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L. Seiger, SD Mesa College, September 2005

Geology Basics: Rocks and Minerals, Plate Tectonics, Climate History, Surface Water and Groundwater

This page is meant to serve as a preliminary source of information for geology concepts not covered in your textbook. For more complete explanations, the geology textbook *Understanding the Earth* by Frank Press and Raymond Siever is on closed reserve. The following information is adapted from that text. In addition, there are CD-ROMs which take you through all of the concepts and have animated demonstrations.

Rocks and Minerals:

Minerals –

A mineral is a *naturally occurring, solid crystalline substance, generally inorganic, with a specific chemical composition.* (26) In a mineral, the constituent atoms are bonded together in a specific, ordered lattice. The way in which a combination of atoms bonds depends on the atomic properties of each element.

Different minerals are classified based on a combination of their chemical composition and their crystal structure. Follow this link for more information on the chemical properties of minerals. Because crystal structures are unique to a mineral, a mineral can be identified by the shape of its faces and by its cleavage, or the planes along which it tends to break. This link has information about all the physical properties of minerals, and their identification.

Minerals form in several ways. When molten rock, or *magma*, falls below its melting point, the atoms and ions that make it up begin to combine in ordered structures and crystallize. When magma cools too quickly for any internal atomic order to be reached, the result is glass. When a solid rock reaches high enough temperatures (at least 250° C (35)) the atoms and ions in the minerals can rearrange themselves into new minerals with different crystal structures. Minerals can also form during precipitation, when liquids evaporate from a solution and elements begin to drop out of the solution and crystallize.

The most **common rock forming minerals** are: **silicates** that combine oxygen and silicon with the cations of other elements, **carbonates** that use the carbonate anion (CO32-) in combination with calcium and magnesium, **oxides** that combine oxygen and metallic cations, **sulfides** that combine the sulfide anion (S2-) and metallic cations, and **sulfates** that combine the sulfate anion (SO42-) with metallic cations.

The most common minerals that you will encounter are: quartz, feldspar (orthoclase and plagioclase), mica (biotite and muscovite), hornblende, pyroxene and olivine (all silicates); calcite and dolomite (both carbonates); magnetite, hematite and goethite (iron oxides and hydroxides); and pyrite (iron sulfide). Follow this link for more complete information on the particular properties of each mineral, or check out this mineralogy database.The rock-forming silicate minerals form from igneous melts at characteristic temperatures in a sequence called "Bowen's Reaction Series."

For a more complete presentation of mineralogy concepts, go to:
http://xtl5.colorado.edu/~smyth/G30101.html#Definition

Rocks –

All rocks are categorized into three basic types: igneous, sedimentary, and metamorphic.

Igneous rocks (from Latin *ignis*, meaning "fire") are formed from the crystallization of magma. This molten rock originates deep in the crust or in the upper mantle, at least 40 km below the surface (10), where the temperature is 700° C or more.(55) Igneous rocks have a crystalline structure, and for the most part each mineral type is evenly distributed throughout the rock (in contrast to metamorphic rocks, see below.)

Based on the size of their crystals, igneous rocks are classified as either intrusive igneous rocks or extrusive igneous rocks. These names refer to the way in which the rocks were formed. As magma cools, its various mineral components begin to crystallize. The slower the cooling process, the larger the resulting crystal is. **Intrusive igneous rocks** are formed deep below the surface, where they cool fairly slowly and form relatively larger crystals. Granite is a well-known intrusive rock. **Extrusive igneous rocks** are formed at or near the surface and cool very quickly, they are the product of volcanism. The most dramatic example of quick-cooling is obsidian, a volcanic rock that is cooled instantaneously with no time for crystal formation, and so instead has a glassy texture. Basalts are another type of volcanic rock that cool fairly quickly, but do have time for very fine crystals to form. The products of volcanoes also include ash flows and various combinations of ash, lava, and rock fragments welded together.

