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Contents

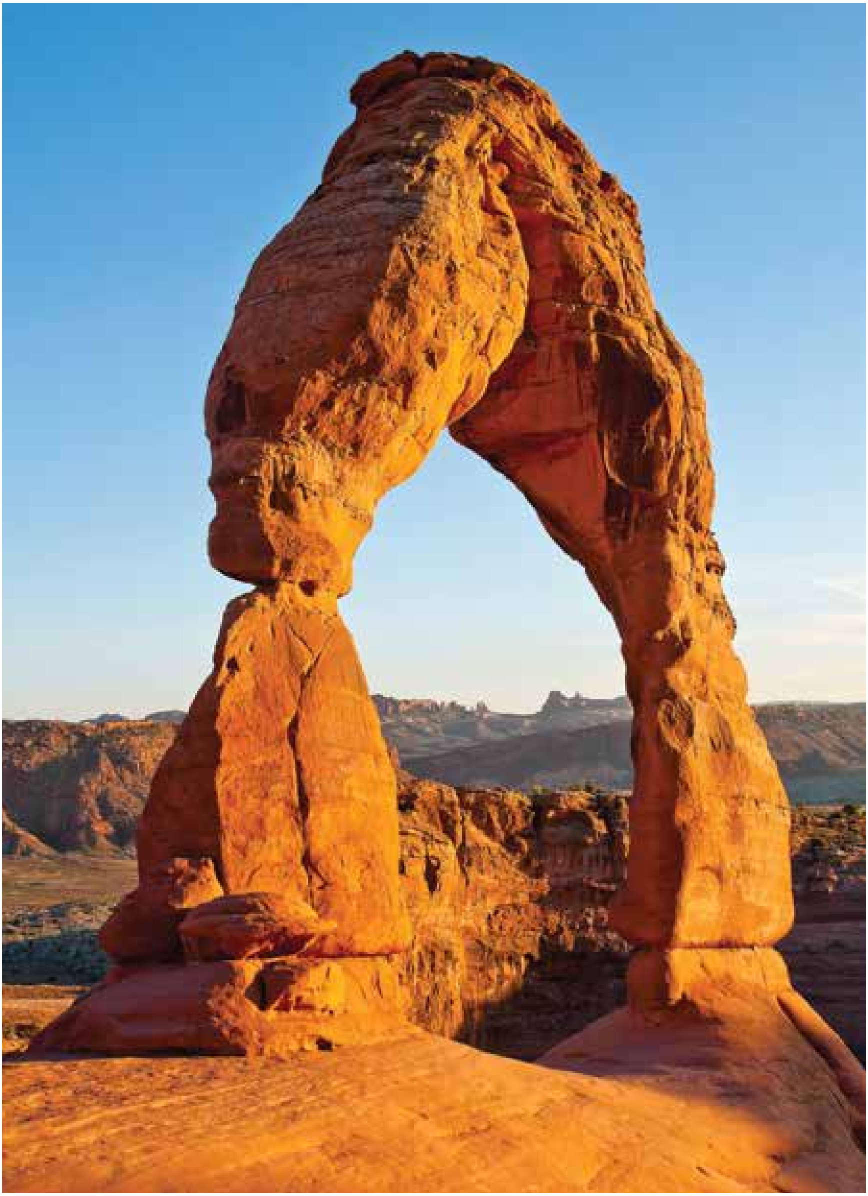
The cataclysmic eruption of Washington's Mount St. Helens in 1980 was a physical process that changed the shape of the mountain. Understanding today's volcanic eruptions helps us understand eruptions of long ago.

What Is Geology?

Geology is the study of Earth. The word comes from the Greek *geo,* meaning earth or land, and *logos,* meaning speech or story. The modern study of geology started more than 200 years ago, when James Hutton published *Theory of the Earth,* claiming that studying the present is the key to unlocking the mysteries of the past. This principle of *uniformitarianism* states that physical processes at work today on Earth, like wind and water erosion, have always been active and are responsible for all the features seen on Earth today, including remnants from the distant past.

Geology includes the study of materials that make up Earth, the processes that change them, and the history of the planet. Human civilization depends on the natural materials available from Earth.

Although much is known about Earth and what it provides humankind, there is much more yet to be discovered—and *that* is the geologist's responsibility.



Winds have sculpted this rock formation in eastern Utah.

Earth Down Under

Earth is a complicated system of land, sea, air, plants, and animals in constant change. Many branches of science must come together for geologists to understand what factors have shaped the land, including

- **Meteorology,** the study of weather, to explain the work done by rain, streams, oceans, rivers, wind, ice, and frost
- **Geomorphology** to study present day hills and valleys and infer the historical processes that formed them
- **Biology** to learn about living plants and animals and their environments
- **Paleontology** to unlock the secrets that fossils and other evidence tell about the past. A fossil is the remains or impression (imprint) of a plant, animal, or shape, such as a shell, bones, leaf, or even a footprint, that was created or formed during a past geologic age.
- **Chemistry** and **physics** to understand the formation and composition of rocks, minerals, ores, and petroleum

A Geologist's Tools

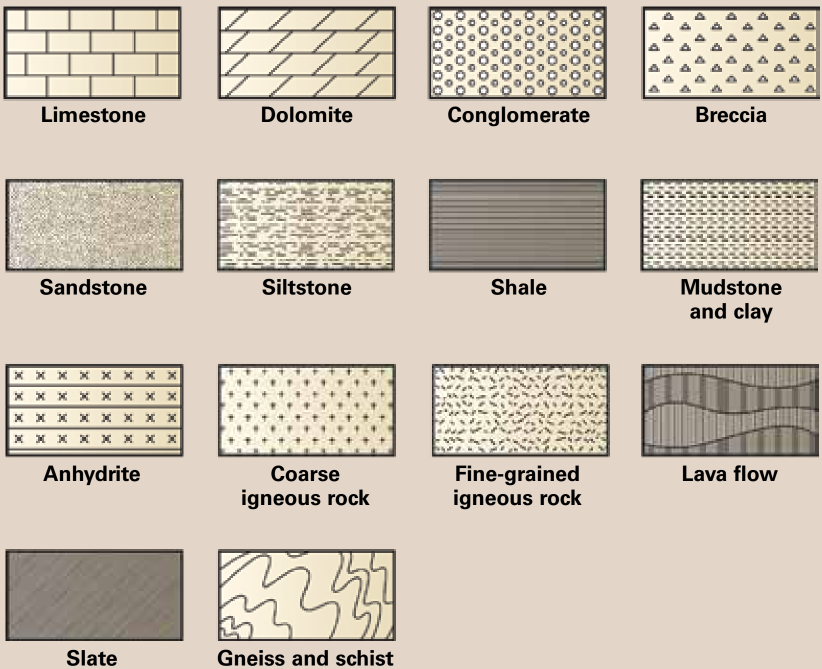
Geologists study the surface and the subsurface of Earth. They have several physical tools and conceptual principles to aid them in their work.

Geological and Topographic Maps

English civil engineer William Smith developed the first geological map in the early 1800s. It proved to be so important that it is still in use today. Geological maps show where rocks and sediments of the same type and age exist on Earth's surface. Each rock or soil type is represented by a different color or line pattern. Rocks of the same age but of different formation commonly are represented by different shades of the same color.

Geological Map Symbols

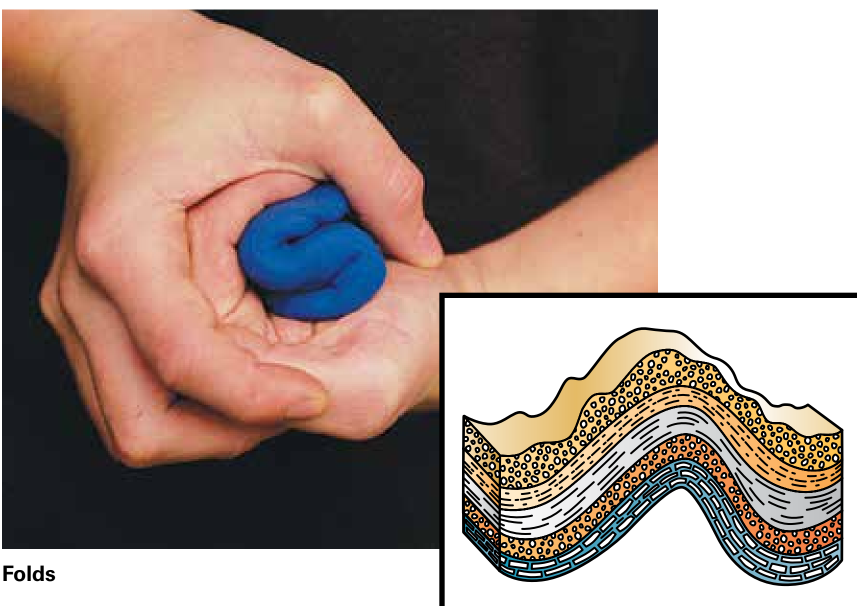
Symbols on a geological map give the reader information about what rocks and structures occur at the land's surface and provide clues about what's under the surface, including underground fault planes, fracture patterns, and dipping formations.



