. The two figures below show two stages of thunderstorm buildup (Figure 199**).**

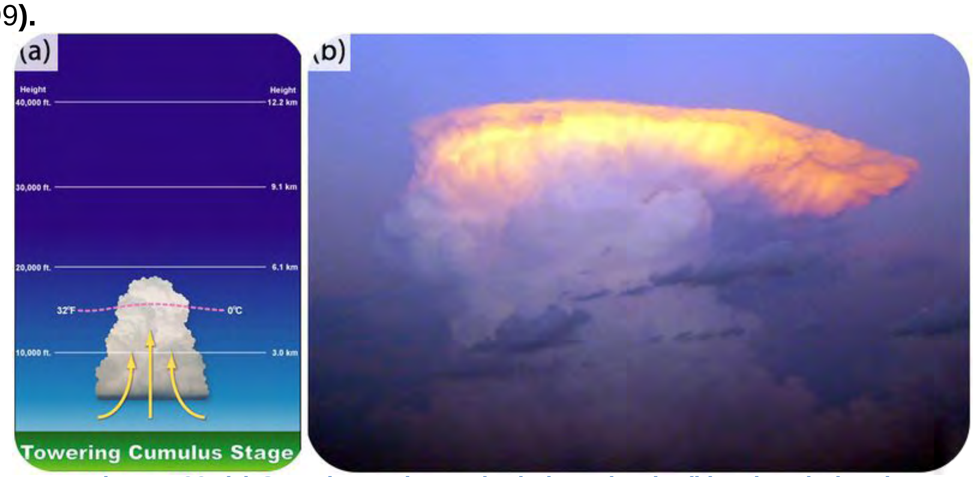


Figure 199: (a) Cumulus and cumulonimbus clouds. (b) A thunderhead.

Growth

As temperatures increase, warm, moist air rises. These updrafts first form cumulus and then cumulonimbus clouds. Winds at the top of the stratosphere blow the cloud top sideways to make the anvil shape that characterizes a cloud as a thunderhead. As water vapor condenses to form a cloud, the latent heat makes the air in the cloud warmer than the air outside the cloud. Water droplets and ice fly up through the cloud in updrafts. When these droplets get heavy enough, they fall.

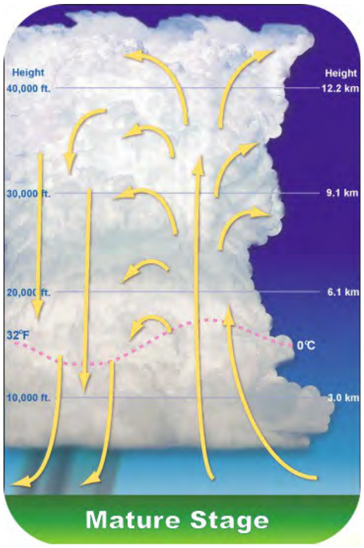


Figure 200: A mature thunderstorm with updrafts and downdrafts that reach the ground.

This starts a downdraft, and soon there is a convection cell within the cloud. The cloud grows into a cumulonimbus giant. Eventually, the drops become large enough to fall to the ground. At this time, the thunderstorm is mature, and it produces gusty winds, lightning, heavy precipitation, and hail (Figure 200).

The End

The downdrafts cool the air at the base of the cloud, so the air is no longer warm enough to rise. As a result, convection shuts down. Without convection, water vapor does not condense, no latent heat is released, and the thunderhead runs out of energy. A thunderstorm usually ends only 15 to 30 minutes after it begins, but other thunderstorms may start in the same area.

Severe Thunderstorms

With severe thunderstorms, the downdrafts are so intense that when they hit the ground, warm air from the ground is sent upward into the storm. The warm air gives the convection cells more energy. Rain and hail grow huge before gravity pulls them to Earth. Severe thunderstorms can last for hours and can cause a lot of damage because of high winds, flooding, intense hail, and tornadoes.

Squall Lines

Thunderstorms can form individually or in squall lines along a cold front. In the United States, squall lines form in spring and early summer in the Midwest, where the maritime tropical (mT) air mass from the Gulf of Mexico meets the continental polar (cP) air mass from Canada (Figure 201).

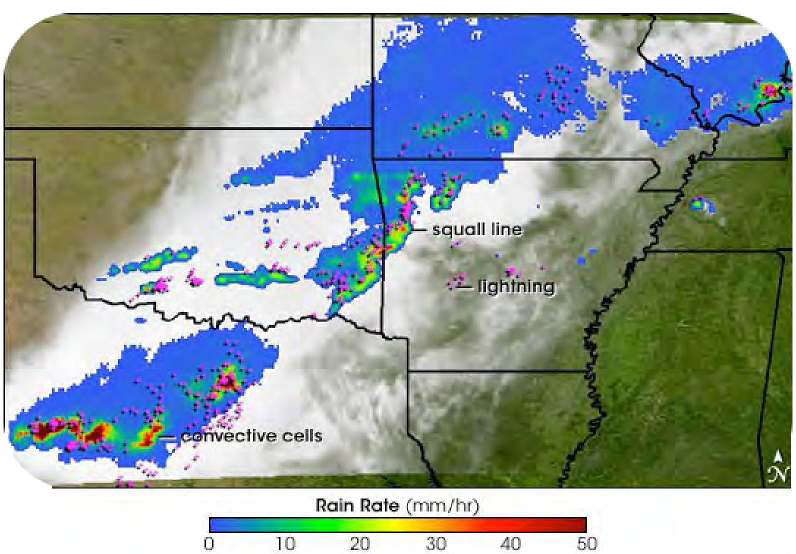


Figure 201: Cold air from the Rockies collided with warm, moist air from the Gulf of Mexico to form this squall line.

Lightning and Thunder

So much energy collects in cumulonimbus clouds that a huge release of electricity, called **lightning**, may result (Figure 202). 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.

Figure 202: Lightning over Pentagon City in Arlington, Virginia.

Damage

Thunderstorms kill approximately 200 people in the United States and injure about 550 Americans per year, mostly from lightning strikes. Have you heard the common misconception that lightning doesn't strike the same place twice? In fact, lightning strikes the New York City's Empire State Building about 100 times per year (Figure 203).

Figure 203: Lightning strikes some places many times a year, such as the Eiffel Tower in Paris.

An online guide to severe storms from the University of Illinois is found here:

- **http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/svr/home.rxml**.

Tornadoes

Tornadoes, also called twisters, are fierce products of severe thunderstorms (Figure 204). As air in a thunderstorm rises, the surrounding air races in to fill the gap. This forms a tornado, a funnel-shaped, whirling column of air extending downward from a cumulonimbus cloud.

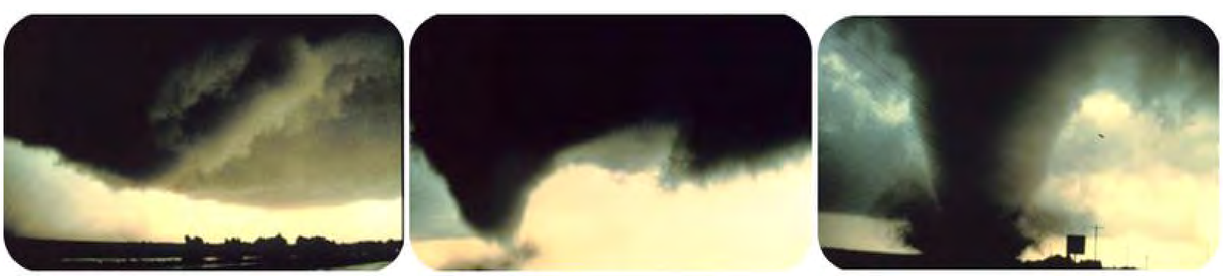


Figure 204: The formation of this tornado outside Dimmit, Texas, in 1995 was well studied.

A tornado lasts from a few seconds to several hours. The average wind speed is about 177 kph (110 mph), but some winds are much faster. A tornado travels over the ground at about 45 km per hour (28 miles per hour) and goes about 25 km (16 miles) before losing energy and disappearing (Figure 205).

Figure 205: This tornado struck Seymour, Texas, in 1979.

Damage

An individual tornado strikes a small area, but it can destroy everything in its path. Most injuries and deaths from tornadoes are caused by flying debris (Figure 206). In the United States an average of 90 people are killed by tornadoes each year. The most violent two percent of tornadoes account for 70% of the deaths by tornadoes.

Figure 206: Tornado damage at Ringgold, Georgia in April 2011.

Location

Tornadoes form at the front of severe thunderstorms. Lines of these thunderstorms form in the spring where where maritime tropical (mT) and continental polar (cP) air masses meet. Although there is an average of 770 tornadoes annually, the number of tornadoes each year varies greatly (Figure 207).

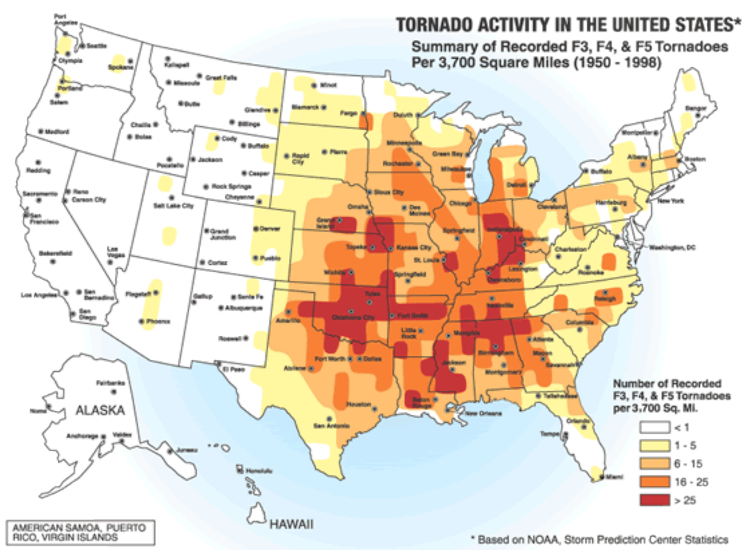


Figure 207: The frequency of F3, F4, and F5 tornadoes in the United States. The red region that starts in Texas and covers Oklahoma, Nebraska, and South Dakota is called Tornado Alley because it is where most of the violent tornadoes occur.

April 2011

In late April 2011, severe thunderstorms pictured in the satellite image spawned the deadliest set of tornadoes in more than 25 years. In addition to the meeting of cP and mT mentioned above, the jet stream was blowing strongly in from the west. The result was more than 150 tornadoes reported throughout the day (Figure 208).

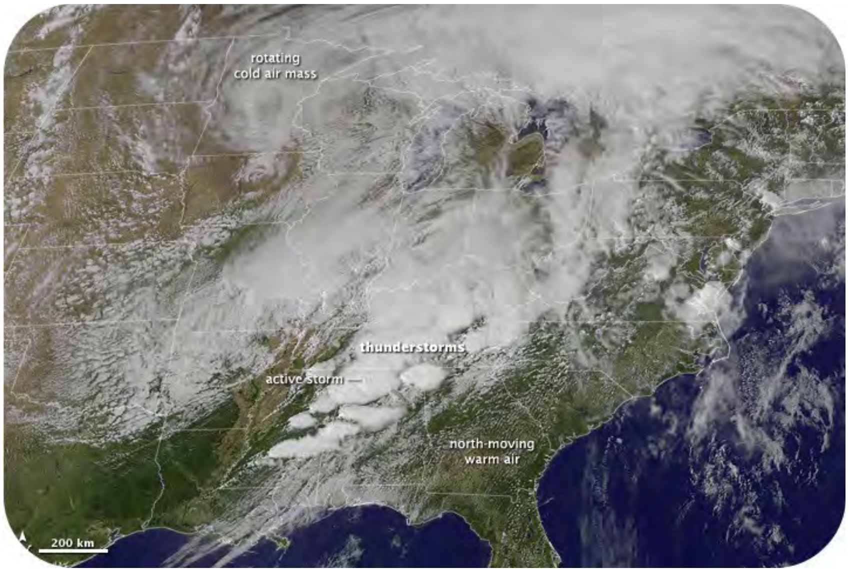


Figure 208: April 27-28, 2011. The cold air mass is shown by the mostly continuous clouds. Warm moist air blowing north from the Atlantic Ocean and Gulf of Mexico is indicated by small low clouds. Thunderstorms are indicated by bright white patches.

The entire region was alerted to the possibility of tornadoes in those late April days. But meteorologists can only predict tornado danger over a very wide region. No one can tell exactly where and when a tornado will touch down. Once a tornado is sighted on radar, its path is predicted and a warning is issued to people in that area. The exact path is unknown because tornado movement is not very predictable.

Tornado catchers capture footage inside a tornado on this National Geographic video:

- **http://ngm.nationalgeographic.com/ngm/0506/feature6/multimedia.html**.

Fujita Scale

The intensity of tornadoes is measured on the Fujita Scale (Table 11), which assigns a value based on wind speed and damage.

Table 11: The Fujita Scale (F Scale) of Tornado Intensity

F Scale	(km/hr)	(mph)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-33	158-206	Severe - houses torn apart, trees uprooted, cars lifted
F4	333-419	207-260	Devastating - houses leveled, cars thrown

F Scale	(km/hr)	(mph)	Damage
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

Table 11: The Fujita Scale (F Scale) of Tornado Intensity

Hurricanes

Hurricanes — called typhoons in the Pacific — are also cyclones. They are cyclones that form in the tropics and so they are also called tropical cyclones. By any name, they are the most damaging storms on Earth.

Formation

Hurricanes arise in the tropical latitudes (between 10° and 25°N) in summer and autumn when sea surface temperature are 28°C (82°F) or higher. The warm seas create a large humid air mass. The warm air rises and forms a low pressure cell, known as a **tropical depression**. Thunderstorms materialize around the tropical depression.

If the temperature reaches or exceeds 28°C (82°F), the air begins to rotate around the low pressure (counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere). As the air rises, water vapor condenses, releasing energy from latent heat. If wind shear is low, the storm builds into a hurricane within two to three days.

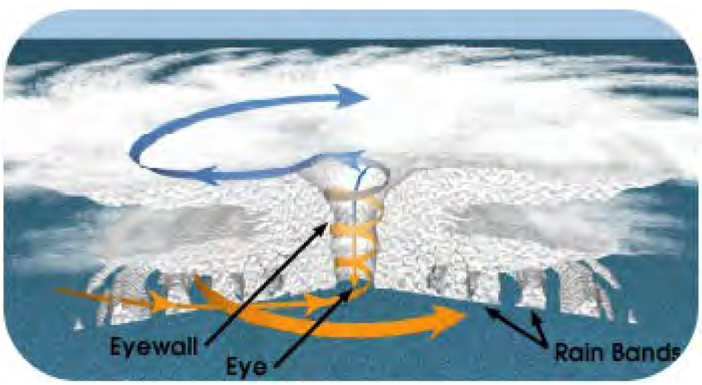


Figure 209: News about Hurricane Katrina from the New Orleans Times-Picayune: http://www.nola.com/katrina/graphics/flashflood.swf.

Hurricanes are huge and produce high winds. The exception is the relatively calm eye of the storm, where air is rising upward. Rainfall can be as high as 2.5 cm (1") per hour, resulting in about 20 billion metric tons of water released daily in a hurricane. The release of latent heat generates enormous amounts of energy, nearly the total annual electrical power consumption of the United States from one storm. Hurricanes can also generate tornadoes.

Hurricanes move with the prevailing winds. In the Northern Hemisphere, they originate in the trade winds and move to the west. When they reach the latitude of the westerlies, they switch direction and travel toward the north or northeast. Hurricanes may cover 800 km (500 miles) in one day.

Saffir-Simpson Scale

Hurricanes are assigned to categories based on their wind speed. The categories are listed on the Saffir-Simpson hurricane scale (Table 12).

Table 12: Saffir-Simpson Hurricane Scale			
Category	**Kph**	**Mph**	**Estimated Damage**
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage, considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failures

Damage
Damage from hurricanes comes from the high winds, rainfall, and storm surge. Storm surge occurs as the storm's low pressure center comes onto land, causing the sea level to rise unusually high. A storm surge is often made worse by the hurricane's high winds blowing seawater across the ocean onto the shoreline. Flooding can be devastating, especially along low-lying coastlines such as the Atlantic and Gulf Coasts. Hurricane Camille in 1969 had a 7.3 m (24 foot) storm surge that traveled 125 miles (200 km) inland.

The End
Hurricanes typically last for 5 to 10 days. The winds push them to the northwest and then to the northeast. Eventually a hurricane will end up over cooler water or land. At that time the hurricane’s latent heat source shut downs and the storm weakens. When a hurricane disintegrates, it is replaced with intense rains and tornadoes.

There are about 100 hurricanes around the world each year, plus many smaller tropical storms and tropical depressions. As people develop coastal regions, property damage from storms continues to rise. However, scientists are becoming better at predicting the paths of these storms and fatalities are decreasing. There is, however, one major exception to the previous statement: Hurricane Katrina.

Hurricane Katrina
The 2005 Atlantic hurricane season was the longest, costliest, and deadliest hurricane season so far. Total damage from all the storms together was estimated at more than $128 billion, with more than 2,280 deaths. Hurricane Katrina was both the most destructive hurricane and the most costly (Figure 210).

Figure 210: Flooding in New Orleans after Hurricane Katrina caused the levees to break and water to pour through the city.

News about Hurricane Katrina from the New Orleans Times-Picayune:

- **http://www.nola.com/katrina/graphics/flashflood.swf**.

An animation of a radar image of Hurricane Katrina making landfall is seen here:

- **http://upload.wikimedia.org/wikipedia/commons/9/97/Hurricane_Katrina_LA_landfall_radar.gif**.

NASA's short video, "In Katrina's Wake":

- **http://www.youtube.com/watch?v=HZjqvqaLltI**.

Hurricanes are explored in a set of National Geographic videos found at National Geographic Video:

- **http://video.nationalgeographic.com/video/environment/environment-natural-disasters/hurricanes**.

At the above link, watch the following videos:

- "Hurricanes 101" is an introduction to the topic.
- "How Katrina Formed" looks at the history of Hurricane Katrina as it formed and passed through the Gulf coast.
- Follow that up with "Doomed New Orleans," which explores how the devastation to the city is a man-made disaster.
- "The Hurricane Ike of 1900" looks at what happened in the days when there was little warning before a hurricane hit a coastal city.

