Basic Geology and Groundwater

This CEU (continuing education unit) has been prepared to refresh the reader’s basic understanding of geology as it applies to the groundwater industry.

Geology is the study of the planet earth, the materials of which it is made and the processes that affect these materials, the changes that the earth has undergone in the past and the changes that it is currently undergoing.

Geology makes better sense if we allow ourselves to think in terms of “geologic time.” Geologic time requires us to view the unfolding of geologic events in terms of “eons.” An “eon” is a time period of 1 million years. The earth is a dynamic planet, undergoing constant changes. However most of these changes occur so slowly and over such a long period that they are much better understood if we allow ourselves to think in eons of time rather than over any shorter time period.

Even though most geologic changes happen over eons, some geologic events can change the structure of the earth immediately. Earthquakes, volcanic eruptions, and storm surges have immediate impacts on the earth. These same events also contribute to the longer term earth changes that happen over eons.

The study of ancient rocks indicates that the earth is 4.6 billion years old. An easy to understand example to illustrate the unfolding of the earth over its entire lifespan of 4.6 billion years is to think of the entire 4.6 billion years as simply a single 24 hour day. This example allows us to more easily see how the timing of certain events in the earth’s history relate to other events. So let us say that the entire age, 4.6 billion years of the earth’s age is simply a 24 hour day, from midnight to noon (the A.M. period) and from noon to midnight (the P.M. period).

The first complex life forms, trilobites, appeared at about 530 million years ago or 9.14 P.M. Note that over 80% of the earth’s history had already occurred by the time these life forms had appeared. At 9.24 P.M. the first fish appeared. Reptiles arrived at 10.27 P.M., or 300 million years ago. Dinosaurs roamed the planet from 230 million years ago until 65 million years ago or until 11.40 P.M.

Florida began moving to its present position at 10.59 P.M. or 195 million years ago. The first birds appear at 11.14 P.M., or 150 million years ago. And then just a minute before midnight, at 11.59 P.M., humankind makes its appearance on earth, or less than two million years ago.

During this entire time, 4.6 billions years, geologic processes have been continually shaping the world. As an example, the basement rocks beneath Florida were once part of Africa and were formed before the Atlantic Ocean.
Tectonic Plates

Drillers are concerned with the earth’s crust, the outermost layer of the earth’s surface. The thickness of the crust varies from 5 to 25 miles. When the earth was newly formed it did not have atmosphere. It is the geologic events that have occurred since the earth’s formation, over eons of time, that have created our atmosphere and all of the earth’s water resources.

These geologic events have resulted in the earth as we know it today. The earliest theory that showed the proper approach to explaining the events that shaped our planet was put forth by a German meteorologist (one who studies the earth’s atmosphere, especially its weather and its weather patterns) in 1912. Alfred Wegener proposed the idea of Continental Drift. His ideas centered around continents moving across the face of the earth. The idea was not quite correct compared to the plate tectonics theory of today - but his thinking was on the proper track.

Today Wegener’s theory of “Continental Drift” has been refined as “Plate Tectonics.” To better understand the theory we must go, for a moment, to the layers beneath the earth’s crust. Below the crust are two layers called the outer and inner mantle. The outer mantle, just beneath the crust extends down 1,800 miles to the second mantle layer (the inner mantle) which ends at the earth’s core, an additional distance of 1200 miles.

Within the upper mantle, approximately 50 to 100 miles within the mantle, conditions of radioactivity, temperature and pressure allow a partial melting of the mantle rock. Once melted the rock material is lighter than its surroundings and seeks to rise to the surface. An easy illustration that perfectly shows the rising of this melted mantle rock is the common “lava light”. Found in stores for the past several decades lava lights are continually in motion as the substance within the light heats, expands and rises. This is exactly the way in which the molten magma seeks to rise from within the mantle layer.

The earth’s surface is divided into approximately 21 tectonic plates. At certain of the borders of these plates, the zones of divergence (see illustration below), magma from the earth’s mantle rises to the surface pushing the plates away from each other as the magma cools and add new rock material to each plate pushing them farther apart.

Each tectonic plate moves independently and is in constant motion. Some plates move toward each other (zones of convergence), others away from each other (zones of divergence). The motion of the plates is well illustrated by the solid and double lines of the picture below:

EARTH’S MAJOR TECTONIC PLATES-DARK SINGLE LINES ILLUSTRATE TRENCH ZONES WHERE PLATES MEET; DOUBLE LINES ILLUSTRATE RIFT ZONES WHERE PLATES ARE PUSHED APART.
It is the continual oozing of the magma from the mantle level of the earth to the crust’s surface that pushes tectonic plates away from each other. When two tectonic plates collide or slip past each other, major geological events occur.