Geological maps are important in showing the distribution of rocks of the same age and type. For example, because different rock types have different characteristics and cause different construction problems, it is important for construction companies to know the type of bedrock before construction begins. A geological map of the area where construction will take place will allow the construction company to plan accordingly.

Geologists create geological maps from information gathered from direct observation in the field, interpretations of aerial photographs, and satellite data. In addition to helping locate faults and other surface information, direct field observations allow geologists to measure the *attitude,* or orientation, of the rocks. Attitude consists of a rock layer's *strike* and *dip*. Strike is the orientation of an inclined rock layer relative to the north compass direction, and dip is the deviation of a rock layer, in degrees, from a horizontal surface.

A geologist also needs a topographic overlay (or overprint) showing what is on "top" of the ground by indicating elevations with contour lines. In the same way that the shape of contours on a topographic map indicate hills, valleys, and stream direction, much can be told about a sedimentary sequence by the shape of its surface expressions, or *outcrops.* For instance, curved outcrops often indicate *folds,* or areas where the rock beds were bent under intense pressure into a series of folded layers, like modeling clay.



Folds

Plate Tectonics

In 1915, German naturalist Alfred Wegener published the idea that 200 million years ago a supercontinent called Pangaea began to break apart, forming the present continents. Since then the continents have moved slowly to their present locations. His hypothesis was called *continental drift*. Because Wegener could not explain how the continents moved, his idea was largely ignored for several decades.

After World War II, new data became available on the nature of Earth's interior, rock magnetism, ocean basin structure, and the distribution of earthquakes and volcanoes. This data was pulled together into the theory of *plate tectonics*, which became generally accepted by the late 1960s.

According to the theory of plate tectonics, Earth's lithosphere (the crust and upper mantle) is composed of seven major and several smaller lithospheric plates, which move slowly (about 1 to 2 inches per year) across the surface of Earth. The theory brings together information from all branches of geology and is fundamental in understanding the physical and biological history of Earth.

Most of the planet's earthquakes, volcanoes, and mountain ranges occur where the plates meet or met in the past.

Principles of Geology

Geologists have found that rock and land formations tend to follow certain patterns. By applying the principles of superposition, stratigraphy, and structural geology, they can make better estimates of the age, formation, and changes underneath Earth's surface.

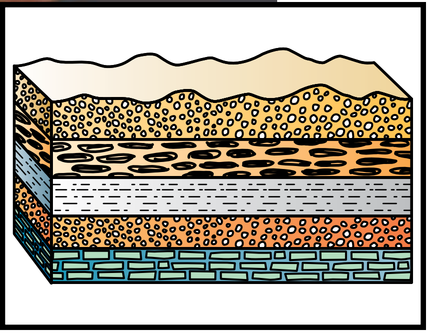
As rock grains drop out of suspension in water, either from a stream or from an ocean current, they generally are deposited in layers, much like a layer cake: The bottom layer must be put on the plate first, followed by the layers above it. In the same way, each layer of sand or mud is covered by another layer, and so on. The *law of superposition* (first defined by Steno in 1669) states that younger layers are on top of older layers. Younger layers may be removed or eroded by streams or rivers, and then even younger layers may be added on top.

Sometimes rocks show a break in the sequence of the layers. These *unconformities* can be caused by erosion (or *nondeposition*) or pressure. Fractures that cut across a series of rock layers generally indicate *faults*, or areas where the rock layers were broken and where the rocks on one side of

Try this. Fill a jar half full with gravel, rocks, sand and soil. Finish filling the jar with water. Close the lid and shake vigorously.

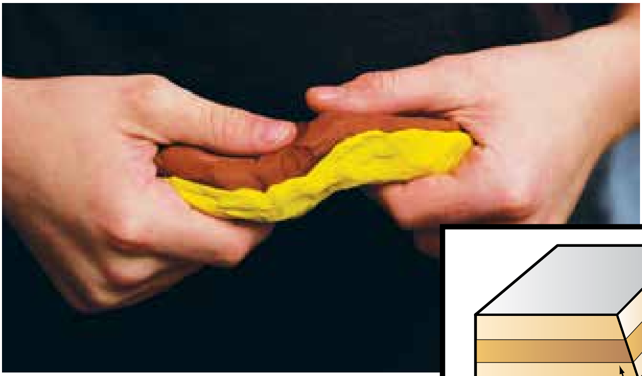
Let it stand still for a few hours. Did layers form? Make a soil chart of the layers. Why did the largest grains settle on the bottom first?

Horizontal layers

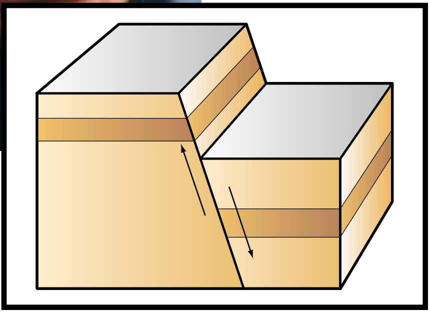


the break move away from the rocks on the other side.

Stratigraphy is the study of Earth's layers and how they formed. The study of how rocks are folded and broken, or faulted, is called *structural geology*. These concepts help geologists



Folds



Faults

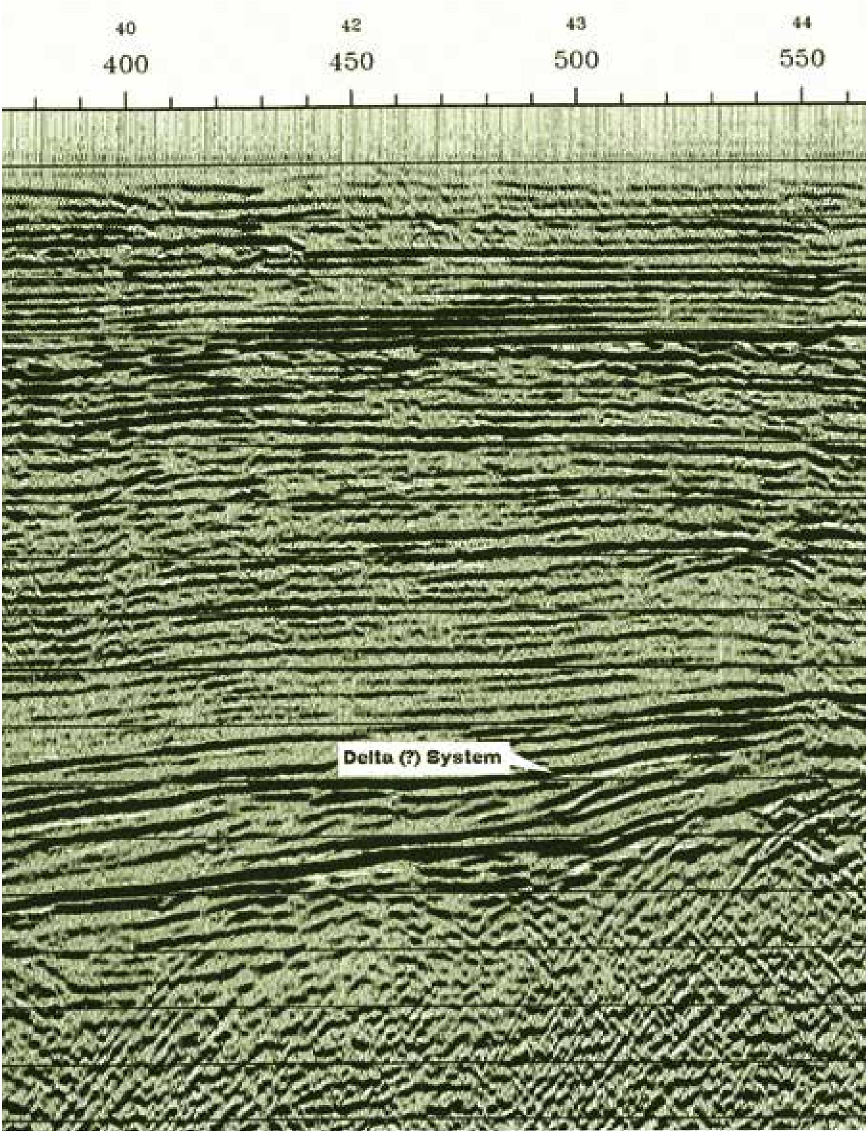
figure out what's beneath Earth using information about Earth's surface.

> Geologists use wells, or *bore holes,* to gain information in the subsurface for mining, engineering, and many other purposes.