Lots of information about hurricanes is found in this online guide from the University of Illinois: **http://ww2010.atmos.uiuc.edu/%28Gh%29/guides/mtr/hurr/home.rxml**.

Practice and Review

1. When you're in a cold place in December and you're planning a vacation for February, are you interested in a location's weather or climate?
    a. If it's a summer day and you want to take a picnic are you concerned with weather or climate?
2. What factors account for a location's weather?
3. If climate is the long-term average of weather, how can climate change?
4. Describe how raindrops form.
5. Why does hail only come from cumulonimbus clouds?
6. How does sleet form?
7. What is humidity? What is relative humidity?
8. Explain what heat index is.
9. Why does water come out of the air at its dew point?
10. What characteristics give warm fronts and cold fronts their names?
11. How does Coriolis effect create an occluded front?
12. Describe the cloud sequence that goes along with a warm front.
13. Why are thunderstorms so common?

14. What is the energy source that feeds a thunderstorm?

15. What causes a thunderstorm to end?

16. What causes the tornadoes of Tornado Alley?

17. How does the Fujita scale resemble the scales for assessing earthquake intensity? Which does it most resemble?

18. What circumstances led to the intensity of tornado activity in April 2011?

19. What is the difference between a hurricane and a mid-latitude cyclone?

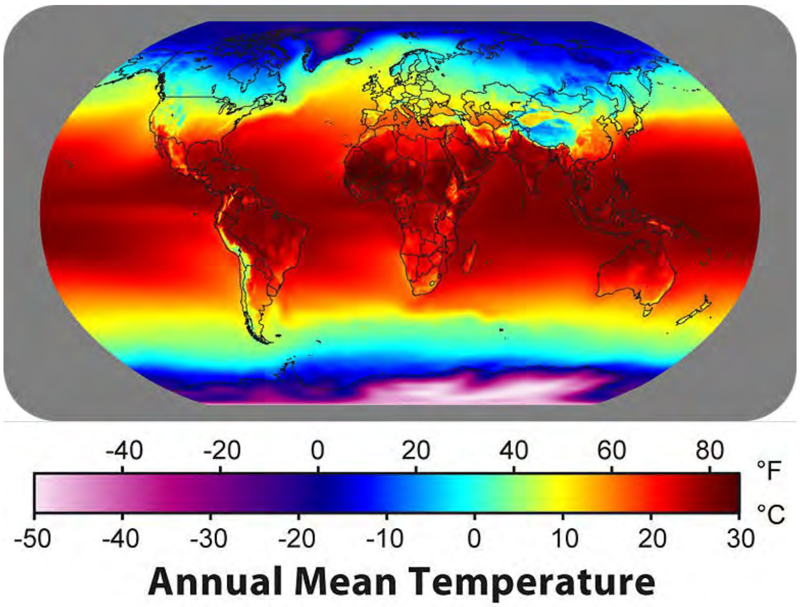
20. How does a hurricane form? Where does the storm get its energy?

21. Under what circumstances does a hurricane die?

Climate

Effects on Climate

Latitude
Many factors influence the climate of a region. The most important factor is latitude because different latitudes receive different amounts of solar radiation.



The equator receives the most solar radiation. Days are equally long year-round and the sun is just about directly overhead at midday.

The polar regions receive the least solar radiation. The night lasts six months during the winter. Even in summer, the sun never rises very high in the sky. Sunlight filters through a thick wedge of atmosphere, making the sunlight much less intense. The high albedo, because of ice and snow, reflects a good portion of the sun's light.

Temperature with Latitude
It's easy to see the difference in temperature at different latitudes on the map above. But temperature is not completely correlated with latitude. There are many exceptions. For example, notice that the western portion of South America has relatively low temperatures due to the Andes Mountains. The Rocky Mountains in the United States also have lower temperatures due to high altitudes. Western Europe is warmer than it should be due to the Gulf Stream.

Atmospheric Circulation Cells
The position of a region relative to the circulation cells and wind belts has a great affect on its climate. In an area where the air is mostly rising or sinking, there is not much wind.

The ITCZ
The **Intertropical Convergence Zone (ITCZ)** is the low pressure area near the equator in the boundary between the two Hadley Cells. The air rises so that it cools and condenses to create clouds and rain (Figure 211). Climate along the ITCZ is therefore warm and wet. Early mariners called this region the doldrums because their ships were often unable to sail due to the lack of steady winds.

Figure 211: The ITCZ can easily be seen where thunderstorms are lined up north of the equator.

The ITCZ migrates slightly with the season. Land areas heat more quickly than the oceans. Because there are more land areas in the Northern Hemisphere, the ITCZ is influenced by the heating effect of the land. In Northern Hemisphere summer, it is approximately 5° north of the equator, while in the winter it shifts back and is approximately at the equator. As the ITCZ shifts, the major wind belts also shift slightly north in summer and south in winter, which causes the wet and dry seasons in this area (Figure 212).

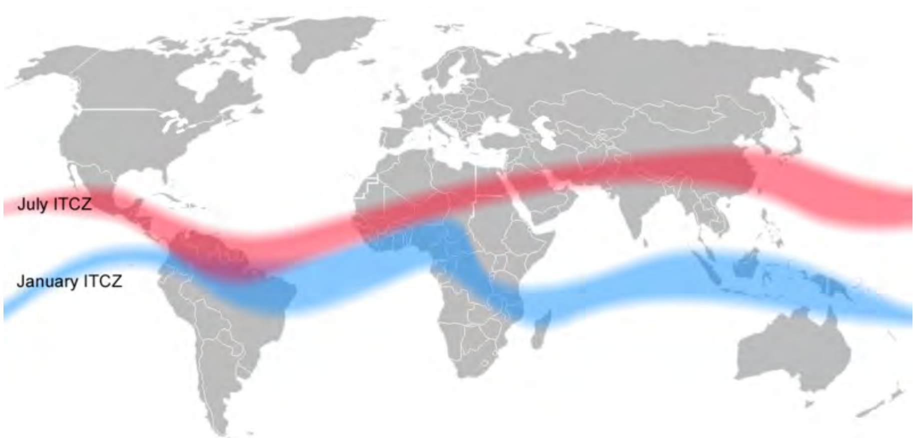


Figure 212: Seasonal differences in the location of the ITCZ are shown on this map.

Hadley Cell and Ferrell Cell Boundary

At about 30°N and 30°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.

Ferrell Cell and Polar Cell Boundary

The polar front is around 50° to 60°, where cold air from the poles meets warmer air from the tropics. The meeting of the two different air masses causes the polar jet stream, which is known for its stormy weather. As the Earth orbits the Sun, the shift in the angle of incoming sunlight causes the polar jet stream to move. Cities to the south of the polar jet stream will be under warmer, moister air than cities to its north. Directly beneath the jet stream, the weather is often stormy and there may be thunderstorms and tornadoes.

Prevailing Winds

The prevailing winds are the bases of the Hadley, Ferrell, and polar cells. These winds greatly influence the climate of a region because they bring the weather from the locations they come from. Local winds also influence local climate. For example, land breezes and sea breezes moderate coastal temperatures.

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°N latitude, within the westerly winds (Figure 213).

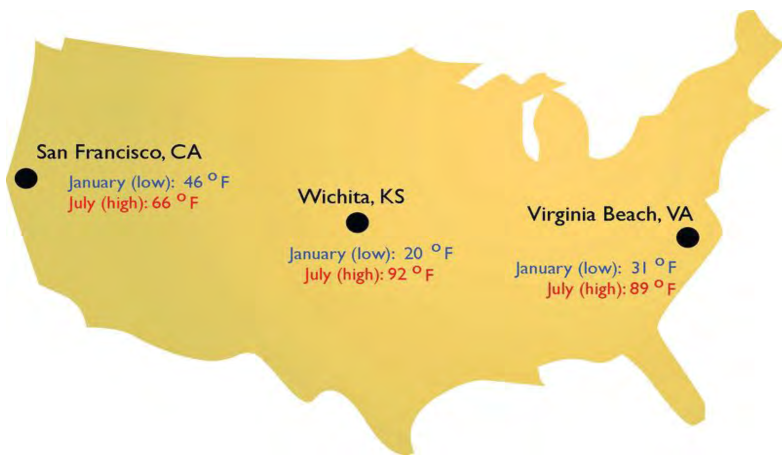


Figure 213: How does the ocean influence the climate of these three cities?

The climate of San Francisco is influenced by the cool California current and offshore upwelling. Wichita has a more extreme continental climate. Virginia Beach, though, is near the Atlantic Ocean. Why is the climate there less influenced by the ocean than is the climate in San Francisco? Hint: Think about the direction the winds are going at that latitude. The weather in San Francisco comes from over the Pacific Ocean while much of the weather in Virginia comes from the continent.

Ocean Currents

The temperature of the water offshore influences the temperature of a coastal location, particularly if the winds come off the sea. The cool waters of the California Current bring cooler temperatures to the California coastal region. Coastal upwelling also brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures. Further north, in southern Alaska, the upwelling actually raises the temperature of the surrounding land because the ocean water is much warmer than the land. The important effect of the Gulf Stream on the climate of northern Europe is described in "Concept Water on Earth."

Altitude and Mountain Ranges

Air pressure and air temperature decrease with altitude. The closer molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide. A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood's (5,640 feet) average annual temperature is 62^{o}F (17^{o}C), while Climax Lake's (11,300 feet) is 42^{o}F (5.4^{o}C).

Mountain ranges have two effects on the climate of the surrounding region:

- Rainshadow effect, which brings warm, dry climate to the leeward size of a mountain range (Figure 214).
- Separation in the coastal region from the rest of the continent. Since a maritime air mass may have trouble rising over a mountain range, the coastal area will have a maritime climate but the inland area on the leeward side will have a continental climate.

Figure 214: The Bonneville Salt Flats are part of the very dry Great Basin of the Sierra Nevada of California. The region receives little rainfall.

Five factors that Affect Climate takes a very thorough look at what creates the climate zones. The climate of a region allows certain plants to grow, creating an ecological biome **(5f, 6a, 6b)**:

- **http://www.youtube.com/watch?v=E7DLLxrrBV8** (5:23).

How important is climate in the history of life?

Dinosaurs lived a long time, geologically speaking, in part because the weather was favorable to them. Giant mammals lived during the ice ages because conditions were favorable. Earth's climate has been warmer and colder in Earth history, but mostly it's been warmer.

Climate Change in Earth History

Climate has changed throughout Earth history. Much of the time Earth's climate was hotter and more humid than it is today, but climate has also been colder, as when glaciers covered much more of the planet. The most recent ice ages were in the Pleistocene Epoch, between 1.8 million and 10,000 years ago **(Figure 215**). 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.

Figure 215: The maximum extent of Northern Hemisphere glaciers during the Pleistocene epoch.

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°C (10°F) less than Earth’s current average temperature. Temperatures during the interglacial periods were about 1.1°C (2.0°F) higher than today (Figure 216).

Since the end of the Pleistocene, the global average temperature has risen about 4°C (7°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

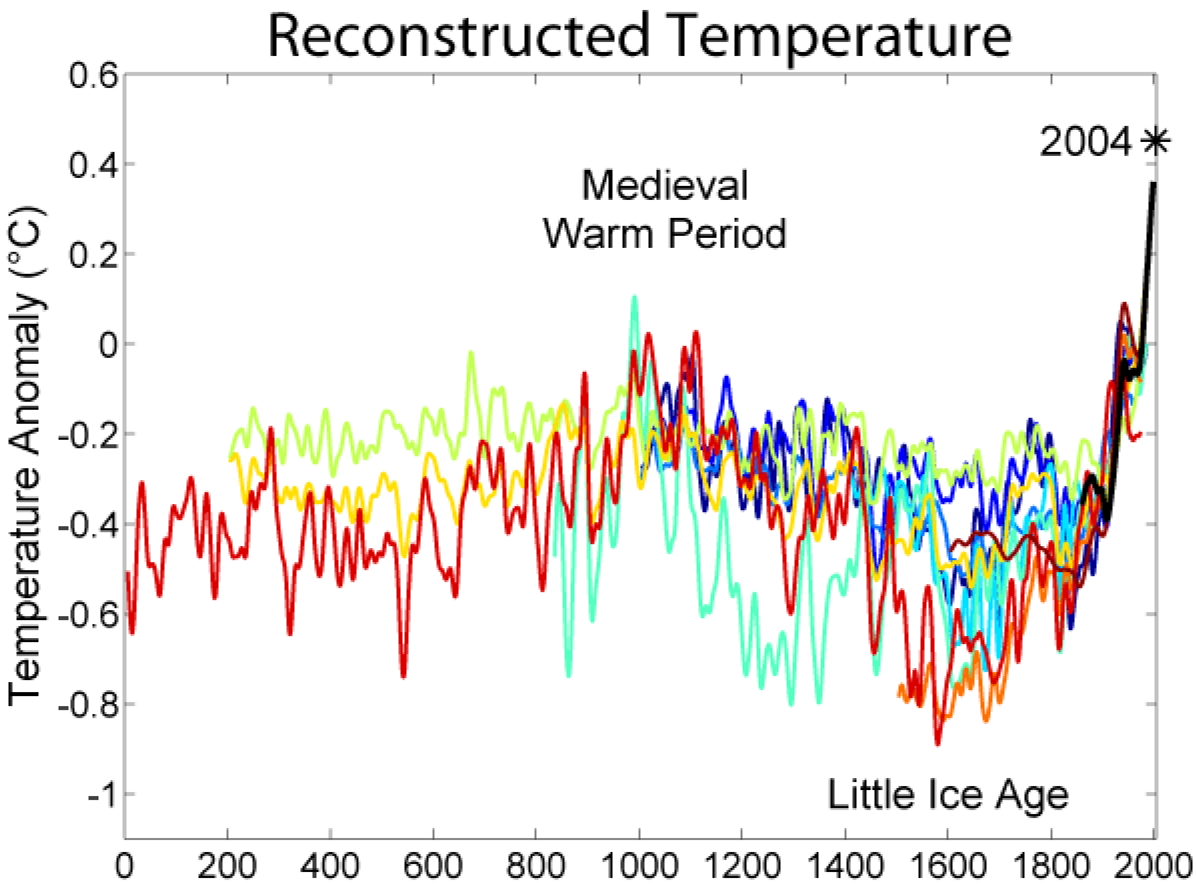


Figure 216: The graph is a compilation of 10 reconstructions (the colored lines) of mean temperature changes and one graph of instrumentally recorded data of mean temperature changes (black). This illustrates the high temperatures of the Medieval Warm Period, the lows of the Little Ice Age, and the very high (and climbing) temperature of this decade.

Carbon Cycle and Climate

Carbon is a very important element to living things. As the second most common element in the human body, we know that human life without carbon would not be possible. Protein, **carbohydrates**, and fats are all part of the body and all contain carbon. When your body breaks down food to produce energy, you break down protein, carbohydrates, and fat, and you breathe out carbon dioxide.

Carbon occurs in many forms on Earth. The element moves through organisms and then returns to the environment. When all this happens in balance, the ecosystem remains in balance too.

Short Term Cycling of Carbon

The short term cycling of carbon begins with carbon dioxide (CO_2) in the atmosphere.

Photosynthesis

Through photosynthesis, the inorganic carbon in carbon dioxide plus water and energy from sunlight is transformed into organic carbon (food) with oxygen given off as a waste product. The chemical equation for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6\ CO_2} + \underset{\text{water}}{6\ H_2O} + \text{Energy from sunlight} \rightarrow \underset{\text{glucose (sugar)}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\ O_2}$$

Figure 217: Equation for photosynthesis.

Respiration

Plants and animals engage in the reverse of photosynthesis, which is respiration. In respiration, animals use oxygen to convert the organic carbon in sugar into food energy they can use. Plants also go through respiration and consume some of the sugars they produce.

The chemical reaction for respiration is:

$C_6H_{12}O_6 + 6\ O_2$ $\quad$ $6\ CO_2 + 6\ H_2O$ + useable energy

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2; in respiration, O_2 is converted to CO_2.

Remember that plants do not create energy. They change the energy from sunlight into chemical energy that plants and animals can use as food (Figure 218).

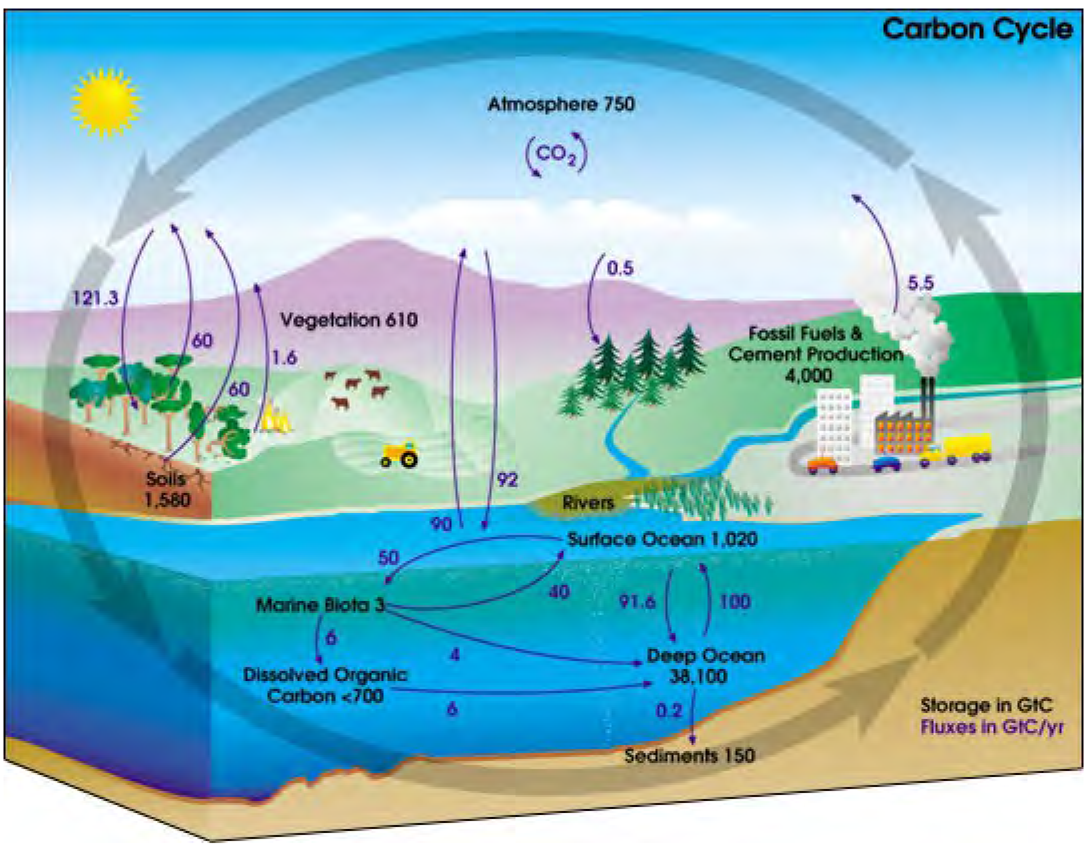


Figure 218: The carbon cycle shows where a carbon atom might be found. The black numbers indicate how much carbon is stored in various reservoirs, in billions of tons ("GtC" stands for gigatons of carbon). The purple numbers indicate how much carbon moves between reservoirs each year. The sediments, as defined in this diagram, do not include the ~70 million GtC of carbonate rock and kerogen.