Earthquakes occur when plates slide past each other. When one plate is driven beneath another, volcanoes may form. When two plates collide mountain ranges may form.

Since the diameter of the earth must remain constant, if magma is constantly pushing plates apart, at other points of plate contact one plate passes underneath another and is reabsorbed into the mantle. The two pictures below clearly show the rift zones where the molten magma comes to the earth surface and the trench zones where plates are reabsorbed into the mantle layer.

**RIFT ZONE- MOLTEN MANTLE ROCK (MAGMA) COMES TO THE SURFACE, PUSHING TECTONIC PLATES APART.**
As the North American plate continues to move away from the African and Eurasian plates the Atlantic Ocean expands. (Refer to tectonic plate diagram above) To put the growth of the Atlantic Ocean in perspective, the ocean can be said to be expanding at about the same rate as human fingernails grow per year or less than two inches.

Pangea

320 million years ago, the earth’s land masses came together to form one colossal continent, called Pangea. Pangea included the continents of: North and South American, Africa, Europe, Asia, Australia and other land masses.
Over a two hundred million year period, Pangea separated along tectonic plate boundaries and the continents drifted to their present positions again through the action of molten magma coming to the surface and depositing at rift zones.

The Atlantic Ocean formed as the North and South American Plates were pushed apart from the African and Eurasian plates. Part of what had been a was left behind and became the basement rocks under what is now Florida.

The formation of Florida

Geological speaking Florida is one of the most recently formed states in America. The Florida platform is a wide relatively flat feature made up of limestone and dolomite and lies between the deep waters of the Atlantic Ocean and the Gulf of Mexico and was largely under water until 24 million years ago.
As the Appalachian Mountains eroded some of their sands and clays were deposited in areas to the south but the gulf trough prevented these deposits from depositing on the Florida peninsula. Over millions of years the gulf trough was filled and the sands and clays of the Appalachian Mountain erosion mixed with developing limestone to form the Florida peninsula. As well most of Florida’s beach sand comes from the erosion of the Appalachian Mountains.

Mineral Formation

Minerals are the basic chemical compounds of the earth. Rocks are made of mixtures of minerals. Many of the properties of a rock are related to its
origin. Rocks are classified by origin into three main groups: Igneous rocks, sedimentary rocks, metamorphic rocks.

Igneous rocks are formed when magma from the earth’s interior cools and solidifies. Granite and basalts are examples of igneous rocks.

Sedimentary rocks are of two types. The first type-detrital, are particles of earlier existing rocks that have been weathered and decomposed from previous solid rock formations exposed at the surface. Sandstone and shale are examples of detrital sedimentary rocks. Detrital rocks may have weathered in place or have been transported by water, ice or air (such as glacial activity) to new sites. Detritus is the name given to materials produced by the disintegration and weathering of rocks.

The second sedimentary rock type is – chemical, formed minerals in solution are made insoluble and deposited. Major river systems, lakes, tidal flats, reefs and lagoons are amount the sites where chemical type sedimentary rocks are formed. Limestone and coal are examples of chemical sedimentary rocks.

The final major classification by origin is metamorphic. Metamorphic rocks develop as igneous and sedimentary rocks are changed (metamorphosed) by heat and pressure in the earth into totally different types of rocks. Metamorphic rocks are formed when other rock types are caught in areas of earth movement such as when mountain ranges or oceans are opened up. Marble and slate are examples of metamorphic rock. Marble is metamorphosed limestone while slate is metamorphosed shale.

The Evolution of the hydrosphere

It was earlier stated that the earth had no water resources and no atmosphere at the time of its original formation. Both the atmosphere and water resources of the earth evolved as a result of natural geologic processes occurring over the past 4.6 billion years.

Volcanoes are formed in the areas where tectonic plates collide and or slide past each other. This is illustrated by the dark solid line in the tectonic plate picture above.

Volcanic eruptions release huge amounts of gases principal among which is water vapor. Over geologic time, large amounts of the water vapor released by volcanic action formed what is called juvenile water. That is water that had never existed on earth before. Aside from the water vapor liberated by the melting of rocks during volcanic eruption, water vapor is also released during the weathering of rocks, -the process by which detrital sedimentary rocks are formed.

As plant life developed on earth, large amounts of oxygen were contributed by photosynthesis. This oxygen combined with hydrogen also given off during volcanic eruptions also created juvenile water.
Although this may seem too brief a description to explain the formation of the entire water supplies of the earth, it makes more sense when viewed from the perspective of geological time. Imagine continuous volcanic eruptions for millions of years and it is then easier to understand how the gases liberated during this period became the juvenile water that came to be the earth’s water resources.