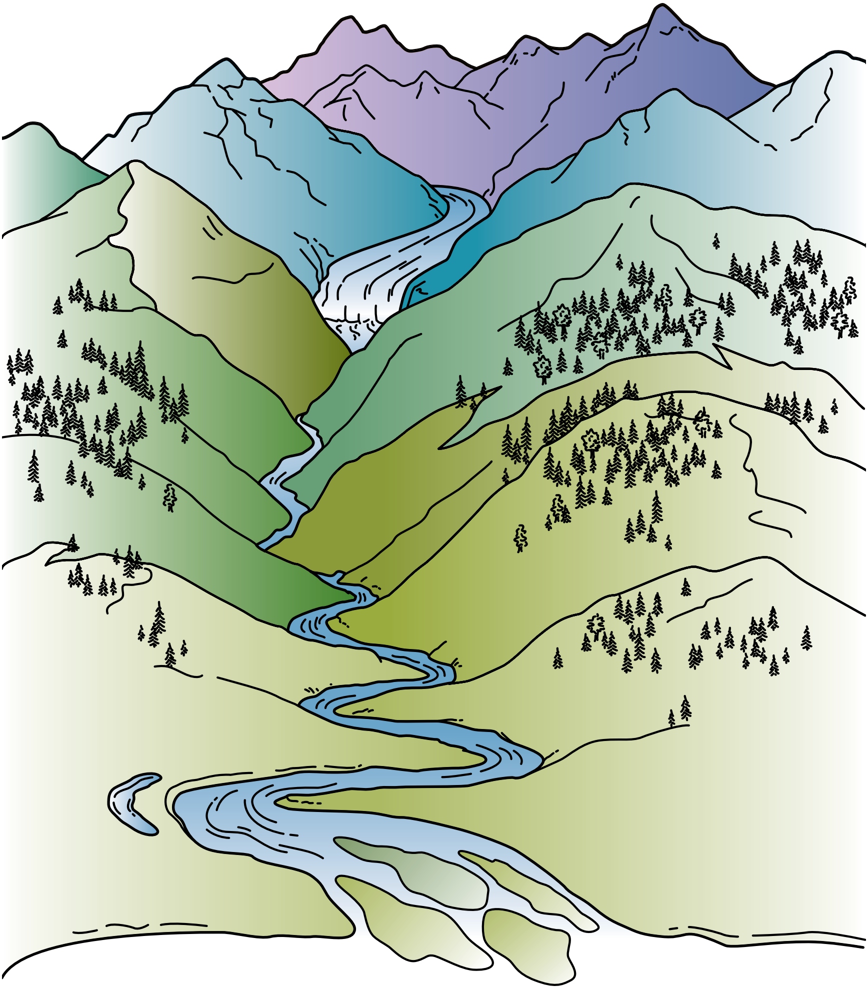
Other Tools

Geological maps are very important. They help geologists interpret how current topography developed and how surface geologic structures extend into the subsurface. Geologists have many other tools and sources of information. An example is *well information.* You might think of wells as pipes that bring water or petroleum to the surface, but they also can give us much information about Earth's subsurface, including information about the sequence of beds and structural features many thousands of feet below the surface. Measurements made in wells, using electrical graphs, or *well logs,* and actual rock samples like cores and cuttings retrieved during drilling, precisely show the rocks in that location.

One of the most common tools in the oil industry is *reflection seismology,* in which sound waves are sent into Earth to measure the *reflections,* or echoes, to the tops of various rock layers. Seismic reflections give an indirect measure of subsurface rocks and give geologists clues as to what lies under Earth's surface.



This illustration was created from seismic reflection information collected by recording the timing and reflection angles of energy waves generated by seismic trucks. The darker waves and lines are representative of the rock formations under Earth's surface.



Streams Carving Earth's Surface

Geologists study rocks to learn the history of their formation. Rivers and streams carry small pieces of rock, called *sediment,* in their current, and those pieces settle when the current loses its energy.

Sedimentary geologists study how moving water erodes rock grains from their original position, sorts them by size, and redeposits them into their new location. After deposition and burial in this new location, other processes cement the grains together into rock units.

Because round grains do not fit perfectly together when packed into volume, there are spaces between the grains (pores) where water, oil, natural gas, or other fluids can collect. The new rock is like a giant sponge. Although it looks solid, it can hold a lot of fluid in its pores.

Sedimentary rocks are the most common rock formations on the continental surface.

The 1848 California Gold Rush. Only a few prospectors struck it rich in California. Some of them were lucky, but the smartest prospectors knew where to pan for gold in a stream, because they knew where gold accumulated. The tiny yellow flakes of gold were heavy for their small size. In fact, a volume of gold weighs 19 times more than the same volume of water. For this reason, gold settles to the bottom of a stream quickly as the current loses speed. The successful prospector knew these things, which geologists know today.

There is not a corner of North America that does not have a streambed for Scouts to study.

Sediments in Suspension

The force of water current provides the energy to hold particles of dirt and rock in *suspension,* from the point where they wash into the stream until they settle to the bottom. The amount of stream energy determines how big a grain can be transported. Bigger grains require more energy, or faster stream flow. Stream energy also determines where the grain is dropped, or *deposited.* When a stream slows down, it loses energy, and the bigger or heavier grains are dropped.

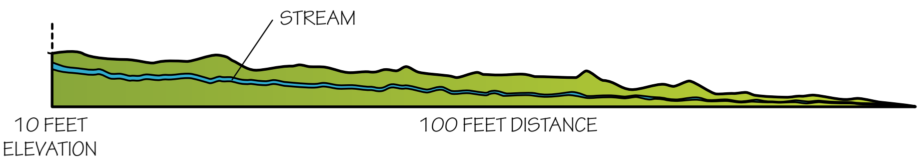
The shape of a stream's path, or its *morphology,* affects the stream energy. Every winding stream has places where the current is faster or slower. Geologists study the pattern of fluid flow to help determine the flow pattern in ancient streams now represented by rock formations.

To calculate stream gradient, you must first convert any measurements that are in miles to feet. To do that, simply multiply the number of miles by 5,280. (There are 5,280 feet in a mile.)

Stream Gradient

A stream's energy is determined by the speed of the water flow. Streams have a higher overall energy in the sections with a steeper gradient or downhill slope. Water rushing from higher elevation to lower elevation is never stopped, but it can be slowed down by local rock formations or by traps and dams. Remember that fast-moving water transports larger and heavier grains while slower-moving water begins to drop the larger and heavier grains.

One way to estimate how fast water will flow is to calculate the *stream gradient,* or the ratio of vertical versus horizontal distance, in equal units. In other words, if the elevation of a stream drops 10 feet for every 100 feet that it flows, you say that the gradient is 10 to 100 (or 1 to 10). A stream with this high gradient will have a great deal of energy in its water flow. A slow stream might be one that flows 10 miles (or 52,800 feet) for every drop of 10 feet. In this case, the ratio will be 10 feet to 52,800 feet (or 1 to 5,280). This would be a low gradient representing low energy and a slow-moving stream.



Activity 1. How Do Sediments Settle From Suspension?

You have learned that sediments are carried by river current and deposited downstream. In this experiment you will learn how sediment size, river gradient, and obstacles affect suspension.

PROCEDURES

Step 1—Create a mountain slope from a piece of plywood or a cardboard box (even a pizza box) reinforced with a yardstick. Cover the cardboard with a plastic garbage bag. With an adult's help, spray foam insulation on the mountain slope to make an S-shaped furrow for a river to flow through.

Step 2—When the foam has dried, elevate one end of the mountain slope on one brick. You may allow the other end to rest on a concrete surface like a driveway.

Step 3—Mix 1 teaspoon of sand, 1 teaspoon of dirt, and 2 teaspoons of gravel in approximately 2 cups of water. Stir. Notice if the sand, dirt, and rocks are suspended in the water.

Step 4—Pour the mixture into the furrow at the high end of your mountainside. Record your observations.

Step 5—Raise the upper end of the mountain by adding a second brick, then repeat steps 3 and 4.

Step 6—Elevate the upper end of the mountain four to eight times higher by adding more bricks or other support, then repeat steps 3 and 4.

OBSERVATIONS

1. When you stirred the sand, dirt, and gravel in the water, did they become suspended? What settled first after you stopped stirring? What do you think would settle first in a streambed?
2. When you poured the mixture down the mountain slope, did the sand, gravel, or dirt settle out first?
3. Where on the mountainside did the sand tend to settle, on the point bar or the cut bank? Where did the gravel tend to settle? Where did the dirt tend to settle?
4. As the incline increased and the mountain grew higher, what happened to the amount of sediment that settled on the mountainside?

See "Stream Landforms" later in this chapter for more information about cut bank and point bar.

CONCLUSIONS

When searching for something in a river, be it oil in an ancient river that flowed years ago, gold for the gold rush prospector, or a dropped Scout compass in a stream, it is helpful to know where heavier items settle when flowing downstream. Larger heavier materials like rocks settle out first. The faster the stream flows, the less the suspended solids settle out. The stream moves more slowly when the mountainside is not as high. Sediment of all sizes will settle out when they slow down going around a point bar. Only the heaviest rocks will settle out in a cut bank area. These same principles apply whether in a raging river, a gurgling brook, or a straight or twisting stream.

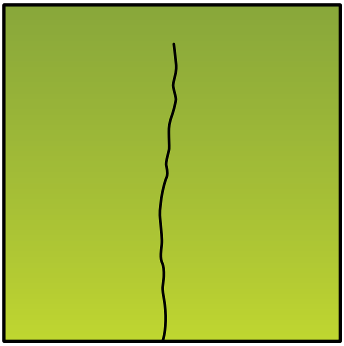
Stream Patterns

The shape of a stream channel, or shape of the stream flow, also can determine the strength of a stream's energy. A geologist can predict the range of stream gradient and stream energy by looking at a map or an aerial photograph.