Different minerals have different melting points, and hence minerals in a rock do not crystallize simultaneously. In some rocks, large crystals begin to form while the magma is far below the surface, but the cooling process suddenly speeds up as the magma is pushed towards the surface. These rocks (called *porphyry* incidentally) have large crystals of one mineral surrounded by finer crystals of other minerals.

Mineral composition of igneous rocks : Igneous rocks are also classified based on their mineral content. The terms **felsic** and **mafic** refer to the relative proportions of elements in both individual minerals and a whole rock. Lighter colored rocks that contain minerals high in silica such as quartz and feldspars are called felsic (from *fel*dspar and *si*lica). Granite is an intrusive felsic rock; rhyolite has the same mineral composition and is the finer grained, extrusive version. Mafic (from *ma*gnesium and *ferrum* (iron)) rocks are darker in color and have a high proportion of iron and magnesium. There are also forms of rock with intermediate compositions (andesites are common intermediate extrusive rocks.) Mafic minerals crystallize at a higher temperature, or earlier, than felsic minerals do. (72) Go to this link for more about components of igneous rocks.

Sedimentary rocks are formed when layers of sediment are lithified (i.e., turned into a rock.) A sediment is any particle (clasts) such as sand, silt, or gravel, that is deposited somewhere, usually by water. Sedimentary rocks are also formed from chemical or biochemical sediments, such as minerals that are precipitated out of the water, or calcium carbonate from the skeletons of marine organisms. Sediments are lithified either by compaction or by cementation, in which minerals precipitate around the deposited particles and bind them together. Sedimentary rocks can be recognized by the fact that they consist of particles rather than crystals, and that they are *bedded*, or deposited in parallel layers.

Sedimentary rocks are classified based on the size of their particles. Gravel is defined as any clast larger than 2 mm in diameter. (157) **Conglomerates** are lithified mixtures of clasts too large to be considered sand. Sand consists of particles between 0.062 and 2 mm in diameter (157), lithified sand is called **sandstone**. Sandstone is easy to identify because the particles are large enough to be seen by the naked eye. Silt is between 0.0039 and 0.0062 mm in diameter and clay, which is smaller than 0.0039 mm in diameter, is actually fine enough to be indistinguishable as a particle. Lithified particles smaller than sand form **siltstones**, **mudstones**, **shales,** and **claystones**. Shale is made up of silt and clay, and readily breaks along bedding planes. There are also various types of chemical and biochemical sedimentary rocks. **Limestone** is a very important sedimentary rock. It can form from individual particles of calcite that are precipitated out of calcium carbonate rich waters, or from the accumulation of shells and other bits of marine organisms. A good way to determine whether a sample is limestone is to see if it reacts with hydrochloric acid. For a table of sedimentary rocks, their texture and mineral content, go here.

An important element to be aware of in studying sedimentary rocks is **depositional environment**. Both the material of the sediment itself, and the pattern in which it was deposited, can indicate a great deal about the original conditions of deposition. For instance, a homogenous layer of very fine particles indicates that the environment was calm enough to let these small particles settle, while shell fragments or well-rounded sand grains indicate a more turbulent environment. Go to this link for more information about grain shape. Also important to note is whether particles are well or poorly sorted. A **well-sorted** bed consists of fairly homogeneous particles, while a **poorly-sorted** bed contains a heterogeneous mix of various particle sizes. In addition, some beds are graded. Whether a bed is well or poorly sorted depends on the manner in which it was deposited.

Metamorphic rocks were igneous, sedimentary, or other metamorphic rocks in a past life. They are rocks that have been subjected to enough temperature and pressure to cause them to change their mineralogy, texture, or chemical composition while maintaining a solid form. (57) This occurs below the melting point of the rocks (700°

C) and above about 250° C. (57) Different types of metamorphic rock reflect their original forms. Marble is metamorphosed limestone, slate is (often) metamorphosed shale. Metamorphic rocks subjected to a minimum of temperature and pressure are referred to as *low-grade rocks*, while those subjected to very intense pressure and temperature are known as *high-grade rocks.* After enough metamorphic activity, it can become extremely difficult to determine the original form of a rock.