Long-Term Carbon Cycling

Carbon Sinks and Carbon Sources

Places in the ecosystem that store carbon are reservoirs. Places that supply and remove carbon are **carbon sources** and **carbon sinks**, respectively. If more carbon is provided than stored, the place is a carbon source. If more carbon dioxide is absorbed than is emitted, the reservoir is a carbon sink. What are some examples of carbon sources and sinks?

- Carbon sinks are reservoirs where carbon is stored. Healthy living forests and the oceans act as carbon sinks.
- Carbon sources are reservoirs from which carbon can enter the environment. The mantle is a source of carbon from volcanic gases.

A reservoir can change from a sink to a source and vice versa. A forest is a sink, but when the forest burns it becomes a source.

The amount of time that carbon stays, on average, in a reservoir is the residence time of carbon in that reservoir.

The concept of residence times is explored using the undergraduate population at UGA as an example. In this example the reservoir is the university:

- **http://www.youtube.com/watch?v=cIuaedcVvQg** (2:44).

Atmospheric Carbon Dioxide

Remember that the amount of CO_2 in the atmosphere is very low. This means that a small increase or decrease in the atmospheric CO_2 can have a large effect.

By measuring the composition of air bubbles trapped in glacial ice, scientists can learn the amount of atmospheric CO_2 at times in the past. Of particular interest is the time just before the Industrial Revolution, when society began to use fossil fuels. That value is thought to be the natural content of CO_2 for this time period; that number was 280 parts per million (ppm).

By 1958, when scientists began to directly measure CO_2 content from the atmosphere at Mauna Loa volcano in the Pacific Ocean, the amount was 316 ppm (Figure 219). In 2011, the atmospheric CO_2 content had risen to 390 ppm.

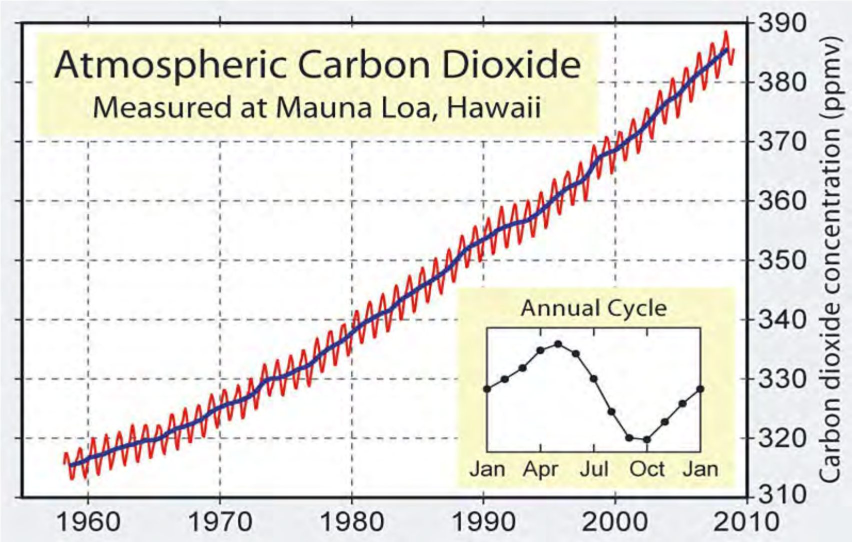


Figure 219: The amount of CO2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The blue line shows yearly averaged CO2. The red line shows seasonal variations in CO2.

This is an increase in atmospheric CO_2 of 40% since the before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958.

Human Actions Impact the Carbon Cycle

Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for combustion of propane, which is a simple hydrocarbon looks like this (Figure 220):

$$\underset{\text{propane}}{C_3H_8} + \underset{\text{oxygen}}{5\,O_2} \rightarrow \underset{\text{carbon dioxide}}{3\,CO_2} + \underset{\text{water}}{4\,H_2O}$$

Figure 220: Propane combustion formula.

The equation shows that when propane burns, it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas, the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph above.

The second largest source of atmospheric CO_2 is **deforestation** (Figure 221). Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2. If the tree is burned or decomposes, it becomes a source of CO_2. A forest can go from being a carbon sink to being a carbon source.

Figure 221: This forest in Mexico has been cut down and burned to clear forested land for agriculture.

Why the Carbon Cycle is Important

Why is such a small amount of carbon dioxide in the atmosphere even important? Carbon dioxide is a greenhouse gas. Greenhouse gases trap heat energy that would otherwise radiate out into space, which warms Earth. These gases were discussed in Concept Atmospheric Processes.

This video *Keeping up with Carbon* from NASA, focuses on the oceans. Topics include what will happen as temperature warms and the oceans can hold less carbon, and ocean acidification: **http://www.youtube.com/watch?v=HrIr3xDhQ0E** (5:39).

A very thorough but basic summary of the carbon cycle, including the effect of carbon dioxide in the atmosphere, is found in this video: **http://www.youtube.com/watch?v=U3SZKJVKRxQ** (4:37).

Practice and Review

1. Why do the poles receive so much less solar radiation than the equator considering that it's light for six months at the poles?
2. Why is latitude considered the most important factor in determining temperature?
3. Look at a map of geological features and look at the temperature map to try to determine why some of the exceptions exist. What's the big blue blob north of India?
4. What are prevailing winds and how do they affect climate?
5. What is the ITCZ? How does its location affect weather?
6. Where is there not much wind?
7. If upwelling stopped off of California, how would climate be affected?
8. From which direction would weather come to a city at 65-degrees north?
9. Why is the climate of San Francisco so different from the climate of Virginia Beach when both are near an ocean?
10. Why does an increase in altitude cause a change in temperature?

11. What is rainshadow effect?

12. Besides rainshadow effect, how else do mountains affect weather downwind?

13. How has climate changed in the past 1,100 years?

14. What were the temperatures of the glacial and interglacial periods of the Pleistocene ice ages?

15. Why is the fact that climate has changed a lot during Earth history important to a discussion of climate change today?

16. What does it mean to say that photosynthesis and respiration are gas exchange processes?

17. How do scientists learn about carbon levels in the past?

18. How do human activities affect the carbon cycle?

Practice Test Weather and Climate

Water Cycle

1) This drives the water cycle.

a) The ocean

b) The sun

c) The core

d) The air

2) When water changes from a liquid to a gas.

a) Precipitation

b) Condensation

c) Evaporation

d) Hydration

3) Rain, sleet, hail, or snow are examples of this.

a) Precipitation

b) Condensation

c) Evaporation

d) Hydration

4) Which of these is an example of sublimation?

a) Ice changing to water

b) Water changing to ice

c) Water vapor changing to a cloud

d) Dry ice changing to air

5) How is soil helpful to water?

6) Plants do this process where water vapor can go into the air through the leaves.

a) Sublimation

b) Condensation

c) Transpiration

d) Precipitation

7) Another name for the water cycle is this.

a) Atmospheric cycle

b) Lithospheric cycle

c) Biospheric cycle

d) Hydrological cycle

8) Humans have created these to help collect water directly from streams or ponds.

9) When water molecules evaporate from oceans or lakes, what is left is this.

a) Sugar

b) Calcium

c) Salt

d) Iron

10) Most of Earth's water is stored here.

a) Lakes

b) Glaciers

c) Oceans

d) Underground

Seasons

1) The reasons for the seasons is

a) The temperature

b) The sun is closer

c) The tilt of Earth’s axis

d) The time

2) This refers to when the position of the Sun is closest to the poles.

a) Axis

b) Solstice

c) Summer

d) Winter

3) True or false. During the summer, we experience shorter days and longer nights.

a) True

b) False

4) This area has relatively the same amount of sunlight through the year.

a) North Pole

b) South Pole

c) Equator

d) Axis

5) The Sun’s rays high most the Earth the most around here.

a) The Equator

b) The Tropic of Cancer

c) None of the above

d) A and B are true

6) During the winter solstice

a) The tilt on Earth's axis is farther away

b) The days are shorter

c) The nights are longer

d) All of the above

7) Which is true about the equinox?

a) There is a vernal and autumnal.

b) It is halfway between the two solstices.

c) The daylight and the nighttime hours are exactly equal.

d) All of the above

8) The time when daylight and nighttime hours are exactly equal.

a) Solstice

b) Equinox

c) Equality

d) Hemisphere

9) True or false. During the equinox, the days are longer and the nights are shorter.

a) True

b) False

10) True or false. The vernal equinox happens around September 22 or 23.

a) True

b) False

Importance of the Atmosphere

1) The atmosphere is composed of 78%

a) Carbon dioxide

b) Oxygen

c) Sulfur

d) Nitrogen

2) Photosynthesis helps plants turn carbon dioxide, water, and solar energy into this.

a) Sugar

b) Oxygen

c) All of the above

d) None of the above

3) True or false. The atmosphere is a reservoir for water.

a) True

b) False

4) True or false. The atmosphere provides a source for sound to travel through.

a) True

b) False

5) How does the atmosphere protect us from the sun?

6) Ozone is three

a) Water molecules

b) Oxygen molecules

c) Carbon dioxide molecules

d) Sugar molecules

7) True or false. Respiration is the process of carbon dioxide, water, and sugar turning into oxygen and water.

a) True

b) False

8) Oxygen gas makes up this much of the atmosphere.

a) 11%

b) 21%

c) 31%

d) 41%

9) What is the relationship between photosynthesis in plants and respiration of animals?

10) What would happen if there was no atmosphere?

Composition of the Atmosphere

1) This element makes up 99% of the atmosphere.

a) Nitrogen

b) Oxygen

c) None of the above

d) Both a and b

2) How are nitrogen and oxygen important for life?

3) Humidity is how much of this is in the air.

a) Oxygen

b) Nitrogen

c) Water Vapor

d) Both a and b

4) How are greenhouses helpful?

5) Other than gasses, what else can be in the atmosphere?

6) When water vapor turns into a cloud, it is doing this process.

a) Evaporation

b) Condensation

c) Precipitation

d) Sublimation

7) _________________ is how much water is in the air.

8) Which of these is a greenhouse gas?

a) Ozone

b) Methane

c) Carbon dioxide

d) All of the above

9) True or false. Oxygen is helpful in the production of soil elements necessary for agriculture.

a) True

b) False

10) True or false. In warmer regions, humidity levels increase because water vapor is able to hold more moisture.

a) True

b) False

Heat Transfer in the Atmosphere

1) Tornadoes happen when heat is rapidly transferred between layers in the _______________.

2) The transfer of energy between two objects by electromagnetic waves.

a) Radiation

b) Conduction

c) Convection

d) Connection

3) Heat moving from more heat to areas of less heat by direct contact.

a) Radiation

b) Conduction

c) Convection

d) Connection

4) True or false. Conduction is more effective at higher altitudes, where air density is lower.

a) True

b) False

5) Feeling the heat from the Sun is this kind of heat transfer.

a) Radiation

b) Conduction

c) Convection

d) Connection

6) What drives the water cycle?

a) The Earth's core

b) The Sun

c) Uranus

d) Ozone

7) True or false. The Sun's rays strike the surface most directly at the equator.

a) True

b) False

8) A spoon getting warmed by boiling water is an example of this.

a) Radiation

b) Conduction

c) Convection

d) Connection

9) When air gets warmer

a) It goes upward

b) Molecules move faster

c) Molecules spread apart

d) All of the above

10) Why do the poles receive less radiation?

Circulation in the Atmosphere

1) Convection cells in this layer of the atmosphere create wind.

a) Stratosphere

b) Mesosphere

c) Thermosphere

d) Troposphere

2) True or false. Air in the troposphere is warmer and closer to the Sun.

a) True

b) False

3) Air always flows from an area of ______________ pressure to an area of _______________ pressure.

1) Higher

2) Lower

4) How does warm air rise?

5) How does an area of high air pressure form?

a) When air gets warmer and moves up

b) When air gets warmer and moves down

c) When air gets cooler and moves up

d) When air gets cooler and sinks

6) Air flowing over Earth's surface is called ______________.

7) True or false. Denser air creates an area of low pressure.

a) True

b) False

8) Wind speeds at Mt. Washington in New Hampshire can be up to

a) 31 mph

b) 131 mph

c) 231 mph

d) 331 mph

9) True or false. The greater the difference in pressure, the stronger the wind blows.

a) True

b) False

10) Difference in air temperature can cause _________________.

a) Convection currents

b) Wind

c) None of the above

d) Both a and b

Coriolis Effect

1) The Coriolis effect

a) Describes how Earth's rotation steer winds and ocean currents

b) Causes freely moving objects to move to the right in the Northern Hemisphere

c) Causes freely moving objects to move to the left in the Southern Hemisphere

d) All of the above

2) The apparent deflection of a freely moving object like water or air because of Earth's rotation.

a) Cause and Effect

b) The Butterfly Effect

c) The Coriolis Effect

d) The Greenhouse Effect

3) True or false. Freely moving objects appear to move to the right in the Northern Hemisphere.

a) True

b) False

4) True or false. Freely moving objects appear to move to the right in the Southern Hemisphere.

a) True

b) False

5) True or false. Coriolis is a force.

a) True

b) False

6) True or false. Coriolis is an effect, not a force.

a) True

b) False

7) Wind or water that travels toward the poles from the equator is deflected to the

a) North

b) South

c) East

d) West

8) Wind or water that travels toward the equator from the poles get bent to the

a) North

b) South

c) East

d) West

9) True or false. Objects above earth that are moving straight may appear curved because the Earth is rotating underneath them.

a) True

b) False

10) True or false. The Coriolis effect explains why pilots going long distances cannot fly straight to their destination.

a) True

b) False

Fronts

1) A front is

a) Where two air masses meet

b) Where two masses move apart

c) The main cause of stormy weather

d) Both a and c

2) Fronts occur because

a) The two air masses have the same density

b) The two air masses have different densities

c) The two air masses have the same temperature

d) The two air masses have the same pressure

3) Stationary fronts do not move. A front may become stationary if it is stopped by a barrier such as a

a) tree

b) mountain

c) cloud

d) None of the above

4) Winds blow parallel to a stationary front, but in ____________________ directions.

5) A line of severe thunderstorms that form along a cold front:

a) A thunderstorm line

b) A storm line

c) A cold line

d) A squall line

6) If a cold front occurred in the spring, this type of weather would occur.

a) Thunderstorms

b) Strong rain

c) Snow

d) Strong winds

7) A warm front is

a) A warm air mass slides over a cold air mass

b) A cold air mass slides over a warm air mass

c) Two warm air masses meeting

d) Two cold air masses meeting

8) Which symbol represents an occluded front?

a) 

b) 

c) 

d) 

9) True or false. An occluded front has two air masses.

a) True

b) False

Thunderstorms

1) Thunderstorms are extremely common and may occur

a) 100,000 per day

b) 140,000 per day

c) 40,000 per day

d) 14 million per day

2) Energy that collects in cumulonimbus clouds release electricity called

a) Thunder

b) Static

c) Lightning

d) None of the above

3) True or false. Lightning does not hit the same place twice.

a) True

b) False

4) What causes thunder?

5) True or false. Sound waves travel more slowly, so thunder may come many seconds after lightning.

a) True

b) False

6) True or false. Thunderstorms grow where ground temperatures are low.

a) True

b) False

7) Long lines of thunderstorms that form along a cold front:

a) Squash lines

b) Squander lines

c) Squall lines

d) Square lines

8) Lightning may

a) be between one part of a cloud and another

b) be between two clouds

c) be between a cloud and the ground

d) all of the above

9) Severe thunderstorms can create these natural disasters.

10) What can end a thunderstorm?

Tornadoes

1) Where in the United States has the least chance of a tornado?

2) What is a warning of a tornado coming?

3) The average wind speed of a tornado is about

a) 100 kph

b) 177 kph

c) 277 kph

d) 200 kph

4) On the Fujita Scale, what is the mph of an F2 tornado?

a) 181-253

b) 333-419

c) 420-512

d) 64-116

5) ________________________ is a violently rotating funnel cloud that grows downward form a cumulonimbus cloud.

6) What type of cloud does a tornado stem from?

a) cirrus

b) cumulous

c) stratus

d) cumulonimbus

7) Why is it difficult for a meteorologist to predict when a tornado will strike?

8) What kinds of damage can tornadoes cause?

a) Death

b) Destroy homes and property

c) A and B

d) None of the above

9) What could you do to survive a tornado?

10) Tornadoes are predictable

a) True

b) False

Hurricanes

1) Another name for hurricanes are

a) Twisters

b) Typhoons

c) Cyclones

d) B and C are correct

2) According to the Saffir-Simpson scale, what kinds of damage do you expect for a category 4 hurricane?

a) no real change

b) considerable damage to roof, door, and window

c) some damage to buildings

d) complete roof failure

3) Besides the hurricane itself, what should other things should you be worried about during a hurricane?

4) How long do hurricanes typically last?

a) 1-2 days

b) 3-5 days

c) 5-10 days

d) 10-12 days

5) How do hurricanes form?

6) ____________________ is a low pressure cell that rises in the tropics.