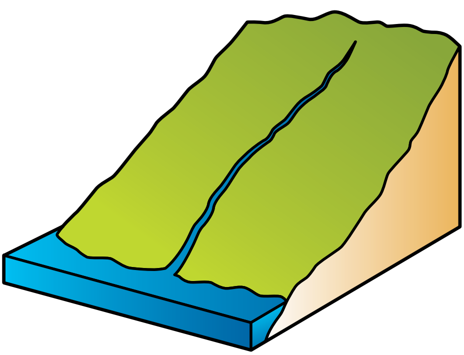
Straight Streams

When a stream flows in a channel without significant bends, geologists say it flows *straight*. Most commonly a straight stream is one that has so much energy and flows so fast that it manages to erode its own channel regardless of rock type. Straight streams tend to have steep sides and the most energy. They can push large rocks and even boulders downhill. Straight streams demonstrate the fastest stream velocity and usually indicate that the stream is dropping fast from a higher elevation to a lower elevation.

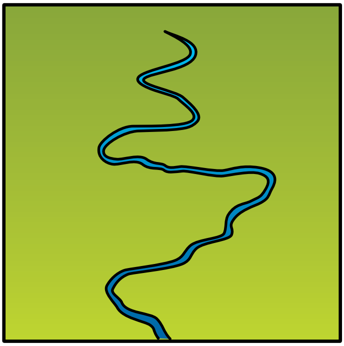
The stream shows you the direction of the downhill slope even if you do not have a topographic map.



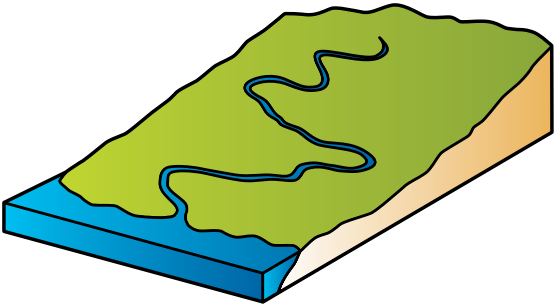
Straight stream map view



Straight stream perspective view



Meandering stream map view



Meandering stream perspective view

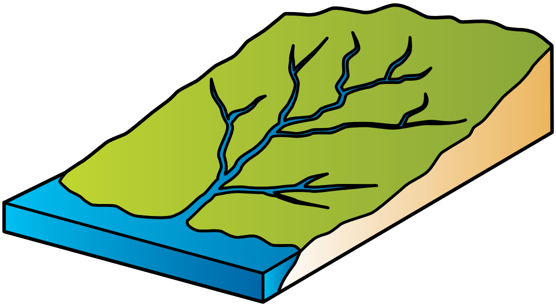
Meandering Streams

Meandering streams are those that seem to twist and turn in a snakelike pattern. Geologists tend to find them in wide, flat areas. When a stream gradient is low, the stream slows down. Then external factors, like friction between the water and the bank or channel bottom, also can affect stream flow. Meandering, curving streams occur where the water current is not strong enough to force its way directly to base level, but only plays back and forth across a (mostly) flat area. Meandering streams are often close to a larger body of water (base level) like a lake, ocean, or a larger river.

In time, this action is exaggerated. The slower zone in the stream begins to drop grains of sediment, which makes the channel shallower as it fills the channel bottom. In a shallow channel, the water flow spreads across more area and creates more friction, which slows the water even more, and so on.

Another cause for a stream to meander might be an obstacle in the channel; perhaps the stream flows to a large boulder or a different kind of rock formation and does not have the energy (stream energy) to move it out of the way or wash it downstream. The low-energy stream will flow around it. Meandering streams tend to have the slowest flow and the lowest stream gradient (energy level).

Dendritic stream map view

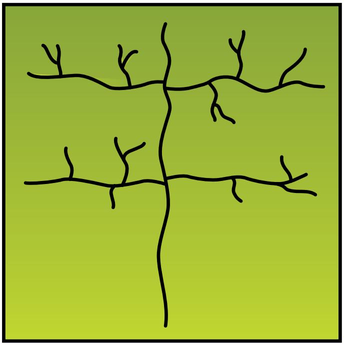


Dendritic stream perspective view

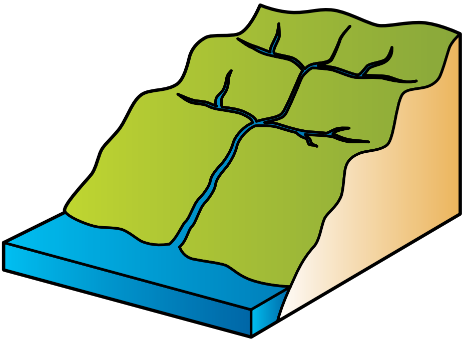
Dendritic Streams

Streams that have a *dendritic* pattern, resembling the veins in a leaf, tend to be made up of both straight and meandering stream segments. This pattern is most common in areas of varying elevation as in hilly or mountainous terrains. Water from one side of a ravine will flow to the bottom of the ravine and join with water from the other side. The combined stream will flow down the valley until it joins another runoff stream from a neighboring valley.

Because water always runs downhill, the intersection of two streams makes a down-pointing arrow pattern on a map. Dendritic streams occupy the middle ground between straight streams and meandering streams, where the stream is still dropping from high ground to low ground, but where the drop is not as steep. There is still enough energy to show a primary direction of flow.



Trellis stream map view



Trellis stream perspective view

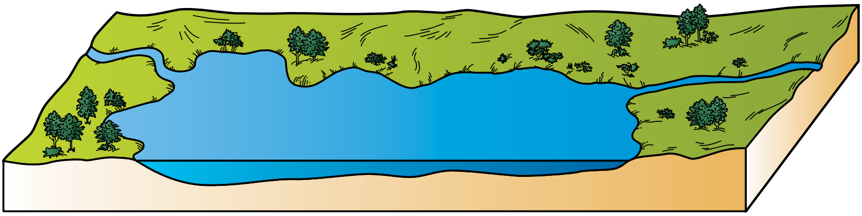
Trellis Streams

Trellis stream patterns are not as common as other patterns. They display a stream pattern influenced entirely by the underlying rocks. In an area where the rocks have been folded, or thrust-faulted, the surface rocks occur in a pattern of parallel ridges. Water will flow along the valley between these ridges until it finds a gap that allows it to escape and flow down to the next level. Although these streams don't flow in a straight line, they flow in very straight segments and their valley walls probably are steep-sided.

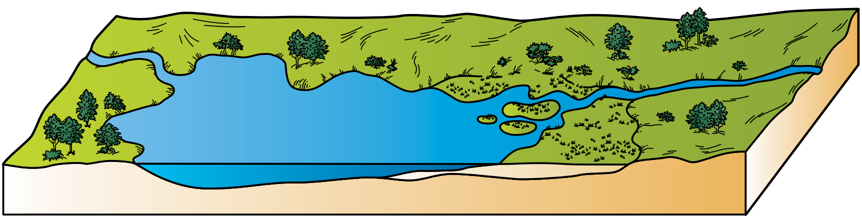
Trellis streams may have very high energy and very fast water. The *softer* rocks, which erode more easily than others, erode from between the *harder* layers and leave behind ridges of higher ground. These parallel ridges print their pattern into the stream pattern because the water always runs downhill through the eroded valleys and flows around the higher ridges.

Lakes

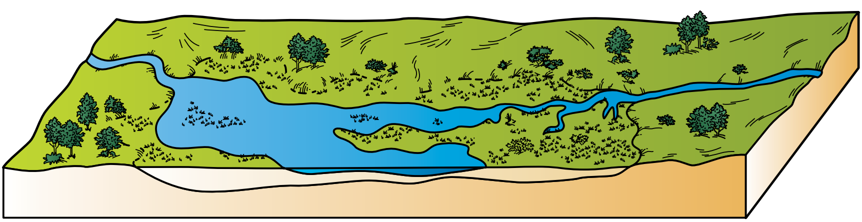
Envision a lake as a very wide, slow part of a stream. A stream usually fills the lake at one end, and the overflow spills through a low spot somewhere on the edge of the lake, allowing the stream to continue its flow downhill. Lakes are quiet, still water. The *base level* occurs where the stream gradient becomes zero and the stream drops all the remaining grains from suspension. There usually is very little current associated with a lake unless storm water is flowing into the upper end, so the very finest grains can settle from suspension. The cloudiness you see in a lake is mostly due to algae and other lake life.



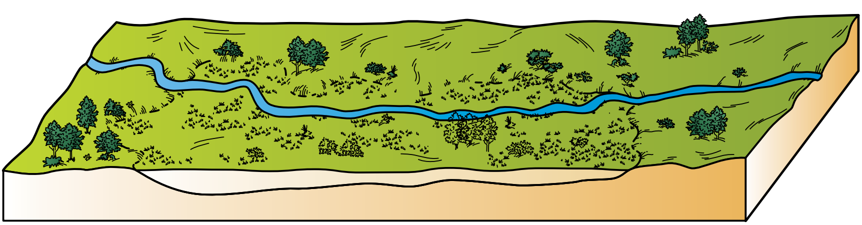
A LAKE WITH A RIVER.



A RIVER BUILDS A DELTA AS IT ENTERS THE LAKE.