In **regional metamorphism**, a widespread area is affected by high temperature and pressure. This occurs during plate collision and resulting mountain building (see tectonics.) **Contact metamorphism** occurs when high temperature and pressure are restricted to a limited area. For example, it can be seen in rocks that border a magmatic intrusion. There are several other types of metamorphism as well.

When subjected to pressure, minerals that form platelike, sheety, or elongated crystals orient themselves perpendicular to the direction of the compressive forces. This is called their *preferred orientation.* The result is **foliation**, a set of flat or wavy parallel planes produced by deformation. (174) Depending on the grade and the specific mineral content of a rock, foliation can be apparent as slaty cleavage, a preponderance of sheety micas, or dark and light bands of minerals in rocks like schists and gneisses.

Nonfoliated rocks are composed mainly of crystals that are equidimensional and so have no preferred orientation. For instance, pure quartz sandstones form quartzite, a hard white unfoliated rock. They can also result when rocks are subjected to high temperature but not pressure, so that elongated crystals are randomly oriented.

Plate Tectonics:

Structure of the Earth: The earth can be divided up into three chemically distinct layers, the core, mantle, and crust. The **core**, which begins at 2900 km depth, is composed of iron. The outer core is molten, but the inner core is solid, as a result of the increased pressure at the center of the earth. The **mantle**, composed of materials with an intermediate density, comprises the bulk of the earth and ranges from 40 to 2900 km in depth. The **crust** is the thin outer layer made of cool solid rock. It is about 40 km thick, and is composed of lighter elements such as oxygen, silicon, and aluminum. (10) Continental crust and oceanic crust differ in important ways. **Continental crust** tends to be thick (up to 65 km) and contain rocks that are high in silica and therefore less dense. **Oceanic crust** is only about 5 km thick, and its rock is dense and mafic. Here is a picture of the two types of crust in relation to each other.

It is also possible to divide the earth according to the physical properties of its layers. The outer rigid layer, made up of the crust and upper mantle, is known as the **lithosphere** (from the Greek *lithos*, or rock). It is between 100 and 200 km thick. Beneath the lithosphere is the **asthenosphere**, which behaves as a ductile solid. When subjected to forces, the lithosphere is brittle and breaks, while the asthenosphere flows.Go to this site for a picture of the earth's layers.

Plates and Plate Boundaries: The lithosphere is not continuous, but rather broken into several large, rigid plates. Each plate moves as a single unit, while rifting, sliding, and subduction along plate boundaries allow the plates to move in relation to each other over time. While some plates are predominantly oceanic crust, others contain regions of ocean and regions of continent. Two hundred million years ago the continents were joined in the super-continent of Pangaea, but tectonic activity has caused the continents to move to their current positions. They are still moving. This site lets you play with maps of the moving continents, and this animated map is a little bigger and easy to see.

Plate movement is driven by convection cells in the mantle. Although the mantle acts as a solid in the short term, it flows over long periods of time. Convection cells are created as hot, less dense matter from nearer the core rises to the surface, and cooler denser matter from the surface sinks towards the core. Geologists are unsure as to how much of the mantle is actually involved in convection. (444)

The upwelling currents in the mantle cause plates to **rift** apart. Along these **divergent boundaries**, upwelling magma is constantly forming new basalt on the ocean floor and causing sea floor spreading. The plates on either side of the rift are being pushed/pulled) apart, and so there is also faulting from the tensional forces. Cooled magma from the mantle forms rocks that are dense and mafic - oceanic crust. When a rift valley opens in the middle of a continent, a new ocean basin begins to be formed. Therefore, rifts that have been active for a geologically long period of time are in the middle of oceans. These form mid-oceanic ridges, for the younger rock at the center of the rift is hotter and more buoyant, while the older rock on either side of the rift grows successively colder and denser and sinks topographically. (459) A prime example of divergent boundaries is the mid-Atlantic ridge, where the Eurasian and African plates on the east, and the North American and South American plates on the west, are being pushed farther and farther away from each other at a rate of about 5 cm a year.