Glaciers

The age of glaciation was marked by several periods of time when ice advanced and retreated over large portions of the northern United States. The impact of glaciation was felt even in areas never specifically touched by the glaciers themselves. Florida is such an area. Ocean levels rose and fell dramatically with the advancement or retreat of the glaciers. Glacial melting caused oceans levels to rise as much as 100 feet above present day levels. During periods of advancement glaciers caused the sea levels to drop to over 300 feet above present day levels. Florida’s present day topography was largely shaped by the rising and falling of the ocean levels as the glaciers advanced and melted far to the North.

The latest ice advances began about 80,000 years ago with the ice withdrawing about 10,000 years ago from most areas in the northern United States, southern Canada and Scandinavia. These most recent glaciers were not as large as some earlier glaciers.

As these latest glaciers retreated, they left sediments called glacial till (detritus) deposited irregularly in both extent and depth. Unlike sediments deposited by other agents of erosion (wind and running water) glacial till can consist of all sizes of sediment intermixing huge rocks with clays or fine sand. Drilling in areas of glacial till is often challenging as these formations may contain huge boulders.

GLACIAL TILL

During times of glacial melt, strong river flows originating from the melting glaciers transported significant amounts of coarse sands and gravels through what became major river systems. Aquifers formed from this glacial melt action are called outwash planes and can represent excellent sources of groundwater.
GROUNDWATER

Over 95% of the world’s total fresh water supply is held in the ground. Groundwater may be stored wherever formations are porous, that is, having sufficient spaces in the formation where the water may be captured. If the formation is also permeable, that is, it allows ready communication between the pores, and then groundwater may flow easily. Permeable formations containing water are called aquifers. An aquifer is a water bearing layer or formation of earth, gravel or porous rock with interconnecting openings or pores through which the water can move. It is not enough for the formation to be porous, it must also be permeable.

Porosity

The capacity of soil or rock to hold water is called porosity. Saturated sand contains about 20% water; gravel, 25%; and clay, 48%. Saturated bedrock with few crevices commonly contains less than 1% water. Clay is not a good water source despite its high water content, or porosity, because the extremely small size of the openings between microscopic particles creates friction that effectively halts water movement. Saturated clay is virtually impermeable.

Permeability

Permeability is a measure of how fast water will flow through connected openings in soil or rock. Impermeability refers to soil or rock that does not allow water to pass through it. The specific yield is the actual amount of water that will drain out of saturated soil or rock by gravity flow. It does not drain out completely because some water forms a film that clings to soil and rock. Permeability is critical for water supply purposes; if water
Aquifers

Some water producing formations or aquifers are better producers of water than others. How much water the aquifer will produce depends very much on the sort of rocks that make up the aquifer.

A water-bearing soil or rock formation that is capable of yielding useable amounts of water is called an aquifer. Mixed clay, sand, gravel, and fine particles that were deposited by continental glaciers (glacial till) yield low amounts of water. Materials sorted into distinct layers will yield high amounts of water from coarse-grained sand and gravel, but low amounts from fine-grained sand, silt or clay. Bedrock aquifers will yield substantial amounts of water if there are large openings or cracks, but small amounts if there are few openings in the rock.

Good aquifers are those with high permeability such as poorly cemented sands, gravels, and sandstones or highly fractured rock. Large aquifers can be excellent sources of water for human usage such as the High Plains Aquifer (in sands and gravels) or the Floridian Aquifer (in porous limestones).

Types of Aquifers

Clean Gravel Deposits

These absorb water rapidly. The gravel has large pores through which water can move. The formation holds large quantity of water and is easily tapped to produce large yields.
Sand and Gravel Mixtures

These are also very good aquifers. Where the percentage of gravel to sand is very high, the aquifer is a good water producer. Sand holds large quantities of water but because of the small holes between the grains in the sand, water is not easily obtained. A large portion of clay in the sand or sand and gravel aquifers destroys their value. Clay is very porous but its pores are so small that water cannot flow, making it impermeable.

The two aquifers described above are unconsolidated. Consolidated formations can also provide aquifers ranging from poor producers to excellent producers of water.

Consolidated Aquifers

Some sandstone deposits may form good aquifers depending on the sandstone cementing agents. Sandstone aquifers cemented by silica or calcium carbonate may be good water producers. However, if clay is the bonding agent the rock is a poor water producer.

Limestone

This sedimentary rock often provides an excellent source of water. The Floridan aquifer underlying Florida is considered the world's most productive aquifers. Because limestone can be dissolved and worn away by water, these formations may develop large underground caves.

Basalt

Basalt can be a good producer of water, particularly if it is full of small holes or is well fractured. Weathered basalts however tend to be poor producers because minerals in the salt decompose to clay.