SEDIMENT BUILDUP CONVERTS THE LAKE TO A SHALLOW SWAMP.



A LAKE BASIN FILLED WITH SEDIMENT; ONLY THE RIVER REMAINS.

Vanishing lake

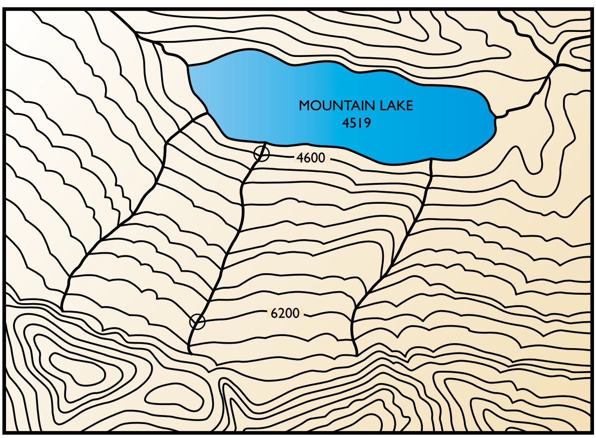
Activity 2: Reading Topographic Maps for Stream Gradient

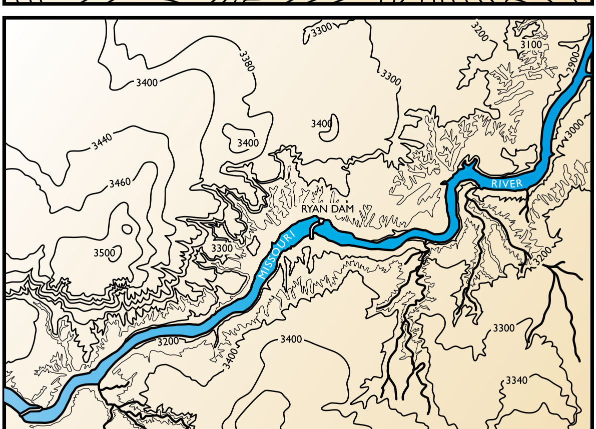
You now know how to recognize four types of streams: straight, meandering, dendritic, and trellis. In the following activity, you will calculate the stream gradient for an example of each type of river and determine what that tells you about the stream.

PROCEDURES

Step 1—Use a contour map provided by your counselor, or use the four provided in this pamphlet. Identify the types of streams found on the maps.

Step 2—Find a starting and ending place on the map where the stream crosses a contour line. The stream on the map is not straight. Use a piece of string to follow the stream on the map,



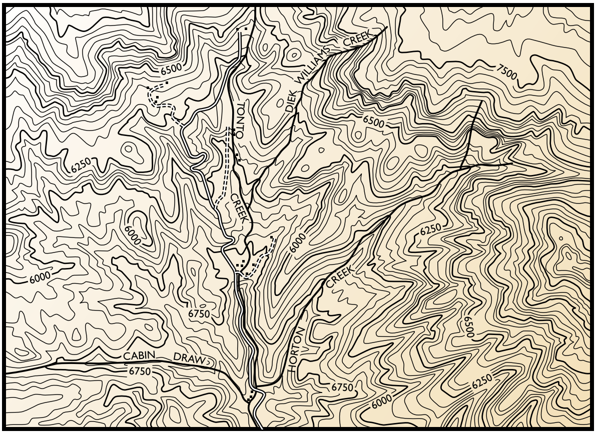


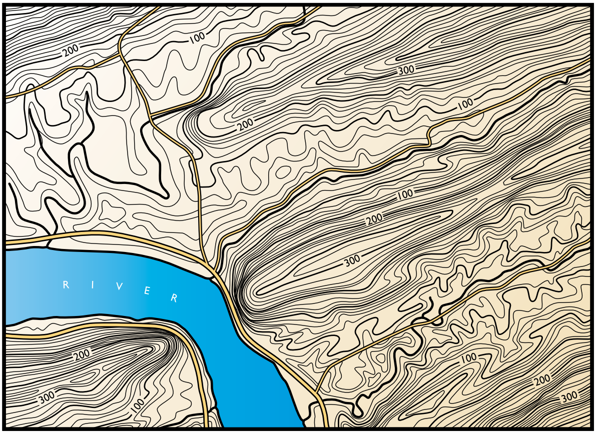
then measure the string with a ruler and the miles scale on the chart to get the distance the water traveled. Measure as closely as possible the distance between the points with a ruler and convert it to feet or miles using the scale on the map. If the distance is in miles, multiply it by 5,280 to convert it to feet.

Step 3—Read the elevation of the stream at the beginning and ending points you selected in the last step. Often not all contour lines are labeled, but the interval is the change in elevation between each contour line. Use this information to find the elevation of the contour lines that cross the stream.

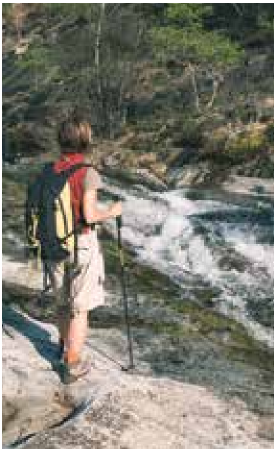
Step 4—Calculate the stream gradient—the ratio of elevation change to distance. Stream gradients are expressed in ratio form so they can be reduced to the lowest common denominator.

Step 5—Repeat steps 1 through 4 with the other three maps.





OBSERVATIONS



1. Which type of stream flows the fastest. Why?
2. Which type of stream flows the slowest. Why?
3. Which type of stream would carry the largest grains of sediment? Why?
4. What kind of stream gradient would a waterfall have? Do waterfalls flow fast or slow?

CONCLUSIONS

Straight streams tend to have the highest gradient and the most energy, and therefore are able to carry the most sediment. Meandering streams normally have the lowest gradients and the least energy, and are able to carry only the smallest sediments.

Stream Landforms

If you were a prospector in the California gold rush of the mid-1800s, you would have carefully observed stream landforms.

CUT BANK

On the meandering stream with its S-shaped curves, the force of water pushes on the outside of the bend. The rushing water continues to erode, or cut away, the outside of the bend named the *cut bank*. Just as a race car in the outer lane of a bend has to travel faster to keep up with a race car on an inner lane, the water on the outside of a river bend travels faster than water on the inside of a bend. Because the water in a cut bank is high stream energy, flowing quickly, it often picks up dirt and sediment, eroding the cut bank. Typically no grains will settle in this area.

POINT BAR AND FILL BANK

While the water on the outside of a bend travels quickly, the water on the inside slows down and has low stream energy.

This creates an area where the bigger or the heavier grains are dropped. Where the inside of a river bend often fills with sediment is called a *fill bank* or *point bar*.

DELTA

Deltas form where a stream flows into a lake or ocean and drops its sediment. Deltas can show different patterns of deposition but there is usually an area where the delta ends and the slope drops quickly into deeper water. Stream channels can occur within a delta. As long as the stream has any energy to flow it will continue to maintain its form and transport grains to the delta slope where the stream energy drops to zero.

MEDIAL CHANNEL BAR

An elongated mound of sediment in the middle of a channel or waterway is a *medial channel bar,* sometimes called a *sandbar.* A delta may have a number of medial channel bars in the waterway where the sediment settles as the flow slows entering a lake or ocean. Grains settle out like in a delta.

Glaciers

To understand the glaciers of the Ice Age, geologists study today's remnant glaciers, called mountain glaciers, and continental ice sheets. *Mountain glaciers* still can be found in Glacier National Park in Montana and in Alaska. *Continental ice sheets* still exist in Greenland and Antarctica.

Throughout geologic time, glaciers have shaped Earth's surface. Many scientists believe that massive ice sheets like those that cover Antarctica today once covered the north half of Eurasia and from the North Pole to what is now Kansas and Illinois. Because these glacial sheets were so thick—nearly a mile in some places—and may have taken thousands of years to melt, entire rivers flowed around them. When the continental ice sheets finally finished melting, the glaciers had carved out the channels of today's major river systems through Canada and the United States. Most geologists believe that glaciers weighing trillions of tons dug out the low spots that became the Great Lakes.

Mountain glaciers exist only in a single mountain valley. Today's mountains show evidence of long-gone mountain glaciers. Have you ever hiked the high country and noticed wide, U-shaped mountain valley walls (compared with narrow, sharply pointed V-shaped valleys). To form a U-shaped valley, a single river of ice flowed through and cut away the sides and bottom of the valley, creating its wider appearance.

Glaciers also scrape up huge amounts of rock and dirt and, as the ice melts, deposit this material. Large deposits of glacial sediment, or *till,* and glacially derived wind-blown deposits called *loess* can be seen today. At the end of a glacier, the till is deposited in a mound called a terminal moraine. Other till deposits accumulate beneath the glacier as ground *moraine* or, on mountain glaciers, along the sides as lateral moraine.

Activity 3: Finding Sediment With a Magnifying Glass

Looking at a riverbed you know there are sediment or river rocks that are big enough to easily see, but there also is some sediment that is too small to see with the naked eye. In the following activity, you will need a magnifying glass to study stream water.