Earthquakes and volcanism: Since the earth has a finite surface area, lithosphere must be destroyed as well as created. Sea floor spreading along some plate boundaries cause plates to collide on other parts of the earth, or to slide past each other. Earthquakes are caused by the friction of plates sliding against each other or pulling apart. The basic types of faulting are: **normal faults**, caused by tensional forces pulling plates apart; **thrust faults**, caused by compressional forces thrusting pieces of crust towards each other; and **strike-slip faults**, in which shearing forces pull plates past each other laterally. Interaction of plates also causes volcanism along plate boundaries.

Along **convergent boundaries**, where plates collide, **subduction zones** are created. If oceanic crust collides with continental crust, the denser oceanic crust will subduct under the continental crust. It is possible that the weight of the now quite cool oceanic crust sinking into the mantle helps drive plate tectonics. (458) In these subduction zones, a deep-sea trench forms off-shore of the continent, where one the oceanic plate along with sea floor sediments and some sea water sinks beneath the continental plate. Water lowers the melting point of rock (105), and so as the subducted crust begins to melt it also induces melting in the wedge of mantle above it, and creates magma for volcanic activity. Here is a diagram of the process. This process can be observed along the west coast of South America, where the Andes mountains were created by volcanic activity associated with the Nazca plate subducting underneath the South American plate. The Pacific Ocean is bordered by subduction zones, which correspond to the so-called "ring of fire," or ring of volcanic activity around the perimeter of the Pacific.

If two oceanic plates collide, one will subduct under the other, with the similar result of a deep ocean trench and a volcanic island arc. Japan was created by volcanic activity from the Pacific plate subducting under oceanic crust of the Eurasian plate. Islands are also created by hot spots. If two sections of continental crust collide, they will both stay afloat. The Himalayas are the product of such an event, in which folding, thrusting, and general thickening of the continent is taking place, creating very high mountains.

Some plate boundaries are neither divergent nor convergent, but instead plates slide past each other. These are called **transform boundaries**. Since no lithosphere is being subducted, these boundaries do not cause volcanic activity. They do, however, create earthquakes with strike-slip faulting. The California coast, where the North American plate slides south and the Pacific plate slides north, creating the infamous San Andreas fault, is an example of a transform boundary.

Rock type and plate boundaries: Different types of rocks form at divergent and convergent plate boundaries, depending on the rock type that is partially melted to form magma and the additions to that partial melt between its source and the surface. For instance, at mid-ocean ridges, asthenospheric mantle is partially melted to form mafic magma with the composition of basalt. Not surprisingly, basalt is the main rock type found in ocean basins. Volcanoes on oceanic islands such as Hawaii, formed from basalt, have a characteristic shield shape. At subduction zones, partially molten basalt (from the subducting plate), mantle (from the overlying mantle wedge), and crust (melted as the magma nears the surface) together form magma of intermediate composition. Volcanoes formed from this andesitic magma are typically cone-shaped, like Mt. Fuji and Mt. Rainier. When continental crust melts, the result is a felsic magma, which tends to explode rather than erupt quietly. These massive explosions result in calderas - giant holes in the ground - of which Yellowstone is a prime example.

Evidence of Plate Tectonics: Evidence supporting the theory of plate tectonics exists in the fossil record, the rock record, climate data, and in magnetic anomaly patterns. For example, fossils of the late Paleozoic reptile *Mesosaurus* are found in South America and Africa only. While it is remotely possible that *Mesosaurus* could swim the ocean and simply chose to live in eastern South America and west Africa exclusively, it is much more likely that these two areas represent what was a continuous range several hundred million years ago, when the reptile lived and the two continents were joined. (455) This link has more about fossil evidence. Other fossils show similar patterns of cross-Atlantic matching, as do rock formations and ancient mountain ranges. Evidence in the climate record consists of the fact that there is record of ancient glaciers in areas that are now in equatorial latitudes, while there is record of tropical swamps during the same time period at what are now very northern latitudes. If the continents are reassembled further south and contiguous, as they are believed to have been, the ancient glaciers sit comfortingly close to the south pole, while the tropical swamps are in the (then) equatorial region.