7) A tornado is a cyclone that forms in the tropics and spins around a low pressure center.

a) True

b) False

8) The scale that categorizes hurricanes by their winds speed.

a) Saffir-Simpson Scale

b) Richter's Scale

c) Fujita Scale

d) Mercalli's Scale

9) In 2005, this hurricane hit New Orleans, making it the longest, costliest, and deadliest hurricane to date.

10) Hurricanes can also generate tornadoes.

a) True

b) False

Latitude on Climate

1) The _______________ receives the most solar radiation and the _____________ receives the least amount of solar radiation.

2) True or false. The polar regions have a high albedo.

a) True

b) False

3) In the polar region, the night lasts

a) For 12 hours

b) For 6 days

c) For 6 hours

d) For 6 months

4) True or false. The daylight is equal all year long at the equator.

a) True

b) False

5) Even though South America is close to the equator, not all parts are warm. Where are there low temperatures and why?

6) What causes Western Europe to be warmer than the rest of Europe?

a) The Gulf Stream

b) The Benguela Current

c) The Arctic Current

d) The East Australian Current

7) What prevents the poles from getting sunlight?

8) True or false. Latitude is the only factor that determines the temperature of a region.

a) True

b) False

9) True or false. At the equator, the sun is just about directly overhead at midday.

a) True

b) False

Continental Position on Climate

1) How does water affect land temperature?

2) Maritime climate is strongly influenced by the nearby _________.

3) Why is there less of a difference in temperature between January and July in San Francisco, CA than in Wichita, KS?

4) Why is the difference in temperatures in Virginia Beach, VA greater than in San Francisco, CA even though they are both located near oceans?

5) True or false. Ocean currents can affect the temperature of land.

a) True

b) False

6) Continental climate has great differences in

a) Temperature between day and night

b) Temperature between summer and winter

c) No difference

d) Both a and b

7) ________________________ brings cold, deep water up to the ocean surface off of California, which contributes to the cool coastal temperatures.

8) This ocean current affects the climate of northern Europe.

a) The Gulf Stream

b) The Humboldt Current

c) The Canaries Current

d) The Alaska Current

9) True or false. Continental climates are affected by the sea.

a) True

b) False

Mountains on Climate

1) Air pressure and air temperature _____________ with altitude.

a) Stay the same

b) Increase

c) Decrease

d) None of the above

2) How does air get warm?

3) True or false. Collisions between molecules increase temperature.

a) True

b) False

4) Why are there lower temperatures the higher you go?

5) The ____________________ occurs on the leeward side of a mountain range, which brings warm, dry climate.

6) Mountain ranges separate the coastal region from the rest of the continent, preventing

a) Continental climate from going to the leeward side

b) Maritime climate from going to the leeward side

c) Both a and b

d) None of the above

7) True or false. The higher the altitude, the more spread out the air molecules are.

a) True

b) False

8) True or false. Climax Lake's average temperature is lower than Lakewood because Climax has a higher altitude.

a) True

b) False

9) True or false. Continental climate can be found on the leeward side of the mountain.

a) True

b) False

10) The lower the altitude

a) The more dense the air

b) The colder the air

c) The warmer the air

d) None of the above

Climate through History

1) True or false. Throughout Earth's history, its climate has always been colder and less humid than it is today.

a) True

b) False

2) The most recent ice age was in ____________.

a) The Pleistocene Epoch

b) Karoo Ice Age

c) Quaternary Glaciation

d) Andean-Saharan

3) The average global temperature during glacial periods was only

a) $-5.5\,^{o}C$

b) $-10.5\,^{o}C$

c) $5.5\,^{o}C$

d) $10.5\,^{o}C$

4) True or false. When glaciers retreat, sea levels rise.

a) True

b) False

5) How did climate change help the Viking civilization?

6) True or false. For the past 2,000 years the climate has been relatively unstable.

a) True

b) False

7) How is climate stability beneficial to the human civilization?

a) It allows the expansion of agriculture

b) It allows the development of towns and cities

c) Both a and b

d) None of the above

8) The Vikings were forced out of Greenland during this period.

a) The Big Ice Age

b) The Smallest Ice Age

c) The Great Ice Age

d) The Little Ice Age

9) True or false. Many scientists think that we are now in a warm, interglacial period.

a) True

b) False

Carbon Cycle

1) Which statement is NOT true about carbon?

a) It is the most common element in the human body

b) Diamonds are made of carbon

c) It is part of CO_2

d) Fats contain carbon

2) True or false. You breathe in oxygen and breathe out carbon dioxide.

a) True

b) False

3) The waste product of photosynthesis is

a) Glucose

b) Oxygen

c) Carbon dioxide

d) Both a and b

4) True or false. Respiration can be considered the reverse process of photosynthesis.

a) True

b) False

5) In photosynthesis, plants change this into chemical energy that plants and animals can use as food.

a) Sunlight

b) Oxygen

c) Sugar

d) All of the above

6) _________________ are reservoirs where carbon is stored, such as forests and oceans.

7) This is an example of a carbon source.

a) Forest

b) Ocean

c) Fault

d) Volcano

8) True or false. The amount of carbon dioxide in the atmosphere is very high.

a) True

b) False

9) During the Industrial Revolution, society began to use this, which increased the amount of carbon dioxide in the atmosphere.

a) Solar panels

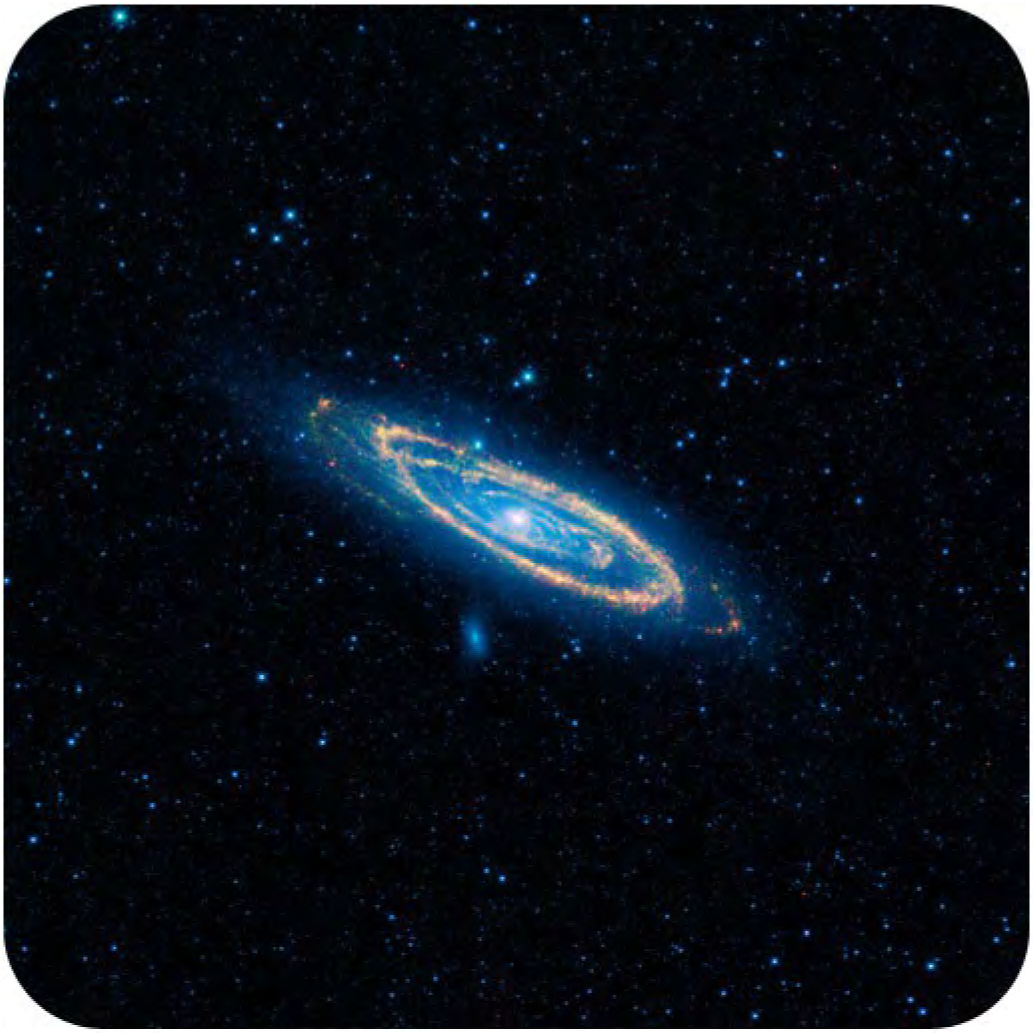
b) Wind turbines

c) Fossil fuels

d) Water

10) If trees are a carbon sink while they are alive, how can they become a carbon source when they are dead? Based on this information, what can you infer is an impact of deforestation on CO2 levels in the atmosphere?

Astronomy



How do scientists learn about space?

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. What can astronomers use to study space? Light and other electromagnetic waves, of course. This is the Andromeda Galaxy as it appeared 2.5 million years ago. Why is the light so old?

Introduction to Astronomy

Electromagnetic Spectrum

Earth is just a tiny speck in the universe. Our planet is surrounded by lots of space. Light travels across empty space. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light and other energy that comes to us to gather information about the universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our sun, takes about eight minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Whirlpool Galaxy is about 23 million light-years from Earth (Figure 222). When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 23 million years ago!

Figure 222: The Whirlpool Galaxy as it looked 23 million years ago.

Since scientists can look back in time, they can better understand the Universe's history. Check out

- **http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm** to see how this is true.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. Pictured below is a diagram of an electromagnetic wave (Figure 223). An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields vibrate up and down, which makes the wave.

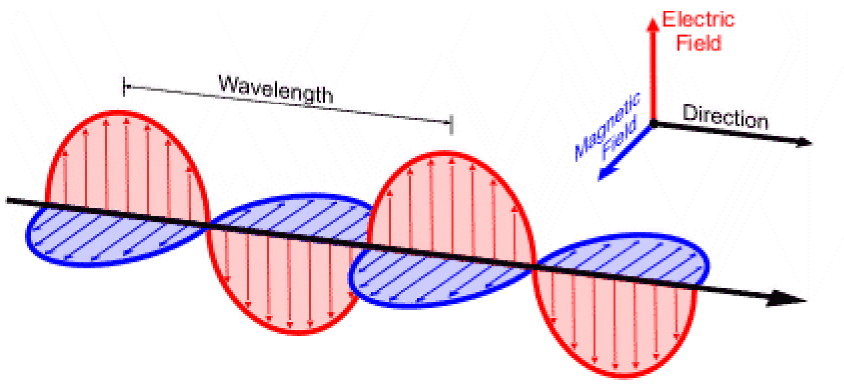


Figure 223: An electromagnetic wave has oscillating electric and magnetic fields.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (Figure 224) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

Visible light is only a small part of the electromagnetic spectrum. There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.

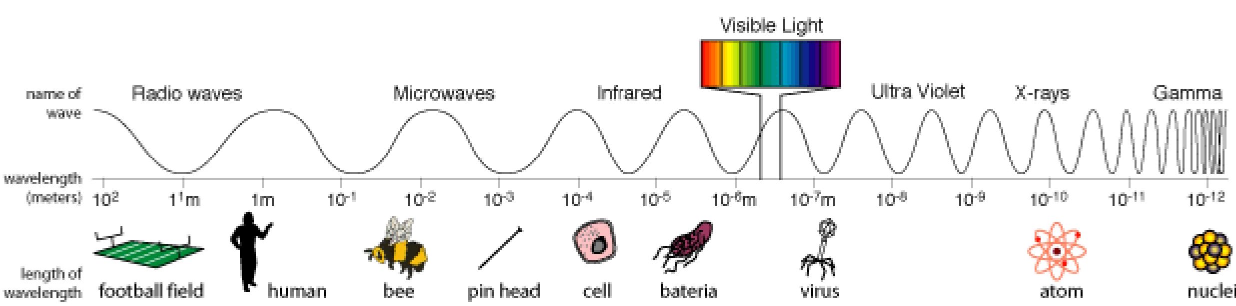


Figure 224: The electromagnetic spectrum from radio waves to gamma rays.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at ultraviolet wavelengths. There are extremely hot objects that emit X-rays and even gamma rays. Some very cool stars shine mostly in the infrared light wavelengths. Radio waves come from the faintest, most distant objects.

To learn more about stars' spectra, visit:

- **http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/**.

Earth Orbits a Star

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

The Geocentric Universe

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

One problem with the geocentric model is that some planets seem to move backwards (in retrograde) instead of in their usual forward motion around Earth. A demonstration animation of retrograde motion of Mars as it appears to Earth can be found here:

- **http://projects.astro.illinois.edu/data/Retrograde/index.html**.

Around 150 A.D. the astronomer Ptolemy resolved this problem by using a system of circles to describe the motion of planets (Figure 225). In Ptolemy's system, a planet moves in a small circle, called an epicycle. This circle moves around Earth in a larger circle, called a deferent. Ptolemy's version of the geocentric model worked so well that it remained the accepted model of the universe for more than a thousand years.

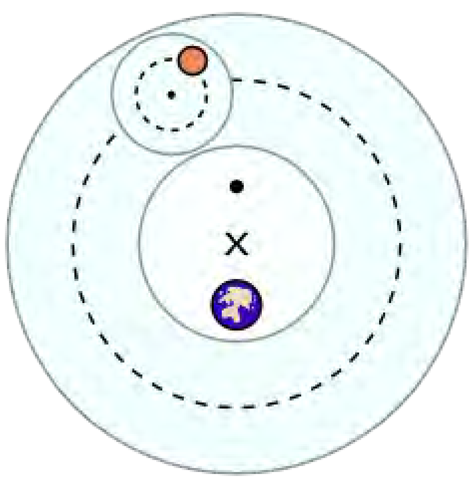


Figure 225: According to Ptolemy, a planet moves on a small circle (epicycle) that in turn moves on a larger circle (deferent) around Earth.

An animation of Ptolemy's system can be seen here:

- **http://www.youtube.com/watch?v=FHSWVLwbbNw&NR=1**

The Heliocentric Universe

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

Although Copernicus' model was simpler – it didn't need epicycles and deferents - it still did not perfectly describe the motion of the planets. Johannes Kepler solved the problem a short time later when he determined that the planets moved around the Sun in ellipses (ovals), not circles (Figure 226). Kepler's model matched observations perfectly.

Animation of Kepler's Laws of Planetary Motion:

- **http://projects.astro.illinois.edu/data/KeplersLaws/index.html**

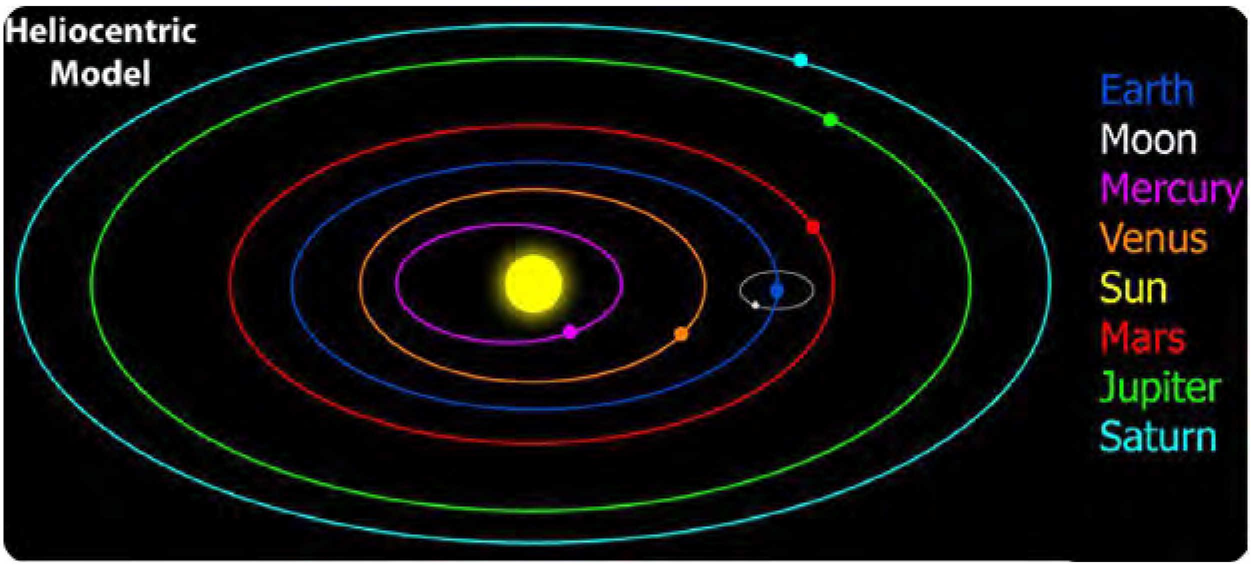


Figure 226: Kepler's model showed the planets moving around the sun in ellipses.

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

An animation of three of Jupiter's moons orbiting the planet can be seen here:

- **http://upload.wikimedia.org/wikipedia/commons/e/e7/Galilean_moon_Laplace_resonance_animation_de.gif**.

Galileo also discovered that Venus has phases like the Moon (Figure 227), which provides direct evidence that Venus orbits the Sun.

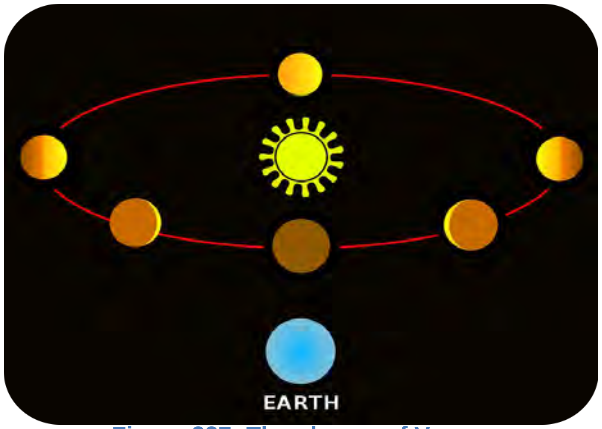


Figure 227: The phases of Venus.