PROCEDURES

Step 1—With your parent's permission and a Scout buddy, visit a nearby stream. Using a clear plastic cup, scoop up some stream water. Using a magnifying glass, look at the water for suspended sedimentary materials. Write down your observations.

Step 2—Find a second location along the stream, perhaps in a fill bank, and scoop up a second sample. Examine it with a magnifying glass and make notes.

Step 3—If you have access to a microscope, maybe at your school, save a sample of stream water and look at the same water through the microscope. You may have to stir or shake the water before making your microscope slide.

OBSERVATIONS

1. Were you able to see more sediment with the magnifying glass?
2. Was there more sediment in the first or second sample?
3. If you were able to use a microscope, what did you observe?
4. Even though some of this sediment is too small to see without magnification, do you think when the river drops this sediment it impacts the stream bottom? Why?

CONCLUSIONS

Some sediment is too small to see without magnification. Rivers and streams move materials in a large variety of sizes, from large boulders to fine grains too small to be seen with the naked eye. Water flowing over our planet is constantly changing the shape of its surface.

Activity 4: Water Direction Clues

Have you ever hiked across a dried-up riverbed? Could you find clues to tell which way the water had flowed? In the following activity, you will hunt for river direction clues.

PROCEDURES

Step 1—With your parent's permission and a Scout buddy, visit a nearby stream. Look at the water to see what direction it is flowing. Drop a stick, leaf, or other natural material on the water to confirm this direction. Even if the water has dried up, look for clues that show the direction of the previous water flow.

Step 2—Look for a second stream feeding into this stream.

Step 3—Look for an obstruction in the stream like a rock or tree. (On an obstruction, sediment will build up on the upstream side and the downstream side may be hollowed out.)

Step 4—Look for debris like twigs and leaves wrapped around trees and rocks along the bank.

Step 5—Look for reeds, grass, litter bending toward downstream.

Step 6—Record all your observations with notes and sketches in a notebook. Share your observations with your counselor.

OBSERVATIONS

1. Are you able to see sediment being carried by the stream current?
2. If you found a second stream feeding into the first stream did they form a V where they converged? What direction did the V point, upstream or downstream?
3. What type of obstruction did you find? What had collected on the upstream side of the obstacle? Was the downstream side of the obstacle hollowed out?
4. Did you find twigs and leaves wrapped around trees and rocks? Did the height of this debris indicate the stream once overflowed its banks?

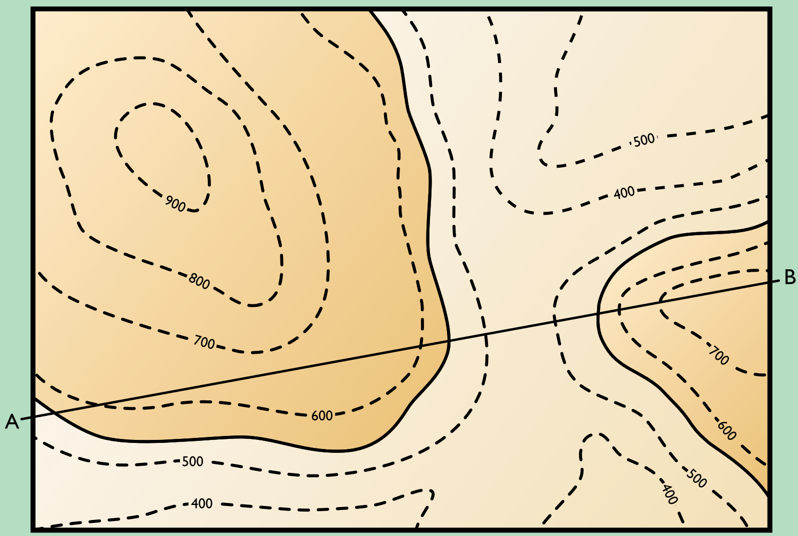
CONCLUSIONS

Even if a stream has dried up, many clues indicate the direction of the water flow. Often two joining streams will form a V pointing downstream. Obstructions like trees and rocks collect sediments as the water slows to pass around it. All streams leave water-flow direction clues.

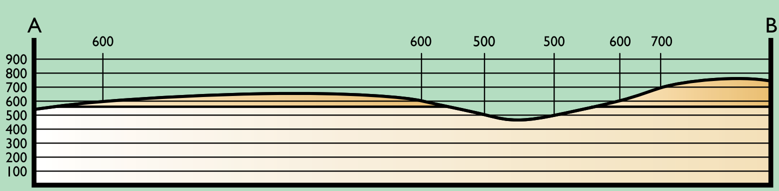
What Is a Topographic Map?

Geologists use topographic maps, two-dimensional pieces of paper that depict the three-dimensional surface of Earth.

Topography is the shape of the land surface, the "top" of the land. Contour lines, which on a mountain peak look like concentric rings, show elevations. Elevation is the vertical height above sea level. The contour lines connect points of the same elevation. Closely spaced contour lines indicate steep slopes. Contour lines far apart represent gentle slopes. In the topographic map below, the contour interval is 100 feet. This interval is the difference in elevation between each contour line.

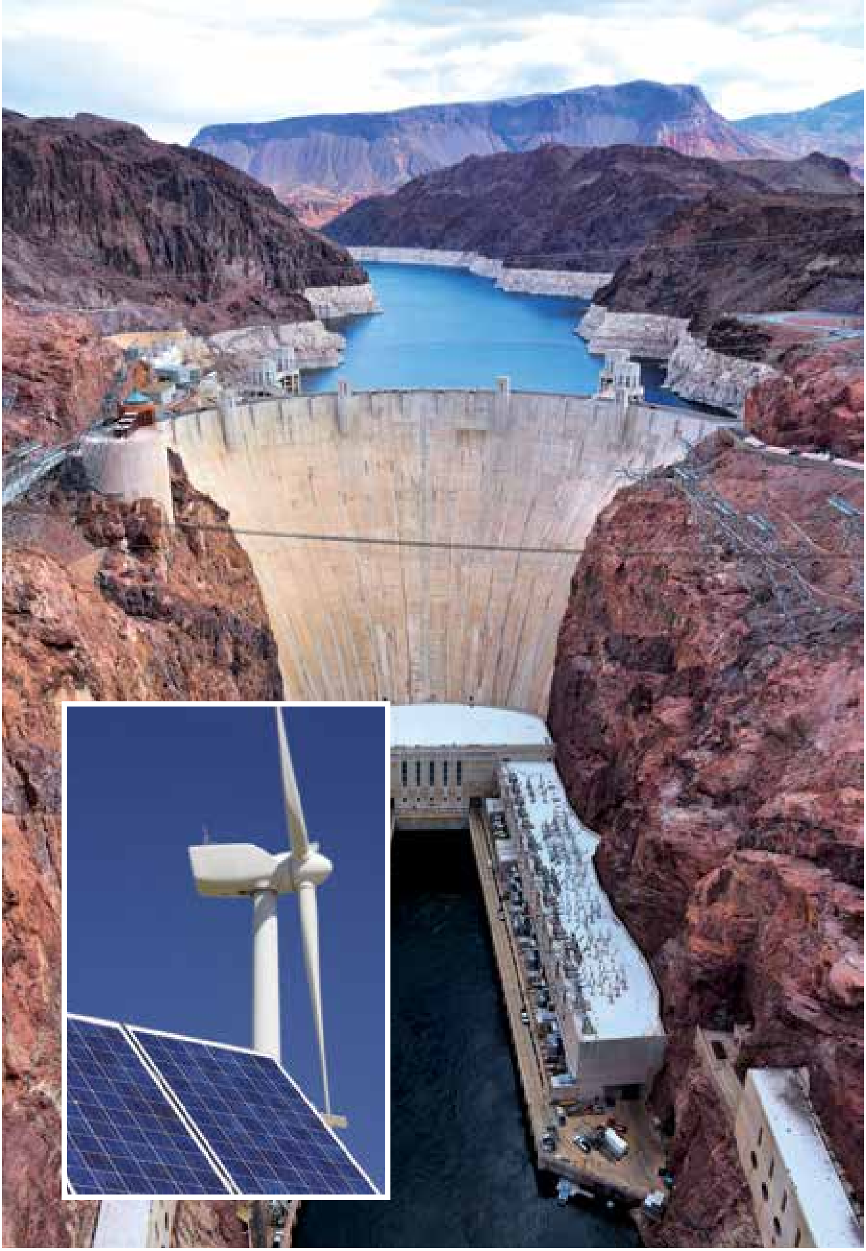


This "topo" map shows contour lines and a study line (transect) from point A to point B.



You can draw a profile across the valley by marking elevation points along the study line (transect A to B). Use graph paper if you can.

Topographic image taken from NASA's Dawn spacecraft



The Hoover Dam in Nevada provides low-cost hydroelectric power for that state, Arizona, and California. Other renewable types of energy come from windmills and solar panels.

Energy From Our Earth

Energy is the vital force powering business, manufacturing, and the transportation of goods and services to serve the United States and world economies. Energy supply and demand plays an increasingly vital role in our national security and the economic output of our nation. It is not surprising that the United States budgets more than $500 billion annually on energy.

When geologists refer to gas or natural gas, they are talking about the natural gas used in a water heater or in heating a home.