Aquifer Size Shape and Configuration

Aquifers may cover very large areas with enormous distances from recharge to outflow. Water may remain in the lower part of aquifers for tens of thousands of years, moving slowly toward outflow.
Groundwater Flow Rates

Valley Aquifers

Long narrow aquifers often associated with river valleys. Usually of sand and gravel these aquifers may draw water from the river at many points and discharge back into the river at many others. Water movement within the aquifer may continue long after surface water has disappeared during times of drought.

Confined Aquifers

Aquifers covered by an impermeable confining layer occurring both above and below the aquifer allow pressures to increase to the point where if a well is sunk into the confined aquifer, water will rise to its potentiometric (or potential) surface. That is, the water will rise above the top level of the aquifer until it reaches the imaginary level (potentiometric level) reached by converting the pressure in the confined aquifer to the height of a column of water that will be supported by the pressure in the confined aquifer.

[The formula for converting pressure, measured in pounds per square inch to feet of head is to multiply the pressure by 2.31. The result will be the height, in feet, which the water will rise above the upper level of the confined aquifer]. Confined aquifers are commonly called artesian aquifers.
The movement of water from the land to the ocean, to the atmosphere, and back to the land is referred to as the hydrologic cycle. When you look at the water cycle illustration above you can see that the water cycle has neither a beginning nor an end.
Evaporation from wet ground, river, lakes or from the sea takes place by heat radiation from the sun causing the vapor to rise where it may collect to form clouds.

Under certain conditions, cloud moisture condenses and falls to earth as rain, hail, sleet or snow. Some of the precipitation wets the ground, and the plants. Part of the remainder runs into lakes and streams, where it provides our fresh water supply.

Groundwater is usually replenished (recharged) by water soaking downwards into the soil beneath the root zone of the plants. This takes place intermittently during and immediately following periods of rain and snow-melt. Recharge occurs where permeable soil or rock allows water to readily seep into the ground. These areas are known as recharge areas. Permeable soil or rock formations where recharge occurs may occupy only a very small area or extend over many square miles. Valley aquifers may also receive recharge from hillside runoff or streams that flow down from hillsides in addition to the rain and snow that falls directly onto the land surface overlying the aquifer.

Recharge Areas and Discharge Areas
The Earth's surface can be divided into areas where some of the water falling on the surface seeps into the saturated zone and other areas where water flows out of the saturated zone onto the surface. Areas where water enters the saturated zone are called recharge areas, because the saturated zone is recharged with groundwater beneath these areas. Areas where groundwater reaches the surface (lakes, streams, swamps, & springs) are called discharge areas, because the water is discharged from the saturated zone. Generally, recharge areas are greater than discharge areas.

**RECHARGE**

![Diagram of recharge and discharge areas](image)
Much of the water that enters the soil is taken in by the roots of plants and is eventually lost into the atmosphere by a process called transpiration. Some water soaks below the plant root area under the influence of gravity and continues moving downward to enter the groundwater reservoir.

A groundwater reservoir with a free upper surface is known as a water table aquifer or unconfined aquifer.

**UNCONFINED AQUIFER**

The upper surface of such an aquifer is known as the water table. All pore spaces and fractures below the water table are filled with water and are called the saturated zone. (see illustration below)
The top of the saturated zone is called the water table. The water table rises and falls according to the season of the year and the amount of rain and snowmelt that occurs. It is typically higher in early spring and lower in late summer. Heavy rainfall or drought conditions may cause changes in the typical pattern, however.

The position and slope of the water table is information of vital interest to hydrogeologists, groundwater hydrologists and drillers. The groundwater moves steadily down the slope. Its outflow or discharge points may be at a spring, a well, a river or into the sea.
The water table may be at, or even above, the ground surface or may be only a few feet below the surface in humid regions. In deserts, the water table can be many hundreds of feet below the surface. Where the water table is close to the surface, we see it as the surface of a swamp or lake as illustrated above.

The streams or rivers carrying both groundwater discharge and surface run-off eventually lead to the oceans, and so the cycle continues.

The concept of the hydrologic cycle commonly begins with the waters of the ocean, since the ocean covers about ¾ of the earth’s surface, but much water is re-cycled before it reaches the ocean.

Therefore we can see that the cycle has neither a beginning nor an end. There are several important general statements or generalizations that can be made about the water table and the way the water table is related to the surface topography and surface drainage.

The water table runs roughly parallel to the topographic surface, that is, it is highest beneath the hills and lower in valleys. In areas of rolling hills, the water table rises and falls with the surface of the land. In flat country the water table is flatter.

A difference in the level of the water table is built up and maintained in areas of high elevation. During periods of heavy rainfall the water table rises in areas beneath the hills and during drought it tends to flatten out.

Always the groundwater movement follows the downhill slope of the water table.

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