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

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

Earth's Revolution

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

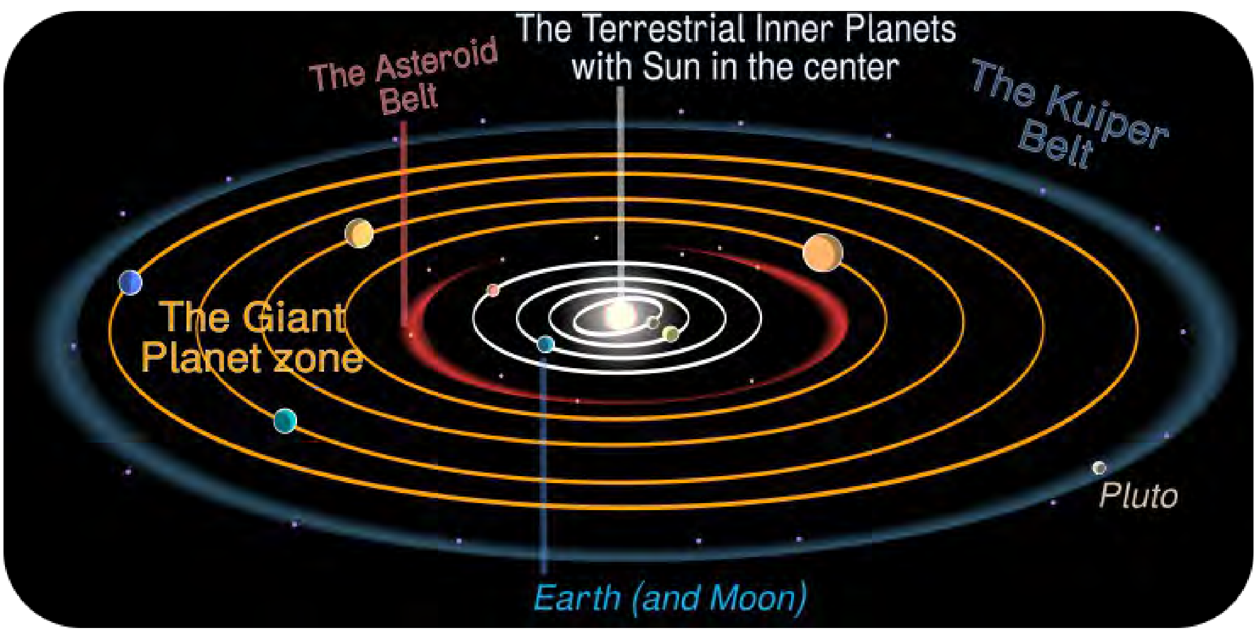


Figure 228: Earth and the other planets in the solar system make elliptical orbits around the Sun.

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

"Accordingly, since nothing prevents the earth from moving...
...I suggest that we should now consider also whether several motions suit it, so that it can be regarded as one of the planets. For, it is not the center of all the revolutions." - Nicolaus Copernicus

The Size and Shape of Orbits
Figure 229 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical, with the Sun located at one of the foci (Figure 228).

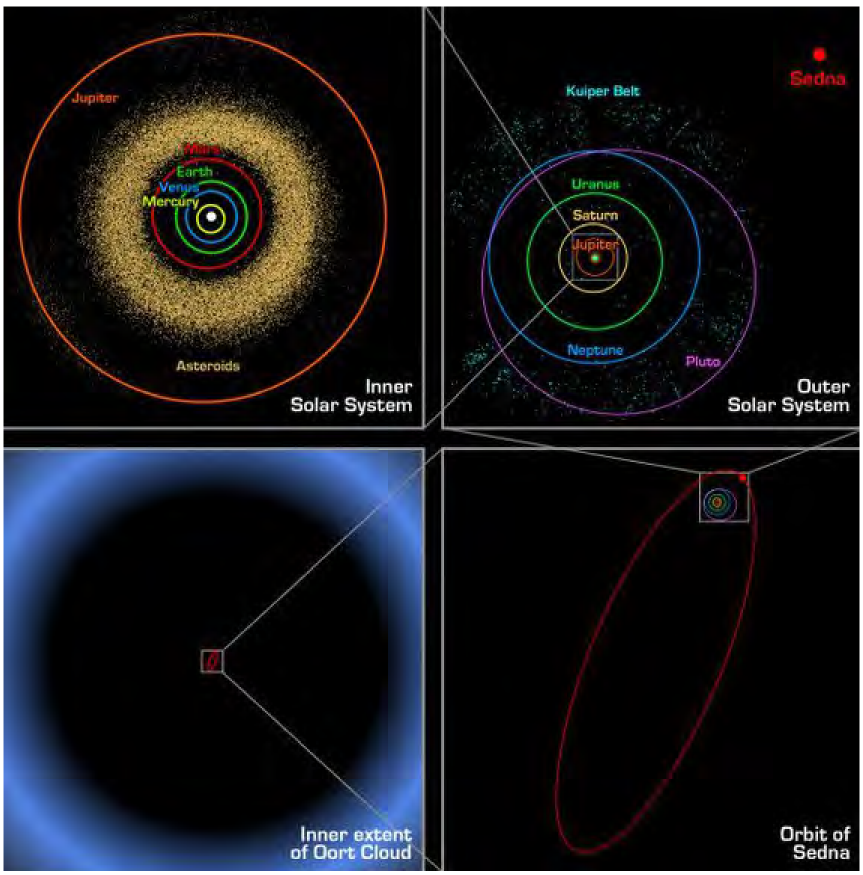


Figure 229: The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to make one complete orbit around the Sun, its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

Scaling the solar system creates a scale to measure all objects in solar system **(1i - I&E Stand)**:

- **http://www.youtube.com/watch?feature=player_profilepage&v=-6szEDHMxP4**(4:44).

Telescopes

Electromagnetic Radiation

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

Visible light — the light that human eyes can see — comes in a variety of colors. The color of visible light is determined by its wavelength. Visible light ranges from wavelengths of 400 nm to 700 nm, corresponding to the colors violet through red. EM radiation with wavelengths shorter than 400 nm or longer than 700 nm exists all around you — you just can't see it. The full range of electromagnetic radiation, or the **electromagnetic spectrum**, is shown in Figure 230.

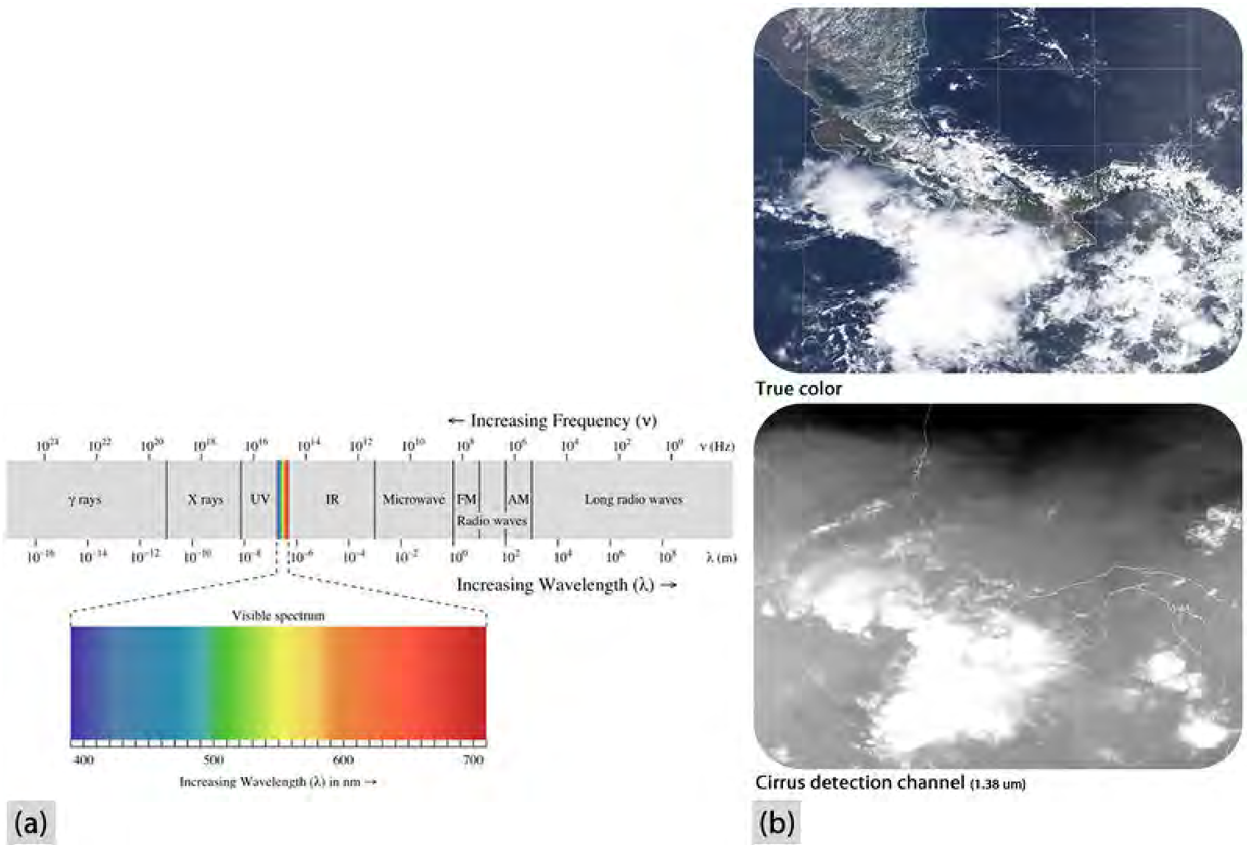


Figure 230: (a) Visible light is part of the electromagnetic spectrum, which ranges from gamma rays with very short wavelengths, to radio waves with very long wavelengths. (b) These are images of the same scene. In the top, only the wavelengths of visible light show. In the bottom, a layer of thick clouds appears in the infrared wavelengths.

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

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

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

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

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

Larger telescopes can collect more light and so they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Several large reflecting telescopes are located at the summit of Mauna Loa volcano in Hawaii, shown in Figure 231.

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

Find out more by watching this video at

- **http://www.kqed.org/quest/television/amateur-astronomers.**

Figure 231: Telescopes on top of Mauna Kea in Hawaii.

Radio Telescopes

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

The largest single telescope in the world is at the Arecibo Observatory in Puerto Rico (Figure 232). This telescope is located in a naturally occurring hole so that it does not collapse under its own weight. Since the telescope is set into the ground, it cannot be aimed to different parts of the sky and so can only observe the part of the sky that happens to be overhead at a given time.

Figure 232: The radio telescope at the Arecibo Observatory has a diameter of 305 m.

A group of radio telescopes can be linked together with a computer so that they are all observing the same object (Figure 233). The computer combines the data, making the group function like one single telescope.

Figure 233: Radio telescopes at the Very Large Array, the National Radio Observatory in New Mexico.

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

See more at

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

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

See more at

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

Space Telescopes

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

The Hubble Space Telescope (HST), shown in Figure 234, has orbited Earth for more than 20 years, sending back the most amazing images and helping to answer many of the biggest questions in astronomy. The James Webb Space Telescope, designed to replace the aging Hubble, is targeted for launch in 2018.

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

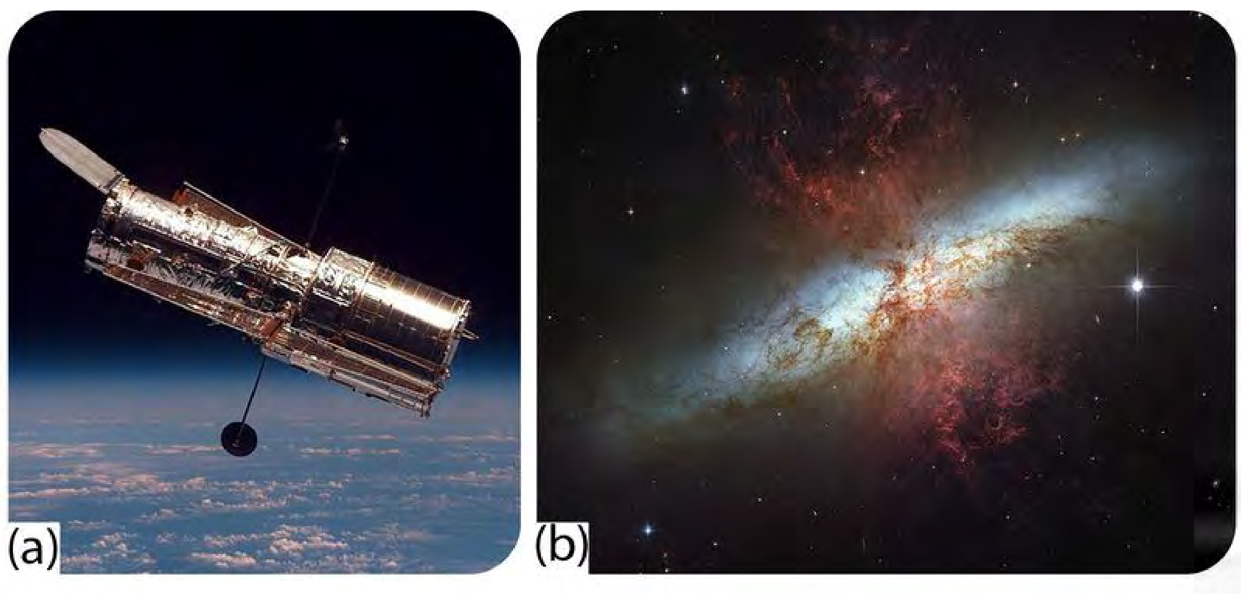


Figure 234: (a) The Hubble Space Telescope orbits Earth at an altitude of 589 km (366 mi). It collects data in visible, infrared, and ultraviolet wavelengths. (b) This starburst cluster is one of the many fantastic images taken by the HST over the past two decades.

Eclipses

Solar Eclipses

A **solar eclipse** occurs when the new Moon passes directly between the Earth and the Sun (Figure 235). This casts a shadow on the Earth and blocks Earth's view of the Sun.

A total solar eclipse occurs when the Moon's shadow completely blocks the Sun (Figure 236). When only a portion of the Sun is out of view, it is called a partial solar eclipse.

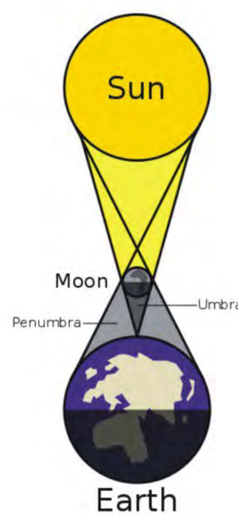


Figure 235: A solar eclipse, not to scale.

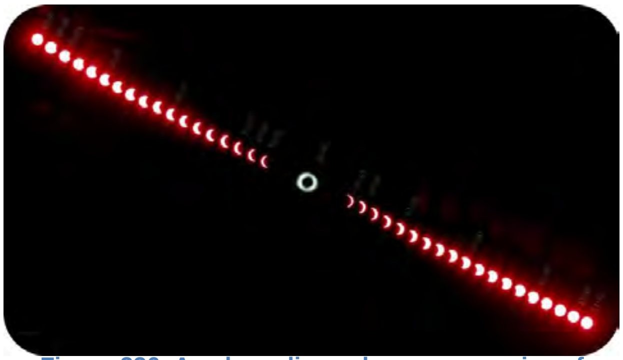


Figure 236: A solar eclipse shown as a series of photos.

Solar eclipses are rare and usually only last a few minutes because the Moon casts only a small shadow (Figure 237).

A BBC video of a solar eclipse is seen here:

- **http://www.youtube.com/watch?v=eOvWioz4PoQ**.

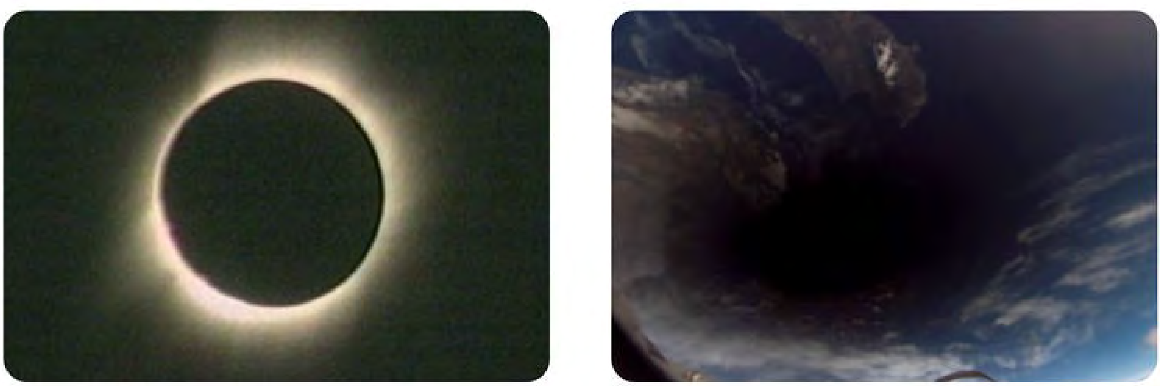


Figure 237: The Moon's shadow in a solar eclipse covers a very small area.

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

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

See more at

- **http://www.kqed.org/quest/television/eclipse-chasers.**

Lunar Eclipse

A **lunar eclipse** occurs when the full moon moves through Earth's shadow, which only happens when Earth is between the Moon and the Sun and all three are lined up in the same plane, called the ecliptic (Figure 238). In an eclipse, Earth's shadow has two distinct parts: the **umbra** and the **penumbra**. The umbra is the inner, cone-shaped part of the shadow, in which all of the light has been blocked. The penumbra is the outer part of Earth's shadow where only part of the light is blocked. In the penumbra, the light is dimmed but not totally absent.

A total lunar eclipse occurs when the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. Earth's shadow is large enough that a lunar eclipse lasts for hours and can be seen by any part of Earth with a view of the Moon at the time of the eclipse **(Figure 239)** A lunar eclipse does not occur every month because Moon's orbit is inclined 5-degrees to Earth's orbit, so the two bodies are not in the same plane every month.

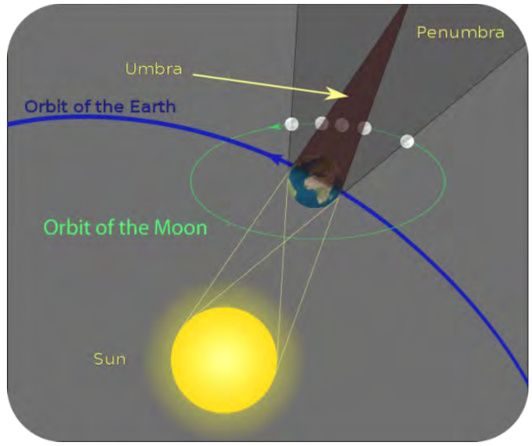


Figure 238: A lunar eclipse.