While the evidence above is largely based on reconstruction of continental arrangement, the sea floor provides some of the most convincing data. Geologists have found it impossible to locate sea floor rocks more than 175 million years old, a phenomenon only explained by the fact that older rocks have been subducted along convergent plate margins. (455) In addition, rocks nearest the mid-oceanic ridges are found to be very young, and they grow successively older the farther distant from the ridge they are located.

Magnetic anomaly patterns, created by the fact that the earth's magnetic field periodically reverses, are an additional piece of evidence and a way to measure the rate of sea-floor spreading. When an iron-bearing rock is formed, it is magnetized in the direction that the field is oriented at the time of formation. Thus, the discovery that the ocean floor has bands of positive and negative magnetic fields, progressing in mirror image from each other away from the ridge axis, supports the idea that the sea floor is constantly spreading. As new rock forms at the ridge, it is imprinted with the current magnetic field, and then slowly begins to migrate away from the ridge. Because geologists have managed to determine the direction of the magnetic field and its reversals through geologic history, they can correlate bands on the ocean floor with specific ages. Thus, the distance from a band to the central ridge, divided by the age of that band, will reveal the average rate at which that piece of ocean floor diverged from its point of origin.

Climate History:

In the beginning: The earth's climate has not been constant in its past, nor is it likely to remain constant into the future. Rather, it is in constant flux. The mechanisms determining climate are complex and depend on a number of interrelated factors. These include atmospheric gases, ocean currents, and phenomena such as volcanic activity and continental drift that affect the oceans and the atmosphere. The very early climate of the earth was drastically different than it is now, simply because there was not the oxygen-rich atmosphere that there is today.

A little more than 4 billion years ago, the earth's early atmosphere and hydrosphere had formed, possibly as a result of out-gassing and volcanism. Many rocks found in the mantle contain water and gases, and as these were brought to the surface they would have been trapped in earth's gravitational field. (548) Photosynthetic organisms evolved a relatively short time after the origin of primitive life, and their existence had a radical effect on the atmosphere, weathering processes, and the possibility of future life on earth. (551) The ozone ($O3$) layer formed, oxidative weathering began to operate on land surfaces, and oxygen-breathing organisms, protected from UV radiation by the ozone layer, began to evolve.

Glaciations: The geologic record shows that the earth has gone through many cycles of glaciations. The first clues came when geologists discovered vast areas of glacial deposits in North America and northern Europe – deposits that suggested continental ice sheets far larger than those currently in existence at the poles. The fact that these deposits came in layers, with older deposits towards the bottom, suggested that these continents had actually been subject to multiple cycles of glaciation. (346) Here is an animation of the most recent glaciation.

During glacial periods, much of the water now in the earth's oceans was instead tied up into massive ice sheets. Thus, glacial periods were times of lower sea levels; interglacials (such as the present one) have relatively high sea levels. This site provides an animation of the changing land forms and coast line since 244 mya of the US, resulting from both tectonics and glaciations.

More precise information on ocean temperatures and sea level comes from the shells of microscopic organisms preserved at the bottom of the oceans. There are two isotopes of oxygen: oxygen-16, and oxygen-18, or heavy oxygen. The ration of oxygen-16 to oxygen-18 absorbed by *single-celled animals called* foraminifera depends on the temperature of the water, so analysis of their calcium carbonate shells ($CaCO3$) reveals temperature changes through time. Also, oxygen-16 is preferentially evaporated from the ocean, so when a great amount of evaporated ocean water is trapped in ice sheets, the remaining water becomes oxygen-18 enriched. Thus, analysis of seabed sediments also indicates fluctuations in sea level. By graphing the relative change in oxygen-18 level, geologists were able to produce a graph of glacial and interglacial conditions through the time that the sediments were laid down. (See Figure 15.32, 347)

This site has a step by step explanation of all the aspects of glaciation, including diagrams of temperature over time, good to refer to.