Natural Resources

Natural resources are very important in our daily lives. All natural resources must be found, extracted, and processed before they can be used. Many are essential to our well-being, and others are important for our comfort. Rock is quarried and crushed for construction. Ore is mined and refined for metals. Petroleum (oil and natural gas) is used for plastics, medicine, and transportation. Coal is used for heat and electricity. Gemstones are used for jewelry. The list of natural resources is endless and diverse.

Finding natural resources may be as simple as knowing the surface rocks in the area, or as complex as looking three miles or more underground. Extraction may be as simple as dredging sand from a riverbed or as difficult as blasting a shaft thousands of feet underground and bringing the ore to the surface. Transporting may be as simple as loading the material on a truck or as complex as laying a 250-mile pipeline. The cost of extraction and transportation must be considered in determining how valuable an Earth resource is to society.

Most of the energy resources we use today are taken from Earth. The energy to heat your home and school, the energy to push your family car or neighborhood bus down the street, the energy required to lift a 747 airplane off the runway—all come from Earth and were formed during Earth's past. It is

the responsibility of geologists working in the hydrocarbon industries to find new deposits of these energy sources.

Where Do We Get Electricity?

In the United States, our energy comes from a number of sources. Electricity is used for power and heat, and to operate appliances and electronics. Electricity is clean and easy to use. But where does electricity come from?

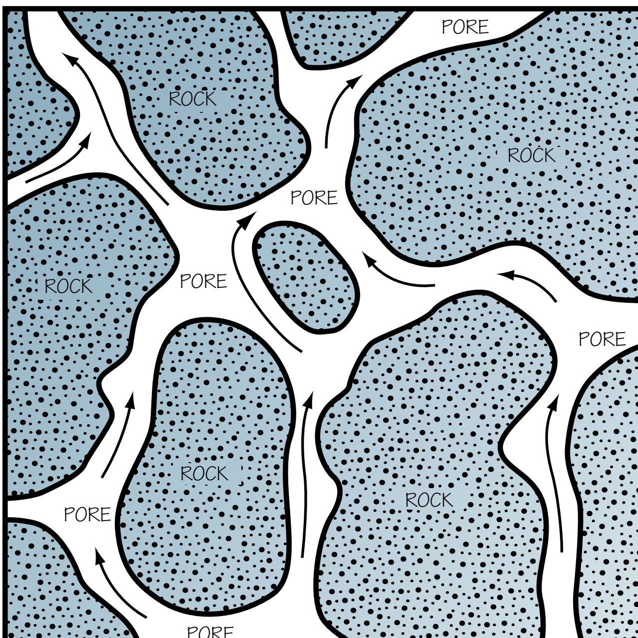
According to the U.S. Department of Energy, in 2021 about 4,116 billion kilowatt-hours (kWh) (or about 4.12 trillion kWh) of electricity were generated at utility-scale electricity generation facilities in the United States. About 61% of this electricity generation was from fossil fuels—coal, natural gas, petroleum, and other gases. About 19% was from nuclear energy, and about 20% was from renewable energy sources like hydropower, wind power, tidal power, solar energy, and geothermal energy. While it is important that today's society continue to develop renewable energy resources, it's clear that we still depend on fossil fuels for more than half our electricity.

Coal

Coal occurs in beds between layers of other sedimentary rocks, such as shale and sandstone. Coal is formed when material from ancient plants accumulates in swamps or bogs and becomes buried under water and sediments. This process stops the decay of wooded material by sealing off the oxygen supply needed for decay.

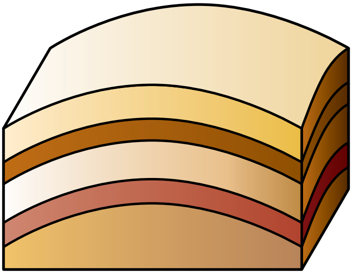
Coal forms in different stages, depending on how long it has been buried and how much pressure and heat have been applied during compaction. In its first stage, coal is called *peat.* If dried, peat can be burned as a fuel.

With more time, heat, and deeper burial, more water is driven out of the peat, creating *lignite,* or brown coal. As continued burial drives off more water and the percentage of carbon is increased, lignite becomes *bituminous coal,* the most common and widely used form of coal in the United States. Bituminous coal is found throughout North America, but the deposits found in many states are not large enough to be economically developed. If bituminous coal is folded during burial, the added pressure and heat of folding changes it to the very highest grade of coal, *anthracite.*

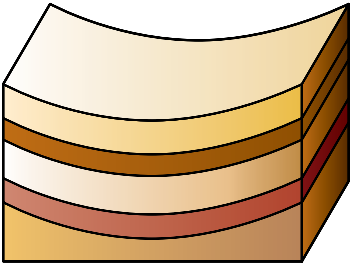


Rock where the oil and gas form is a *source rock.*

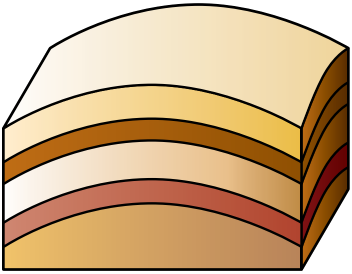
Sometimes if an impermeable barrier does not stop the migration of oil and gas, it will leak out on Earth's surface in a natural seep. There are natural seeps in the United States, notably in the Gulf Coast area and in California.



Anticline: fold arching upward



Syncline: fold arching downward



Dome: inverted bowl shape

Oil and Natural Gas

Living things, like plants and animals, are made of the same basic building blocks as oil, gas, and coal—the carbon and hydrogen atoms. Scientists believe that oil and gas formed from dead plants and microscopic or very small animals, preserved in mud on the bottom of seas and lakes. To be preserved, these plants and animals had to be quickly covered with mud so oxygen could not decay them. During burial, bacteria, heat, and pressure forced chemical changes in the plant and animal material until the carbon-based molecules became oil and natural gas.

While the plant and animal matter settled on the ocean floor, grains of sand or clay were buried and packed into rock. Like marbles packed in a jar, there were spaces, or *pores,* filled with organic material, water, and mostly clay. As the organic material converted into oil or natural gas, it migrated up through these pores.

To see for yourself, fill a bottle with cooking oil and water. Cap it and shake. Watch the oil separate from the water and rise to the top. Since oil and gas are both lighter than water, they do the same thing deep underground. The oil and gas rise until they come to a *trap*—a nonporous rock barrier that traps the

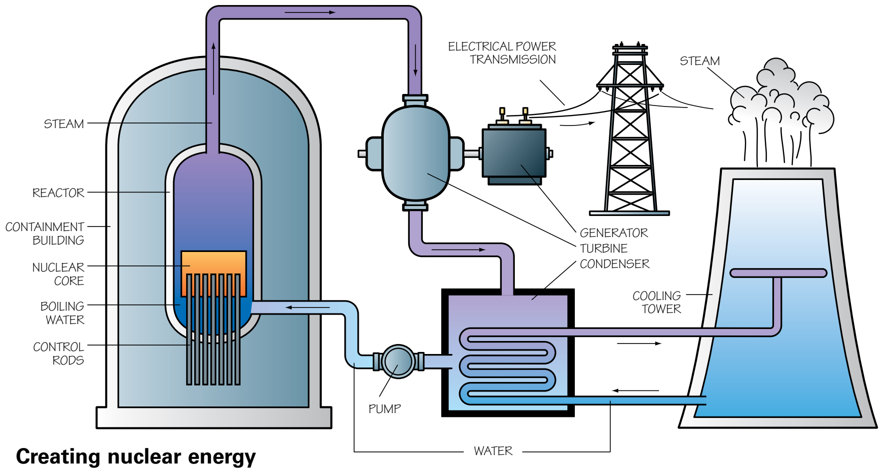
migrating oil and gas. Sometimes oil and gas will travel long distances and collect in a large trap, creating a gigantic oil and gas reservoir. The porous rock below the trap rock, saturated with oil and or gas, is the
reservoir rock.

Few rock layers are perfectly horizontal, and it is common for porous folded or tilted beds to become oil or gas reservoirs. The highest point in the formation becomes the reservoir, so the geologist hunting for oil or natural gas learns to look for these high spots. The science of petroleum exploration is the search for these porous rocks sealed by impermeable rocks. These folded structures are called *anticlines, synclines,* and *domes*. Each type of fold has different characteristics, but anticlines and domes make the best traps for hydrocarbons.

Not all traps are anticlines or domes. Oil can be trapped in tilted layers against an impermeable zone, such as a salt dome or a fault.

Tar Sands

Tar sands are sandstones containing an asphalt-like petroleum that is too thick to be pumped out. Instead, the rock must be heated to release the oil. Large deposits of tar sands exist at the surface in Canada (the Athabasca Tar Sands) where



Creating nuclear energy

they are mined with open-pit quarrying techniques. The world's largest deposits are in Venezuela, where production is just beginning.