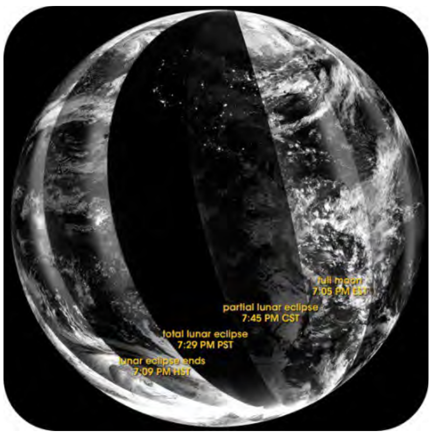


Figure 239: Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common.

The moon glows with a dull red coloring during a total lunar eclipse, which you can see in this video of a lunar eclipse over Hawaii:

- **http://www.youtube.com/watch?v=2dk--IPAi04**

The Phases of the Moon

The moon does not produce any light of its own. It only reflects light from the sun. The moon has phases because it orbits around Earth. One orbit takes about 28 days. As the moon moves around Earth, different parts of it appear to be lit up by the sun. The moon sometimes appears fully lit and sometimes completely dark. Sometimes it is partially lit. The different appearances of the moon are referred to as phases of the moon (Figure 240).

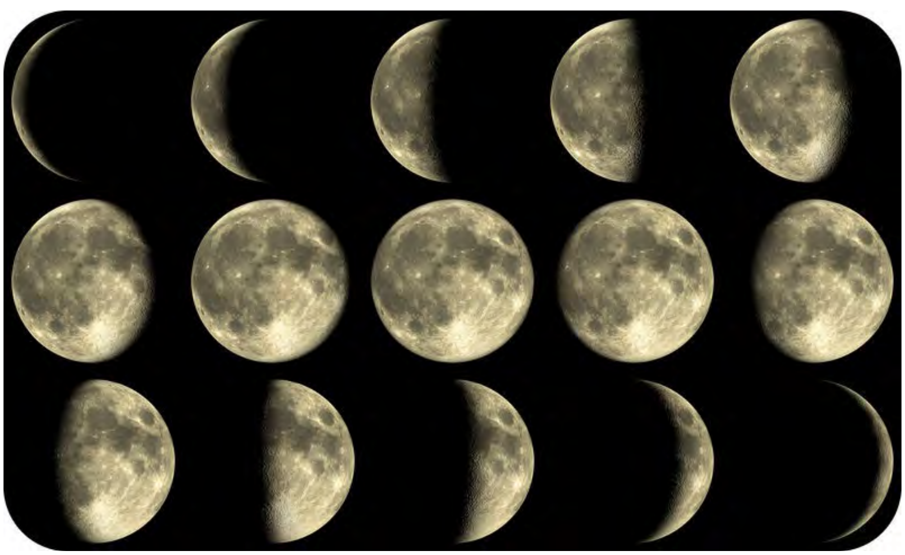


Figure 240: Phases of the moon...

A **full moon** occurs when the whole side facing Earth is lit. This happens when Earth is between the moon and the sun.

About one week later, the moon enters the quarter-moon phase. Only half of the moon's lit surface is visible from Earth, so it appears as a half circle.

Another week later, the moon moves between Earth and the sun. The side of the moon facing Earth is completely dark. This is called a **new moon**. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the moon.

One week after that, the moon is in another quarter-moon phase. Finally, in one more week, the moon is back to full.

Before and after the quarter-moon phases are the gibbous and crescent phases. During the **crescent** moon phase, the moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** moon phase, the moon is more than half lit. It is not full. The moon undergoes a complete cycle of phases about every 29.5 days.

The Role of Gravity

Isaac Newton first described gravity as the force that causes objects to fall to the ground and also the force that keeps the Moon circling Earth instead of flying off into space in a straight line. Newton defined the Universal Law of Gravitation, which states that a force of attraction, called **gravity**, exists between all objects in the universe (Figure 241). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between objects, the smaller the force of attraction.

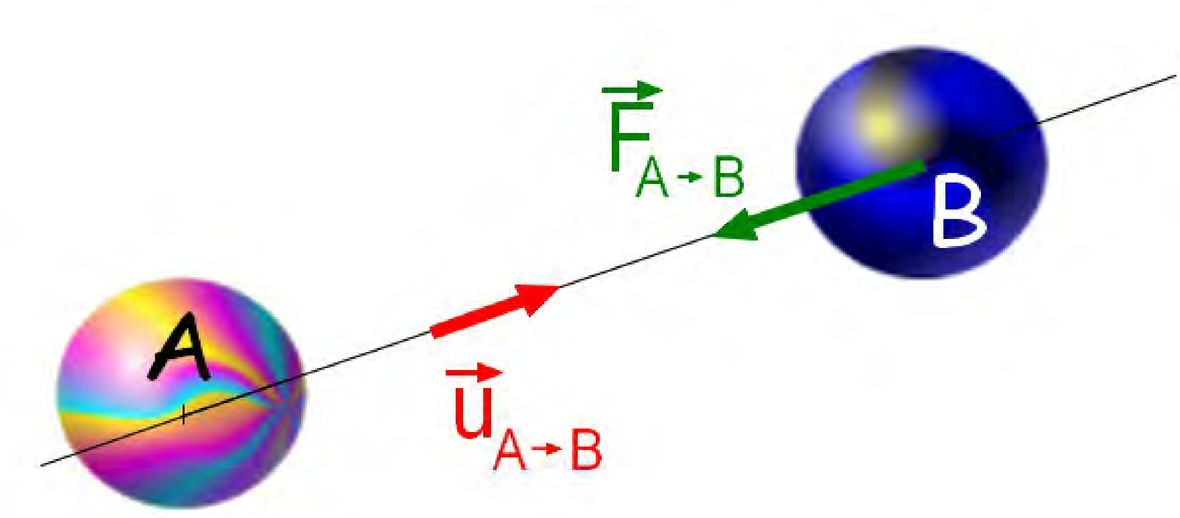


Figure 241: The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them.

The distance between the Sun and each of its planets is very large, but the Sun and each of the planets are also very large. Gravity keeps each planet orbiting the Sun because the star and its planets are very large objects. The force of gravity also holds moons in orbit around planets.

BigThink video: Who was the greatest physicist in history? According to Neal deGrasse Tyson, it was Sir Isaac Newton:

- **http://bigthink.com/ideas/13154**.

Practice and Review

1. Why do astronomers use light years as a measure of distance?
2. In the electromagnetic spectrum, which wavelengths are shorter than visible light? Which are longer than visible light? Which are relatively cool? Which are relatively hot?
3. Why does light we see today tell us something about what happened earlier in the history of the universe?
4. How does the heliocentric model differ from the geocentric model?
5. Why do you think people had a hard time switching from one worldview to the other?
6. Describe Earth's orbit around the Sun.
7. When you look at the diagram of planet orbits, which planet doesn't fit the criteria of a planet?
8. How can a planet's orbital period be used to determine a its distance from the Sun?
9. Why would your age be different on a different planet?
10. Describe each of the types of telescopes discussed here: reflecting, refracting, radio, and space.
11. What are the limitations of each type of telescope discussed here?
12. Look at the electromagnetic spectrum. Do you think other types of telescopes could get other types of information if they gathered different wavelengths?
13. What happens during a solar eclipse?

14. What happens during a lunar eclipse?

15. Why do we not see lunar eclipses every month?

16. Describe how the sun, moon, and Earth are aligned during a full moon.

17. Describe how the sun, moon, and Earth are aligned during a new moon.

18. Draw and label pictures of the moon in its phases.

19. Why is the gravitational attraction of the Moon to Earth greater than the attraction of Earth to Sun?

20. Why doesn't the Moon fly off into space? Why does an apple fall to the ground rather than orbiting Earth at a distance?

21. What is the Universal Law of Gravitation?

Eight Planets

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

Although the Sun is just an average star compared to other stars, it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! Table 13 gives data on the sizes of the Sun and planets relative to Earth.

Table 13: Sizes of Solar System Objects Relative to Earth

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

Orbits and Rotations

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. Table 14 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

Table 14: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62

Table 14: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit			
Planet	**Average Distance from Sun (AU)**	**Length of Day (In Earth Days)**	**Length of Year (In Earth Years)**
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Here is a website that illustrates both the sizes of the planets, and the distance between them:

- **http://www.scalesolarsystem.66ghz.com/#sun**.

The Inner Planets

The **inner planets**, or **terrestrial planets**, are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. Figure 242 shows the relative sizes of these four inner planets.

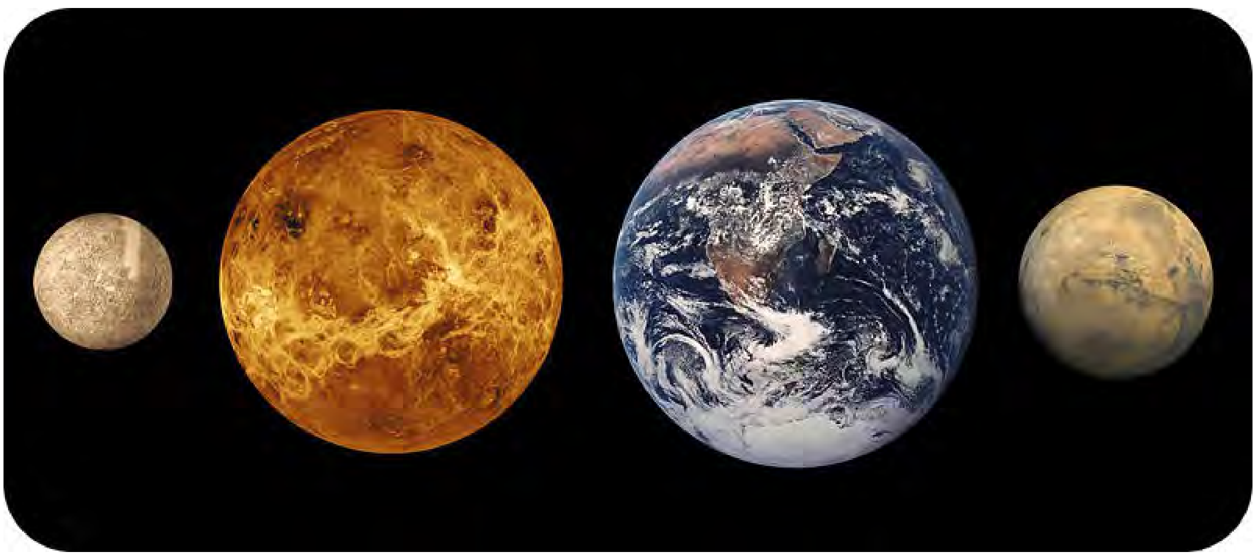


Figure 242: This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings.

The Outer Planets

The four planets farthest from the Sun are the **outer planets**. Figure 243 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called **gas giants**.

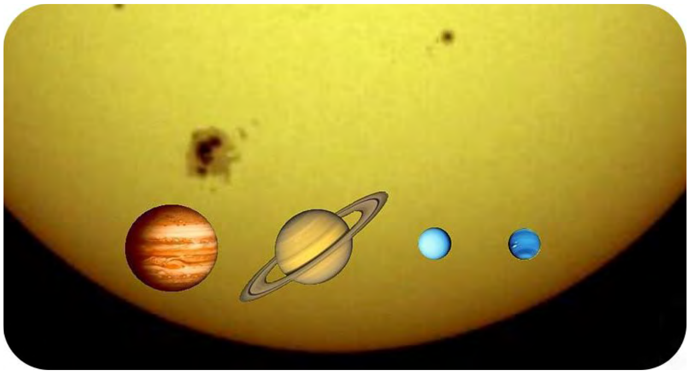


Figure 243: This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers think that hydrogen and helium gases comprised much of the solar system when it first formed. Since the inner planets didn't have enough mass to hold on to these light gases, their hydrogen and helium floated away into space. The Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

All of the outer planets have numerous moons. They all also have **planetary rings**, composed of dust and other small particles that encircle the planet in a thin plane.

Practice and Review

1. Why does the number of dwarf planets recognized by astronomers in the solar system periodically increase?
2. What is the order of planets and dwarf planets by distance from the Sun?
3. What is an astronomical unit?
4. Why is this unit used to measure distances in the solar system?
5. What are the four inner planets?
6. What are the four outer planets?

7. What is the difference in composition between the inner and outer planets? What accounts for the difference?

8. How does the arrangement of planets support the model for the formation of the solar system discussed in "Concept Earth History"?

Our Sun

Star Power

The Sun is Earth's major source of energy, yet the planet only receives a small portion of its energy. The Sun is just an ordinary star. Many stars produce much more energy than the Sun. The energy source for all stars is nuclear fusion.

Nuclear Fusion

Stars are made mostly of hydrogen and helium, which are packed so densely in a star that in the star's center the pressure is great enough to initiate nuclear fusion reactions. In a**nuclear fusion reaction**, the nuclei of two atoms combine to create a new atom. Most commonly, in the core of a star, two hydrogen atoms fuse to become a helium atom. Although nuclear fusion reactions require a lot of energy to get started, once they are going they produce enormous amounts of energy (Figure 244).

Figure 244: A thermonuclear bomb is an uncontrolled fusion reaction in which enormous amounts of energy are released.

In a star, the energy from fusion reactions in the core pushes outward to balance the inward pull of gravity. This energy moves outward through the layers of the star until it finally reaches the star's outer surface. The outer layer of the star glows brightly, sending the energy out into space as electromagnetic radiation, including visible light, heat, ultraviolet light, and radio waves (Figure 245).

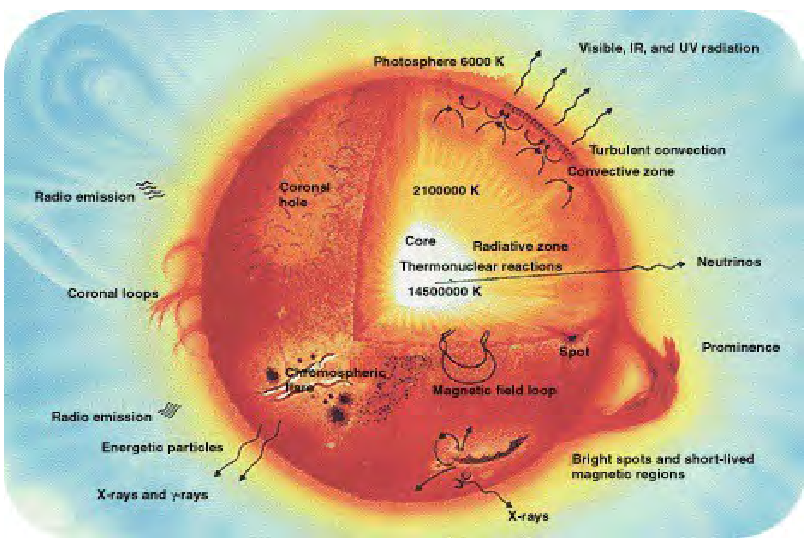


Figure 245: A diagram of a star like the Sun.

Why are the stars in Orion's Belt different colors?

The ancient Greeks thought this group of stars looked like a hunter, so they named it Orion after their mythical hunter. The line of three stars at the center is "Orion's Belt." The many different colors of stars reflect the star's temperature. The bright, red star in the upper left, named Betelgeuse (pronounced BET-ul-juice), is not as hot than the blue star in the lower right, named Rigel.

Color and Temperature

Think about how the color of a piece of metal changes with temperature. A coil of an electric stove will start out black, but with added heat will start to glow a dull red. With more heat, the coil turns a brighter red, then orange. At extremely high temperatures the coil will turn yellow-white, or even blue-white (it's hard to imagine a stove coil getting that hot). A star's color is also determined by the temperature of the star's surface. Relatively cool stars are red, warmer stars are orange or yellow, and extremely hot stars are blue or blue-white (Figure 246).

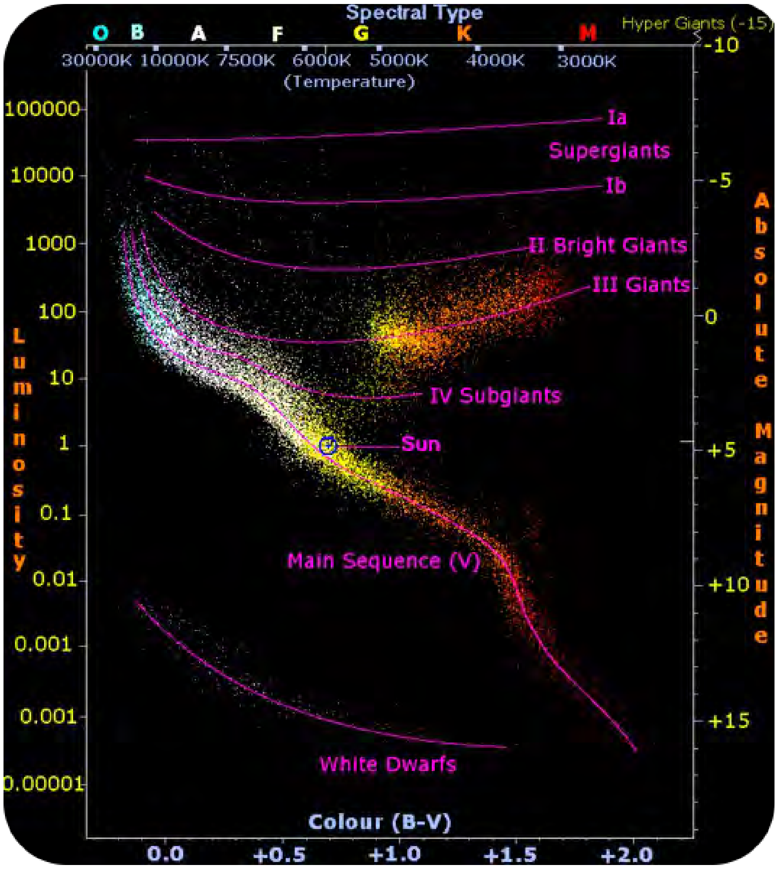


Figure 246: A Hertzsprung-Russell diagram shows the brightness and color of main sequence stars. The brightness is indicated by luminosity and is higher up the y-axis. The temperature is given in degrees Kelvin and is higher on the left side of the x-axis. How does our Sun fare in terms of brightness and color compared with other stars?