Causes: The causes of massive climate change are only partially understood, which is why scientists are unsure of the implications of the present rise in carbon dioxide. The fact that there is a relationship between greenhouse gases in the atmosphere and glacial conditions is evidenced by air bubbles trapped in current ice sheets. The ice sheets over the poles and Greenland are remnants of the sheets that once covered continents. These sheets have been laid down in distinguishable layers, the result of annual accumulation, and so they bear a record of global climate conditions. Similar to seabed sediments, the oxygen-18 ratios in the ice indicate global temperatures at the time that the ice was formed. The air bubbles in these ice sheets indicate that carbon dioxide and methane, both greenhouse gases, were more plentiful in the atmosphere during interglacial warm periods, and more scarce during glacial periods. If you scroll down on this site, there is a graph of temerature versus carbon dioxide.

Ocean currents are also a factor in global climate conditions, for they serve to circulate heat from the equator to the poles. Currently it is the Gulf Stream, bringing warm water up from the Gulf of Mexico, that allows the British Isles and western Europe to have a temperate climate. It is part of a sort of conveyor belt, which brings a warm, shallow current north, where the water cools and becomes more saline (because of less freshwater input in the north) and sinks to return south. If this system were to shut down or be blocked off somehow, climate conditions would change drastically. Some theories attribute the existence of glaciations to continental drift. Throughout most of earth's history, there were no land-masses over the poles, and water circulated freely, distributing heat fairly evenly over the earth. However, with the action of plate tectonics, continents eventually moved over the poles, blocking the previous currents and creating a greater temperature differential between the equator and the poles. (350) In the current configuration of continents, there are negative feedback cycles that seem to have affected glacial periods. When glaciers begin to melt, a large volume of freshwater is introduced into the North Atlantic. This affects the North Atlantic conveyor belt discussed above, and while the implications are not fully understood, Europe could suddenly become very cold. (351) This link is to a very long article about the possibility of sudden climate change. If you scroll through the article, there are pictures of the North Atlantic currents. And here is a very cool satellite image of the gulf stream.

The alternation between glacial and interglacial periods can possibly be explained by astronomical cycles, this is called the Milankovitch theory. The amount of solar energy that the earth receives varies over time based on periods in the shape of the earth's orbit, the tilt of the earth's axis, and the wobble of the axis. All these variations combine to predict a long-term periodic glaciation every 100,000 years, and shorter ones about every 40,000 and 20,000 years. (350)

Effects: From the point of view of humans trying to cope with global climate change, it is alarming to note that major changes in global climate seem to take place over a very short period of time. Here is an article on the quick nature of climate change. For instance, the last major glaciation, which ended about 11,700 years ago, did so in the span of about 10 years. (351) Indeed, the peaks and valleys of climate change graphs are consistently steep. Rapid changes of this sort could be disastrous from the point of view of agriculture, human settlement, and most plant and animal populations, because vegetation and population patterns would not have time to adjust to the new conditions. The most we know of glaciations recorded in human history is from the Little Ice Age, which occurred from A.D. 1400 to 1650 (some scientists believe the Little Ice Age lasted well into the 19th century). For graphs and evidence of the Little Ice Age, see this site. During this time the Baltic Sea froze over, and ice on the Thames, which does not freeze in modern times, reached a thickness of several inches. (352) This sudden change in climate was rather hard on the populations affected. However, the decrease of global temperature during the Little Ice Age was less than 1° C. For a Washington Post article on conditions during the Little Ice Age, go here.

Surface Water and Ground Water:

Hydrologic Cycle

Water on earth exists in solid, liquid, and gaseous forms. Powered by heat from the sun, this water cycles through a series of reservoirs that include the oceans, glaciers and polar ice, underground waters, lakes and rivers, the atmosphere, and the biosphere. Like any earth system, the hydrological cycle is very complex with many possible inputs and outputs in each reservoir. In a simplified depiction, sun evaporates water from the oceans and transports it as water vapor in the atmosphere. Eventually, this water is precipitated as rain or snow. It may soak into the ground by infiltration, at which point it could re-evaporate from the soil surface, be absorbed by plants and then released through the leaves in transpiration, or be incorporated into the groundwater store on a long term scale. Some of this groundwater will re-emerge on the surface via springs, and in addition to precipitation that runs over the surface as runoff**,** will make up the store of surface water in lakes, rivers, and streams. Precipitation that falls as snow could eventually melt and become surface or groundwater, or could become tied up in glaciers or ice sheets for long periods of time. Both surface and groundwater flow eventually makes it back to the oceans. Go to this site to learn more details about evaporation, condensation, transport, precipitation, groundwater, transpiration, and runoff.

How much water is there?

There is an enormous quantity of water on earth, about 1.46 billion cubic kilometers. However, 95.96% of this water is stored in the oceans, and another 2.97% is tied up in glaciers and polar ice. Only 1.059% is available as fresh water in lakes, rivers, and groundwater. Illustration. For this reason, the avialability of freshwater on the earth cannot be taken for granted. Here is a human-centered diagram of the water cycle.

Groundwater

A great deal of water flows through the ground in soil and porous rock. **Porosity** is the amount of pore space in a rock, and determines how much water a rock can hold. Grains that are more loosely packed leave more pore space - smaller grains can be packed more tightly, as can poorly sorted grains of irregular sizes. Cementing minerals between grains also decrease porosity. **Permeability** is the ease with which water can move through the rock body. In general, higher porosity indicates higher permeability, but permeability also depends on how well pores are connected. Loosely packed sandstones or gravels are likely to have the greatest porosity and permeability, while fine grained shales will have very low porosity and permeability. Water can also flow through rock that does not have pore space between grains but instead has a series of fractures. Here is a graphic depiction of water in rocks.

The **water table** is simply the depth at which the soil or rock becomes saturated. Depending on the aridity of the region, the water table can be just a few feet down or extremely deep. The water table can also fluctuate seasonally, rising during periods of heavy precipitation and infiltration, and falling as precipitation ceases and water is evaporated from the soil surface or transpired by plants. Groundwater flows based on the slope of the water table - this slope does not necessarily mirror the surface topography.

The reservoir of groundwater is increased and decreased through **recharge** and **discharge**. Recharge occurs by infiltration from precipitation, or from **influent streams**. In arid conditions, where the water table is deep, water in streams fed by runoff seeps from the stream bed down through the rock and recharges the groundwater supply. **Effluent streams** contribute to discharge, or the exit of groundwater to the surface. In humid conditions stream channels can intersect the water table, and they are fed by this discharge. Here is an illustration of groundwater flow and effluent and influent streams.

An **aquifer** is a bed of rock that can store and transmit water in sufficient quantity to supply a well. In an **unconfined aquifer**, water flows through beds that are of more or less uniform permeability all the way to the surface, and the top of the aquifer is the top of the water table. Relatively impermeable beds, such as shales, are called **aquicludes**. A **confined aquifer** is a permeable bed such as a sandstone bounded above and below by aquicludes. This water flows under pressure, and is know as an **artesian flow**. Wells drilled into a confined aquifer do not require pumping and are known as **artesian wells**. If an aquiclude exists above the main water table of an unconfined aquifer, there may be a small aquifer formed above it called a perched water table. Here is an illustration of aquifers and wells.