Classifying Stars by Color

Color is the most common way to classify stars. Table 15 shows the classification system. The class of a star is given by a letter. Each letter corresponds to a color, and also to a range of temperatures. Note that these letters don't match the color names; they are left over from an older system that is no longer used.

Table 15: Classification of Stars By Color and Temperature

Class	Color	Temperature Range	Sample Star
O	Blue	30,000 K or more	Zeta Ophiuchi
B	Blue-white	10,000–30,000 K	Rigel
A	White	7,500–10,000 K	Altair
F	Yellowish-white	6,000–7,500 K	Procyon A
G	Yellow	5,500–6,000 K	Sun
K	Orange	3,500–5,000 K	Epsilon Indi

Table 15: Classification of Stars By Color and Temperature			
Class	**Color**	**Temperature Range**	**Sample Star**
M	Red	2,000–3,500 K	Betelgeuse, Proxima Centauri

(*Sources*: **http://en.wikipedia.org/wiki/Stellar_classification;http://en.wikipedia.org/wiki/Star**, License: GNU-FDL)

For most stars, surface temperature is also related to size. Bigger stars produce more energy, so their surfaces are hotter. Figure 247 shows a typical star of each class, with the colors about the same as you would see in the sky.

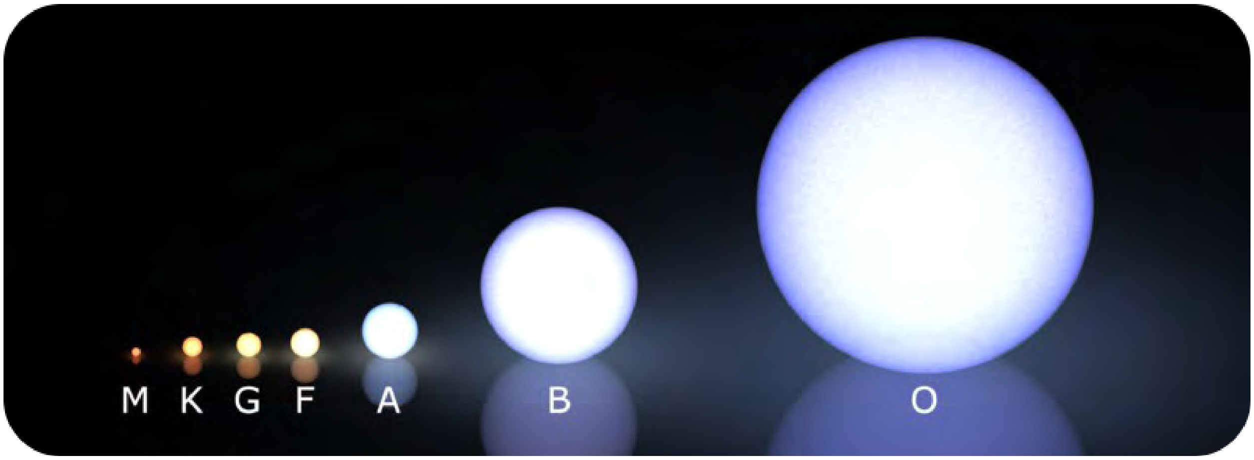


Figure 247: Typical stars by class, color, and size. For most stars, size is related to class and to color. The colors are approximately as they appear in the sky.

Life Cycles of Star

What changes do stars undergo in their lifetimes?

Stars have a life cycle, just like people: they are born, grow, change over time, and eventually grow old and die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Formation

As discussed in "Concept The Solar System," stars are born in clouds of gas and dust called nebulas, like the one shown in Figure 248.

Figure 248: The Pillars of Creation within the Eagle Nebula are where gas and dust come together as a stellar nursery.

For more on star formation, check out:

- **http://www.spacetelescope.org/science/formation_of_stars.html** and **http://hurricanes.nasa.gov/universe/science/stars.html**.

The Main Sequence

For most of a star's life, nuclear fusion in the core produces helium from hydrogen. A star in this stage is a **main sequence star**. This term comes from the Hertzsprung-Russell diagram shown above. For stars on the main 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 in a transitional phase. When the light elements are mostly used up, the star can no longer resist gravity and starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a **red giant**.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a **white dwarf** (Figure 249). A white dwarf will ultimately fade out.

Figure 249: Sirius, the brightest star in the sky, is actually a binary star system. Sirius A is on the main sequence. Sirius B, the tiny dot on the lower left, is a white dwarf.

Supergiants and Supernovas

A star that runs out of helium will end its life much more dramatically. When very massive stars leave the main sequence, they become red supergiants (Figure 250).

Figure 250: The red star Betelgeuse in Orion is a red supergiant.

Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces, so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a **supernova** (Figure 251). A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time. All elements with an atomic number greater than that of lithium were formed by nuclear fusion in stars.

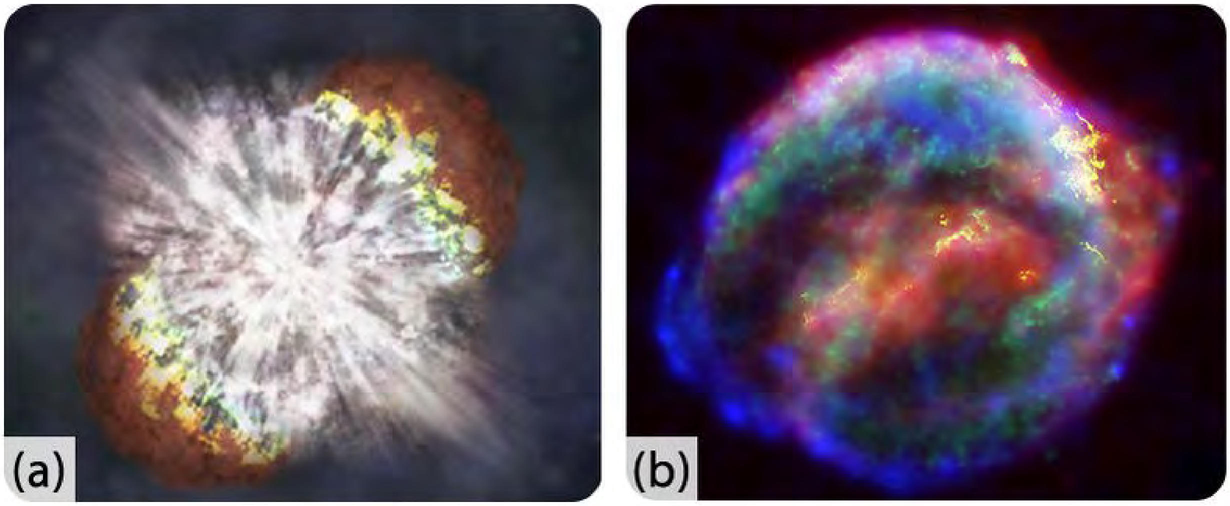


Figure 251: (a) NASA's Chandra X-ray observatory captured the brightest stellar explosion so far, 100 times more energetic than a typical supernova. (b) This false-color image of the supernova remnant SN 1604 was observed as a supernova in the Milky Way galaxy. At its peak it was brighter than all other stars and planets, except Venus in the night sky.

Neutron Stars

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a **neutron star** (Figure 252). A neutron star is more massive than the Sun, but only a few kilometers in diameter. A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

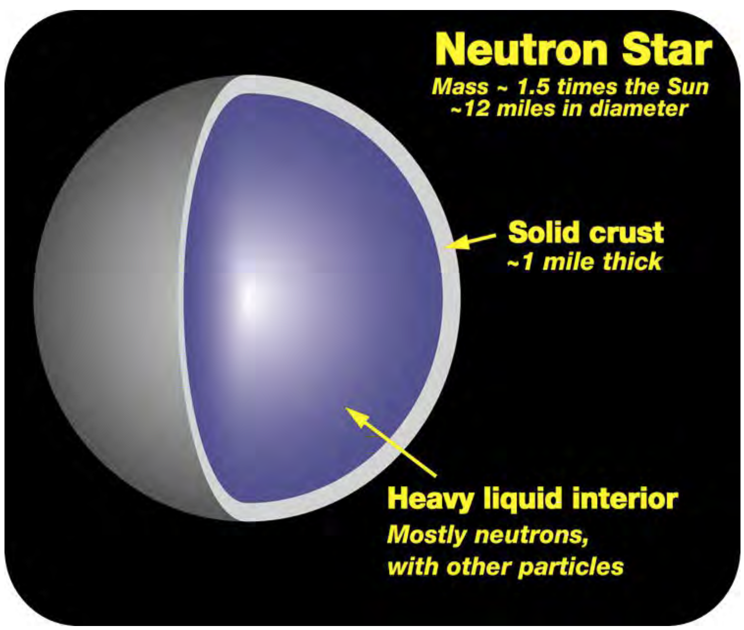


Figure 252: After a supernova, the remaining core may end up as a neutron star.

Black Hole

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a **black hole**. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it, and by radiation that leaks out around its edges.

How to make a black hole:

- **http://www.space.com/common/media/video/player.php?videoRef=black_holes#playerTop**.

A video about black holes is seen on Space.com:

- **http://www.space.com/common/media/video/player.php?videoRef=black_holes**.

A Star's Life Cycle video from Discovery Channel describes how stars are born, age and die**(2f)**:

- **http://www.youtube.com/watch?v=H8Jz6FU5D1A** (3:11).

Practice and Review

1. What type of fusion reaction takes place in most stars?
2. Why don't stars collapse on themselves?
3. What information is contained in a Hertzsprung-Russell diagram?
4. What is the order of star colors from coolest to hottest? How is that related to size?
5. Why do stars that are different colors appear in the same constellation?
6. Why do some stars become red giants and others become supernovae?
7. Why are supernovae crucial to the evolution of the universe?
8. How does a star become a black hole? What are the characteristics of a black hole?

Expanding Universe

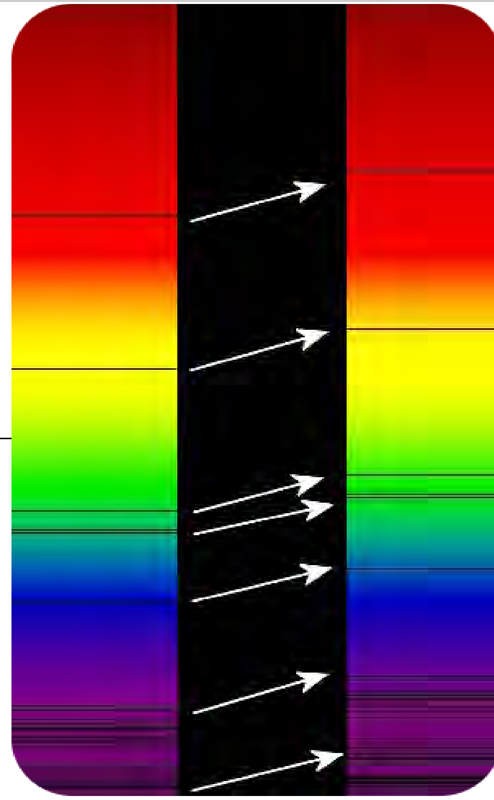


Figure 253: Redshift is a shift in absorption bands toward the red end of the spectrum. What could make the absorption bands of a star shift toward the red?

What is Doppler Effect?

The sound of a siren on an emergency vehicle changes as it passes you: it shifts from higher to lower pitch. As the vehicle moves toward you, the sound waves are pushed together. As the vehicle moves past you, the waves are spread apart. Though redshift involves light instead of sound, a similar principle operates in both situations.

Expansion of the Universe

After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distance to hundreds of other galaxies. His data would eventually show how the universe is changing, and would even yield clues as to how the universe formed.

Redshift

If you look at a star through a prism, you will see a spectrum, or a range of colors through the rainbow. The spectrum will have specific dark bands where elements in the star absorb light of certain energies. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun — not on Earth — by analyzing the absorption lines in the spectrum of the Sun.

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in Figure 253. 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.

If galaxies were moving randomly, would some be redshifted but others be blueshifted? Of course. Since almost every galaxy in the universe has a redshift, almost every galaxy is moving away from Earth.

An animation of Doppler Effect:

- **http://projects.astro.illinois.edu/data/Doppler/index.html**.

The Expanding Universe

Edwin Hubble combined his measurements of the distances to galaxies with other astronomers' measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. What could this mean about the universe? It means that the universe is expanding.

Figure 254 shows a simplified diagram of the expansion of the universe. One way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. Also, the dots farther away from you on the balloon would move away faster than dots nearby.

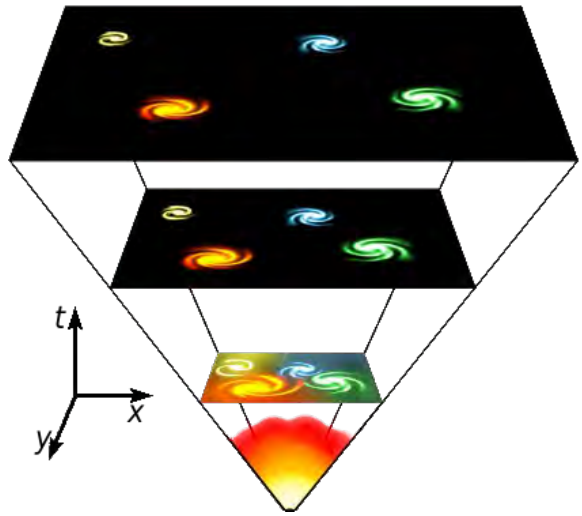


Figure 254: In this diagram of the expansion of the universe over time, the distance between galaxies gets bigger over time, although the size of each galaxy stays the same.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies, just as the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

An animation of an expanding universe is shown here:

- **http://www.astro.ubc.ca/~scharein/a311/Sim/bang/BigBang.html**.

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

The Big Bang Theory

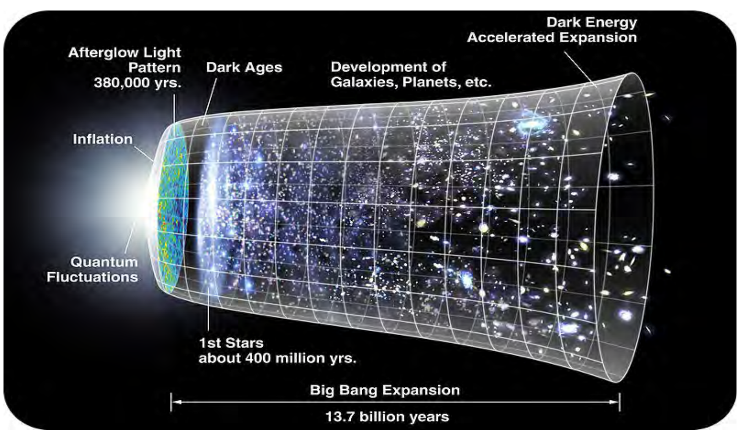


Figure 255: Timeline of the Big Bang and the expansion of the Universe.

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.

After the Big Bang

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

The matter in the early universe was not smoothly distributed across space. Dense clumps of matter held close together by gravity were spread around. Eventually, these clumps formed countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

Figure 256: Images from very far away show what the universe was like not too long after the Big Bang.

If you look at an image of galaxies at the far edge of what we can see, you are looking at great distances. But you are also looking across a different type of distance. What do those far away galaxies represent? Because it takes so long for light from so far away to reach us, you are also looking back in time (Figure 256).

Background Radiation

After the origin of the Big Bang hypothesis, many astronomers still thought the universe was static. Nearly all came around when an important line of evidence for the Big Bang was discovered in 1964. In a static universe, the space between objects should have no heat at all; the temperature should measure 0 K (Kelvin is an absolute temperature scale). But two researchers at Bell Laboratories used a microwave receiver to learn that the background radiation in the universe is not 0 K, but 3 K (Figure 257). This tiny amount of heat is left over from the Big Bang. Since nearly all astronomers now accept the Big Bang hypothesis, what is it usually referred to as?

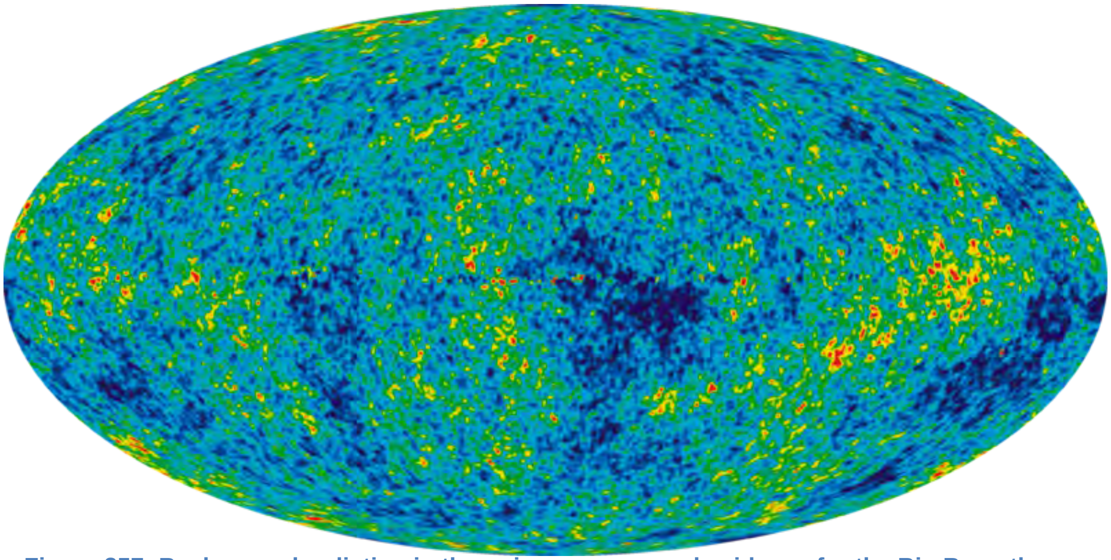


Figure 257: Background radiation in the universe was good evidence for the Big Bang theory.