If a well pumps water from an aquifer at a rate faster than the aquifer can be recharged through infiltration, the water table drops in a local **cone of depression** around the well. Illustration The water level in the well drops to the level of the water table at the bottom of the cone of depression, and if water is pumped too quickly the cone of depression will extend to the bottom of the well and the well will go dry. The combined effect of excessive pumping at many points can cause **depletion** of the aquifer. A side effect of depletion is that materials overlying the aquifer that were formerly held up by the volume of water and pore pressure no longer have this support, causing the land to drop in elevation. In addition, sediments that no longer have water between their grains will compact and cause a further decrease in land volume. Near the ocean's edge, overpumping creates a drop in freshwater groundwater pressure, allowing an incursion of saltwater in an inverse cone of depression. Wells in these areas can start drawing up saltwater.

The rate of recharge and discharge in a aquifer is partly dependent on the speed of groundwater flow. The rate at which water flows from one point to another is directly proportional to the drop in elevation of the water table between the two points, and inversely proportional to the distance the water travels. In other words, it is based on the steepness of the slope. This slope is known as the **hydraulic gradient**. The hydraulic gradient is important because in areas of gentle slope (such as the great plains) aquifers are recharged at a slow rate and it is relatively easy to deplete them.

For more information on aquifer depletion in the Great Plains, read this article on the Ogallala Aquifer depletion.

The quality of groundwater is effected both by the material through which it flows, and by the byproducts of industrial processes and other human-caused contaminants. While safe to drink, water that has percolated through limestones will be rich in calcium and magnesium and therefore 'hard', and water that has passed through waterlogged soil rich in organic compounds may pick up enough hydrogen sulfides to taste and smell rather bad. Lead from industrial processes is a well known pollutant, now routinely eliminated from public water supplies, and contaminants from radioactive waste have also been know to leach into shallow groundwaters (Oak Ridge, Tennessee, and Handford, Washington.) Pesticides, herbicides, and fertilizers are also potential sources of groundwater contamination. To learn more on this subject, check out these two articles.

- Pesticides and groundwater contamination
- Groundwater Quality and the use of Lawn and Garden chemical by homeowners

Surface Water

Surface water is the water in streams lakes rivers and oceans, and all other water that flows over the surface of the earth rather than through the soil and bedrock. Fluid **flow** is distinguished as being laminar or turbulant. **Laminar flow** occurs when streamlines run parallel to each other and do not mix. **Turbulent flow** is a more complicated flow in which streamlines mix and cross and form swirls and eddies. Whether a flow is laminar or turbulent depends on the velocity and the geometry (primarily depth) of the stream. Increased velocity and depth leads to increased turbidity.

Turbidity and velocity also determine how much sediment a river or stream can carry. Turbulence lifts particles from the bed into the flow, and also rolls particles along the bottom of the bed. The greater the velocity of flow, the larger the particles that can be lifted up. The rate at which particles can settle out of suspension depends on their size and on the flow velocity. Larger particles stay in suspension for relatively short times, while small grains of silt and clay settle very slowly and can only be re-deposited at slow velocities. Thus geologists can infer the velocities of ancient currents from grain sizes of the sediments.

Discharge measures the size of a stream's flow - it is the volume of water that passes by a given point in a given time through a specific channel. It is commonly measured in cubic meters per second or cubic feet per second. It is found by mulitiplying the cross-sectional area of the channel by the velocity of the water. An increase in either velocity or cross-sectional area increases the total discharge. In most rivers, discharge increases downstream as more and more water is added from tributaries. The university of Minnesota has provided stream flow information for all the watersheds in Minnesota.

Floods occur when greatly increased discharge causes an imbalance between input and output, and water overflows the banks of the stream channel. Small floods are relatively frequent, occuring every 2 or 3 years on average, while larger floods may occur every 10, 20, or 30 years. While it is impossible to predict the extent of flooding in any given year, it is possible to discuss the probability of a flood of a specific magnitude occuring on a given stream in a given year. This probability is based on the average time interval between floods of that specific size. This average time is called the **recurrence interval**. Therefore, a flood of a magnitude that is likely to occur only once every 50 years is called a 50 year flood, no matter when exactly the last flood of that magnitude was. The recurrence interval for a flood of a specific height varies from stream to stream, and depends on three factors. These are the climate of the region, the width of the floodplain, and the size of the channel.

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