Practice and Review

1. How did Hubble determine that the universe is expanding?
2. How do astronomers determine the composition of distant stars?
3. What is the significance of the idea that the universe is expanding?
4. How is the idea that the universe started in a big bang a logical extension from a fact?
5. What evidence is there that the universe began in a big bang?
6. What happened in the first minutes after the Big Bang?

Practice Test Astronomy

Introduction to Astronomy

1) The planets in our Solar System revolve around

a) The Sun
b) The moon
c) Saturn
d) Earth

2) This 17th century scientist was persecuted for saying the Earth orbits around the Sun.

a) Newton
b) Galileo
c) Ptolomy
d) Wegner

3) True or false. A geocentric model is sun-centered.

a) True
b) False

4) A geocentric model is where the universe revolves around this.

a) The moon
b) The planets
c) The sun
d) The Earth

5) True or false. The planets appear to move slower than the stars.

a) True
b) False

6) True or false. Ptolomy's system was centered around the sun.

a) True

b) False

7) This scientist's heliocentric model proved Galileo's idea that the planets revolved around the Sun.

a) Ptolomy

b) Kepler

c) Newton

d) Copernicus

8) Kepler's solar system model

a) Has the sun in the center

b) Has the planets moving in an elliptical shape

c) Is heliocentric

d) All of the above

9) True or false. Heliocentric means it is sun-centered.

a) True

b) False

10) The Earth's movement around the sun in an orbital path.

a) Axis

b) Evolution

c) Revolution

d) Heliocentric

Telescopes

1) Energy transmitted through space as waves

a) Electromagnetic radiation

b) Electronic waves

c) Sound waves

d) Sonic waves

2) A wavelength is the distance between two

a) Waves

b) Adjacent oscillations

c) Both A and B

d) None of the above

3) True or false. Visible light is light that humans can see.

a) True

b) False

4) The scientist who built the first telescope.

a) Newton

b) Einstein

c) Galileo

d) Lick

5) This scientist created the first reflecting telescope.

a) Newton

b) Einstein

c) Galileo

d) Lick

6) True or false. Refracting telescopes use mirrors.

a) True

b) False

7) Reflecting telescopes use mirrors because

a) They are lighter than the thick refracting lenses

b) Mirrors are easier to make

c) Mirrors are more precise to make

d) All of the above

8) These telescopes collect microwaves

a) Refracting telescope

b) Reflecting telescope

c) Radio telescopes

d) Microscope

9) True or false. Radio telescopes are better to use because it is out in space and is not blocked by Earth's atmosphere and does not get distorted by light.

a) True

b) False

10) The largest single telescope is the

a) Arecibo Observatory in Puerto Rico

b) The telescope on top of Mauna Kea in Hawaii

c) The National Radio Observatory in New Mexico

d) The Allen Telescope Array

Eclipses

1) A total solar eclipse is when

a) The Sun's shadow completely blocks the Moon

b) The Moon's shadow completely blocks the Sun

c) The Earth's shadow completely blocks the Sun

d) The Earth's shadow completely blocks the Moon

2) During a solar eclipse

a) The Moon passes directly between the Earth and the Sun

b) The Sun passes directly between the Earth and Moon

c) The Earth passes directly between the Sun and Moon

d) None of the above

3) True or false. A solar eclipse occurs when the Moon's shadow completely blocks the Sun.

a) True

b) False

4) True or false. Solar eclipses last only a few minutes because the Moon casts a small shadow.

a) True

b) False

5) True or false. A lunar eclipse occurs when the full moon moves through Sun's shadow.

a) True

b) False

6) A lunar eclipse is when

a) The Moon is between the Earth and Sun

b) The Sun is between the Earth and Moon

c) The Earth is in between the Sun and Moon

d) All of the above

7) The inner, cone-shaped part of the shadow, in which all of the light has been blocked.

a) Umbrella

b) Penumbra

c) Umbra

d) Pendulum

8) This occurs when the Moon travels completely in Earth's umbra.

a) Solar eclipse

b) Lunar eclipse

c) Total lunar eclipse

d) Total solar eclipse

9) True or false. The penumbra is the inner, cone-shaped part of the shadow, in which all light has been blocked.

a) True

b) False

10) True or false. A total lunar eclipse can last for hours.

a) True

b) False

Gravity

1) Gravitational force depends on _____________.

a) The mass of the objects
b) The distance of the objects
c) The volume of the objects
d) Both a and b

2) True or false. The greater an objects' mass, the greater the force of attraction.

a) True
b) False

3) True or false. The farther the distance between two objects, the greater the attraction.

a) True
b) False

4) This famous scientist was first to discover the principal of gravity.

a) Galileo Galilei
b) Sir Isaac Newton
c) Albert Einstein
d) Erwin Schrodinger

5) The gravitational pull from the __________ is keeping all the planets in our solar system in orbits around it.

6) Which of these planets experiences the weakest gravitational pull to the Sun?

a) Venus
b) Mercury
c) Jupiter
d) Neptune

7) Which of these planets experiences the strongest gravitational pull from the Sun?

a) Earth

b) Mercury

c) Mars

d) Venus

8) Which of the planets in our solar system has the greatest gravitational pull?

a) Neptune

b) Uranus

c) Saturn

d) Jupiter

9) Which of the planets in our solar system has the weakest gravitational pull?

a) Mercury

b) Mars

c) Earth

d) Venus

10) Which of the pairs of planets has the weakest gravitational pull toward each other?

a) Mercury and Venus

b) Earth and Mars

c) Jupiter and Mars

d) Mercury and Neptune

Introduction to Planets

1) Which of these is a dwarf planet?

a) Jupiter

b) Uranus

c) Pluto

d) Venus

2) Which of these is NOT an astronomer?

a) Copernicus

b) Kepler

c) Galileo

d) All of the above are astronomers

3) The Sun is _______ more the mass of the entire solar system combined.

a) 10 times

b) 20 times

c) 200 times

d) 500 times

4) Distance in the solar system is measured by _______________.

a) Miles

b) Kilometers

c) Astronomical units

d) Light years

5) The Sun is _________________________ million miles from Earth.

a) 93

b) 73

c) 53

d) 33

6) Which two planets have been discovered since the time of Copernicus, Kepler, and Galileo?

7) True or false. Venus rotates more slowly than the Earth.

a) True

b) False

8) Which planet has a diameter 9.41 times the Earth's?

a) Mercury

b) Mars

c) Uranus

d) Saturn

9) What is the order of dwarf planets starting from the one closest to the Sun?

a) Eris, Makemake, Haumea, Pluto, Ceres

b) Pluto, Haumea, Makemake, Ceres, Eris

c) Ceres, Haumea, Makemake, Eris, Pluto

d) Ceres, Pluto, Haumea, Makemake, Eris

10) If you are 10 years old on Earth, about how old are you on Mercury?

a) 1 year old

b) 4 years old

c) 40 years old

d) 80 years old

Inner Planets

1) Which of these is NOT an inner planet?

a) Venus

c) Mars

d) Jupiter

e) Earth

2) True or false. The outer planets have fewer satellites than the inner planets.

a) True

b) False

3) What is Earth's natural satellite?

a) The Sun

b) The Moon

c) An asteroid

d) None of the above

4) The inner planets' cores are made of _____________.

a) Metamorphic rock

b) Sedimentary rock

c) Igneous rock

d) Iron

5) True or false. None of the inner planets have rings.

a) True

b) False

6) The outer planets are also known as _______________.

a) Rocky planets

b) Rocky giants

c) Gas giants

d) Liquid giants

7) Gas giants are primarily made up of _________________.

a) Hydrogen

b) Helium

c) Oxygen

d) Both a and b

8) True or false. All the outer planets have planetary rings.

a) True

b) False

9) Which of these statements are true about the four inner planets?

a) They have slower orbits

b) They spin slower

c) They have no rings

d) All of the above are true

10) Planetary rings are made up of

a) Dust

b) Rock

c) Gas

d) All of the above

Star Power

1) True or false. Stars have the power of an atom bomb that comes from nuclear fusion.

a) True

b) False

2) Stars are mostly made from this element.

a) Hydrogen

b) Oxygen

c) Helium

d) Both a and c

3) Which of these is a type of electromagnetic radiation that the sun emits?

a) Visible light

b) Ultraviolet light

c) Radio waves

d) All of the above

4) This particle accelerator simulates the conditions in the stars to help explain how particles collide.

a) BERN

b) CERN

c) BARN

d) CARN

5) This keeps a star from collapsing from its own gravity.

a) Its moons

b) The corona

c) The energy from fusion

d) The rays emitted

6) True or false. The core of a star like the Sun can be 14,500,000 K.

a) True

b) False

7) Fusion is ____________.

a) The splitting of atoms

b) The combining of atoms

c) The corona of the star

d) The center of the star

8) True or false. The Sun produces more energy than most stars.

a) True

b) False

Star Classification

1) True or false. Orion's Belt consists of three different stars.

a) True

b) False

2) Betelgeuse is a ____________.

a) Bright, red star

b) Blue star

c) Yellow star

d) White dwarf

3) Extremely high temperature stars are __________.

a) Red

b) Orange

c) Yellow

d) Blue

4) Class M stars are ________.

a) Red

b) Orange

c) Yellow

d) Blue

5) Rigel is a ___________.

a) Yellow star

b) Blue star

c) Orange star

d) Red star

6) Our Sun is a ________.

a) Yellow star

b) Blue star

c) Orange star

d) Red star

7) True or false. The brighter the star, the colder it is.

a) True

b) False

8) A white star's temperature ranges from ____________.

a) 30,000 K or more

b) 10,000 – 30,000 K

c) 7,500 – 10,000 K

d) 6,000 – 7,500 K

9) The Hertzsprung-Russell diagram shows _____________________.

a) The brightness and temperature of a star

b) The distance and brightness of a star

c) The distance and temperature of a star

d) The temperature and classification of a star

10) True or false. Red stars are the coolest of stars.

a) True

b) False

Life cycle of a Star

1) Astronomers gather information about stars using __________.

a) Visual telescopes

b) Radio telescopes

c) X-ray telescopes

d) All of the above

2) Nuclear fusion of hydrogen produces ___________.

a) Oxygen

b) Carbon

c) Nitrogen

d) Helium

3) The Hertzsprung-Russell diagram shows ___________________.

a) The brightness and temperature of a star

b) The distance and brightness of a star

c) The distance and temperature of a star

d) The temperature and classification of a star

4) A star in a stage where the core produces helium from hydrogen is called a __________.

a) The main series star

b) The main sequence star

c) The massive series star

d) The massive sequence star

5) True or false. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse.

a) True

b) False

6) Our Sun has been a main sequence star for __________________.

a) One billion years

b) Three billion years

c) Five billion years

d) Ten billion years

7) True or false. Red giants are cooler and will soon collapse.

a) True

b) False

8) The star Sirius B is a ________.

a) Red giant

b) White dwarf

c) Blue giant

d) Blue dwarf

9) When there are no more elements left for a massive star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a _________.

10) If there is any leftover material after the supernova explosion, this can be made.

a) Sun

b) Dwarf star

c) Red star

d) Neutron star

Expansion of the Universe

1) This element was first discovered in our Sun by analyzing the absorption lines.

a) Hydrogen

b) Helium

c) Oxygen

d) Carbon

2) _______________ is the shift of absorption bands towards the red end of the visible spectrum.

3) How do astronomers know when a galaxy is moving away from Earth?

4) Hubble's Law states that:

a) The farther away a galaxy is, the faster it is moving away from us.

b) The farther away a galaxy is, the slower it is moving away from us.

c) The closer a galaxy is, the faster it is moving away from us.

d) The closer a galaxy is, the slower it is moving away from us.

5) True or false. The universe is expanding.

a) True

b) False

6) What is true about the universe?

a) Galaxies stay the same size

b) The space between galaxies is increasing

c) The universe is shrinking.

d) Only a and b

7) True or false. By examining the dark absorption lines, astronomers can determine the composition of elements that make up that star.

a) True

b) False

8) Which example is true about the Doppler Effect?

a) When an emergency vehicle is moving toward you, the sound waves are pushed together

b) When an emergency vehicle is moving away from you, the sound waves are spread apart

c) When an emergency vehicle is moving toward you, the light waves are pushed together

d) All of the above are true

9) True or false. If a galaxy is moving closer to Earth, it would have a blueshift.

a) True

b) False

10) Create a diagram showing a galaxy moving away from Earth. Include the color it would be because of this shift.

Glossary

Agents of erosion: The agents of erosion are wind, water, ice and gravity. They wear away at the surface of the earth. Erosion is referred as the movement of rocks or broken wreckage of rocks by natural agents of transport.

Alluvial Deposits: Material deposited by rivers. It consists of **silt**, **sand**, **clay**, and **gravel**, as well as much organic matter. Alluvial deposits are usually most extensive in the lower part of a river's course, forming floodplains and **deltas**, but they may form at any point where the **river** overflows its banks or where the flow of a river is checked. Refered to as alluvial fan in text.

Angular Unconformity: An erosional surface that separates rock units of differing dips. The rocks below the surface were deposited, deformed and eroded. The younger rocks above then accumulated upon the erosional surface.

Asthenosphere: The upper part of the Earth's mantle, extending from a depth of about 75 km (46.5 mi) to about 200 km (124 mi). The asthenosphere lies beneath the lithosphere and consists of partially molten rock. Seismic waves passing through this layer are significantly slowed. Isostatic adjustments (the depression or uplift of continents by buoyancy) take place in the asthenosphere, and magma is believed to be generated there. Shown in graphics.

Bed Load: Particles of sand, gravel, or soil carried by the natural flow of a stream on or immediately above its bed. Also known as bottom load.

Body Wave: A body wave is a seismic wave that moves through the interior of the earth, as opposed to surface waves that travel near the earth's surface. P and S waves are body waves. Each type of wave shakes the ground in different ways.

Cementation: The hardening and welding of clastic sediments (those formed from preexisting rock fragments) by the precipitation of **mineral** matter in the pore spaces. It is the last stage in the formation of a sedimentary rock. The cement forms an integral and important part of the rock, and its precipitation affects the porosity and permeability of the rock. Many minerals may become cements; the most common is silica (generally quartz), but calcite and other carbonates also undergo the process, as well as iron oxides, barite, anhydrite, zeolites, and **clay** minerals.

Chemical Weathering: (also known as decomposition or decay) is the breakdown of rock (**weathering**) by chemical mechanisms, the most important ones being carbonation, hydration, hydrolysis, (one reactant is water)oxidation, and ion exchange in solution.

Cinder Cone: (also called scoria cones) are the most common type of volcano and are the symmetrical cone shaped volcanoes we typically think of.

Composite (Strato) Cone: **sometimes called stratovolcanoes**. They are typically steep-sided, symmetrical cones of large dimension built of alternating layers of lava flows, volcanic ash, cinders, blocks, and bombs and may rise as much as 8,000 feet above their bases. Some of the most conspicuous and beautiful mountains in the world are composite volcanoes, including **Mount Fuji** in Japan, **Mount Cotopaxi** in Ecuador, **Mount Shasta** in California, and **Mount Hood** in Oregon.

Compressional Force: A directed stress (acts primarily in one direction) which results as a result of a rock being 'squeezed'. Is common along convergent plate boundaries.

Continental Drift Theory: In 1915, the German geologist and meteorologist **Alfred Wegener** first proposed the theory of **continental drift**, which states that parts of the Earth's crust slowly drift atop a liquid core. The fossil record supports and gives credence to the theories of continental drift and plate tectonics.

Continental Volcanic Arc: A curving chain of active volcanoes formed above a subduction zone and adjacent to a convergent plate boundary.

Convergent Boundary: A tectonic boundary where two plates are moving toward each other. If the two plates are of equal density, they usually push up against each other, forming a mountain chain. If they are of unequal density, one plate usually sinks beneath the other in a subduction zone. The western coast of South America and the Himalayan Mountains are convergent plate boundaries. Also called *active margin, collision zone*.

Correlation: The methods by which the age relationship between various strata of Earth's **crust** is established. Such relationships can be established, in general, in one of two ways: by comparing the physical characteristics of strata with each other (physical correlation); and by comparing the type of **fossils** found in various strata (fossil correlation).

Crust: The solid, outermost layer of the Earth, lying above the mantle.

Crystallization: Crystallization is the (natural or artificial) process for the formation of **solid crystals** from a uniform **solution**.

Deposit: An accumulation of dropped sediments.

Deposition: The process of dropped sediments accumulating

Detrital: Rocks that form as sediment grains (detritus or clasts), weathered and eroded from pre-existing rocks, are deposited as layers in low-lying areas such as valleys, lakes, or an ocean basin.

Discharge

Disconformity

Divergent Boundary: The edge where two tectonic plates meet where the two plates are moving away from each other.

Drainage Basin

Earthquake: Shaking of the Earth's crust caused by magma pressure or the movement of plates against each other.

Epicenter: The point on Earth's surface directly above the place where the earthquake occurs

Erosion

Extrusive Igneous Rock (Volcanic)

Fault

Felsic

Fluvial Deposits

Focus

Foliated

Fossil

Frost Wedging

Geologic Time Scale

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Half-life

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Inner Core

Intrusive Igneous Rock (Plutonic)

Law of Superposition

Lithification

Lithosphere

Mafic

Magnitude

Mantle

Mass Wasting

Mechanical Weathering

Metamorphic

Mid-Ocean Ridge

Mineral

Nonconformity

Nonfoliated

Normal Fault

Numerical Date

Orogeny

Outer Core

Paleomagnetism

Pangaea

Plate Tectonics

Polar Wandering

Primary Waves

Principle of Cross-Cutting Relationship

Principle of Fossil Succession

Principle of Original Horizontality

Radiometric Dating

Relative Dating

Resources

Reverse Fault

Rock Cycle

Runoff

Seafloor Spreading

Secondary Waves

Sediment

Sedimentary Rock

Shadow Zone

Shear Force

Shield Cone

Silicon Oxygen Tetrahedron

Soil

Strata

Strike Slip Fault

Subduction Zone

Suspended load

Tensional Force

Transform Fault Boundary

Transpiration

Transportation

Tsunami

Uniformitarianism

Volcanic Island Arc

Water Cycle

Weathering

mesa

PUBLIC SCHOOLS