Oil Shale

Oil shale is a special kind of shale rock that is formed by plant and animal matter deposited together with mud in an ocean or lake bottom. The plant and animal matter compacted with the mud converts to a substance called *kerogen.* Oil, gas, coal, and kerogen are all hydrocarbons, made of hydrogen and carbon atoms. Oil shale is mined like any other rock. It is then heated to release the kerogen. Colorado, Utah, Wyoming, and Canada all have enormous deposits of oil shale. At this time it is expensive to mine the oil shale and remove the kerogen. Oil shale is not economical to mine.

Nuclear Energy

A nuclear power plant uses uranium for nuclear fission, which produces heat to boil water, which then turns steam turbines to generate electricity. Uranium, a heavy metal element, comes mainly from a mineral, *uraninite,* but also can come from *carnotite* and *autinite.* The United States has radioactive mineral deposits in New Mexico, Utah, Colorado, Wyoming, Arizona, and Washington.

Hydropower

Dams produce pollution-free renewable energy. Just as the wheel in a water mill turns under the weight of falling water, a dam's turbine wheel also turns under the weight of falling water. The difference is a dam's turbine is attached to an electric generator.

The benefits of dams include supplying water for agriculture and communities, and reducing the risk of floods and droughts. One of their few drawbacks is the blocked sediment flow, which deprives the downstream flood plains of fertile sediment. Another drawback is that dams serve as a large source of evaporation, which can change the local climate.

Most suitable sites for large dams in developed countries have been exploited. For this reason, hydroelectric power

production is not expected to increase significantly in the United States.

Wind

Wind can turn large windmills that generate electricity. In fact, windmill "farms" can be seen throughout the western United States. For years, ranchers and farmers have used wind-driven pumps, not to generate electricity, but to save electricity. These pumps bring water to the surface for livestock to drink, saving the rancher the expense of taking electricity to distant pastures or the time bringing the livestock to the corral to drink. Although wind energy can be inexpensive to generate and the land it takes up can be multi-use, it has its drawbacks. Wind energy requires a large area and steady wind.

Tidal Power

Tidal power, where water from a rising tide is trapped behind gates of a large impoundment, is used on a limited basis. As the tide drops, the water is slowly released through turbine gates, generating electricity. This energy source is relatively inexpensive but requires a large coastal area and may damage the local shoreline ecosystem.

Although solar energy is abundant, it requires a large area and sunny days. Scientists also are discovering how to store solar energy and make today's solar panels more efficient.

Solar Energy

Solar energy could become an important energy source in the future. Solar energy currently helps save electricity by heating water for homes and businesses. Also, all NASA spacecraft use solar energy to power instruments and communications.

Geothermal Energy

In areas where magma is relatively near the surface, water may be piped down close to the magma. The extremely hot magma boils the water, producing steam that rises through the pipe out of the ground to turn a turbine, which generates electricity.

Exploring for Oil and Gas

Geologists have several high-tech tools in their toolbox that help them find oil or gas. They use these tools to make a map of what they expect to find under the surface. A map of subsurface structures is a tool predicting the shape of rock structures that cannot be directly observed.

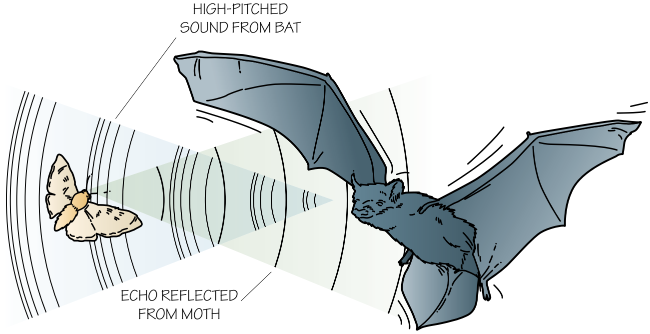
Studying Rock Layers

Thick layers of sediment tend to accumulate in bowl-shaped crustal depressions called regional *basins.* Geologists study and record a basin's stratigraphy—its rock layers from the surface down to the *basement.* They know that if a certain rock formation is a reservoir for oil and gas in one part of the basin, it also may be a reservoir elsewhere in the same basin. If a certain rock is found 8,000 feet beneath the surface in one part of the basin, it might also be found at a similar depth in other parts of the basin. Using the vertical sequence in one part of the basin to help locate a rock formation in another part of the basin is known as *stratigraphic correlation.*

The basement rock is *igneous rock*—rock formed from molten material that makes up Earth's crust and underlies all basins.

Some of the tools a geologist uses to trace a formation in the subsurface include reflection seismic, electrical well logs, core samples, and cuttings.

A geologist must be able to understand what lies buried beneath the surface of the ground or underwater in order to locate reserves of oil and natural gas. Reflection seismic is the process of sending *acoustic waves* (sound waves) through Earth using a wave energy source from either mechanical devices or explosives.



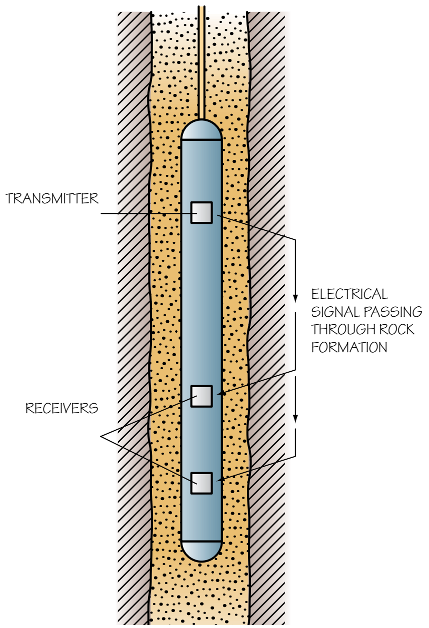
Just as bats use sound echoes to locate flying insects, scientists use reflections of seismic waves to locate underground rock structures that might contain minerals or oil and gas.

Then geophones (earth microphones) detect the reflections as they bounce back to the surface. Computers measure the time it takes for the wave to travel round-trip, then use that information to create useful graphic displays of the subsurface layers or structures where oil or natural gas may accumulate.

These acoustic waves travel through Earth's layers and are reflected back to the surface from rock formation boundaries. Formation boundaries usually are defined where the rock type changes (for example, sandstone to limestone).

Electric Well Logs

Electric well logs are electrical measurements taken in a well after it has been drilled, to create a record of the stratigraphy and rock properties encountered in the well. Electrical current is passed through the rock formation using a long, cylindrical *sonde,* a special tool connected by wire to a computer on the surface. The sonde measures how easily electricity passes through the rock formation. By comparing this electrical *conductivity* to rock properties in other parts of the same basin, geologists can predict the rock formations in other parts of the basin. Engineers use the well log to develop a plan of how to best drill and recover the oil and gas.



In an electric well log, the sonde first takes the electric readings in the well. Then the readings are plotted on a graph against the depth to produce a well log. In the final step, a geologist can use the well log to draw a geological cross section, spacing the well logs in proportion to the actual wells.

Core Samples

Typically seismic and/or well logs provide the information needed to begin drilling a new well. Occasionally geologists and engineers test a special cylinder-shaped rock sample called a *core sample.* Laboratory testing can tell the engineer rock *porosity,* the amount of space between the rock grains. A special hollow drill bit, shaped like a straw, cuts core samples and brings them to the surface. Core samples are often 1 to 2½ inches in diameter yet hundreds to even thousands of feet long.

As the drill bit digs deeper in the rock, ground up rock

Make a Core Sample

To better understand core samples, try this for fun. Cut the top off a 2-liter plastic drink bottle. Mix equal parts of sand and dry plaster of paris. Fill the bottom 3 inches of the bottle with this mix. Now mix equal parts of dirt and plaster of paris. Make a second layer in the bottle with the dirt mixture. Sticks, seashells, and leaves may be added between layers in your core sample. Mix equal parts of gravel or rocks with plaster of paris and add for a third layer. Now add layers, in the thickness and order as you wish, to fill the bottle. Fill the bottle with water. The next day remove your core sample.

pieces called *cuttings* come to the surface. A geologist compares cuttings to what was expected. The cuttings reveal if the predicted vertical sequence, stratigraphy, needs to be modified and give the driller clues to know when the bit has reached the target rock formation. Cuttings are saved for other geologists to examine for clues about the rock formations in other parts of the same basin.

Making the Exploration Map

Geologists make maps of things they cannot see from information gathered with seismic surveys, well logs, core samples, and cuttings.

A first pass in a new basin might include a seismic survey to produce a picture of the *subsurface structures,* which include tops of formations and other underground features. The best seismic surveys allow geologists and geophysicists to compare what they already

Core samples

know about the basin stratigraphy with the structures in the seismic print.

If the basin area has been explored before, geologists will use electric well log plots from nearby wells to estimate at what depth to expect oil and gas. They can build a *subsurface structure map* using the depth-to-formation numbers from the well log plots and may use the same technique to reveal the bottom of the formation and determine its thickness. This *subsurface isopach map* shows the potential thickness of the target reservoir.

A *structural map* represents seismic data measured from the surface to a particular subsurface rock layer of interest. These measurements are given a value in time or depth and are placed on a map at regular intervals from each other according to the surface location of the seismic data. The finished map looks much like a surface topographic map, but it is the subsurface.

Activity 5: Drawing a Subsurface Structure Map

Contour mapping is like drawing a connect-the-dots puzzle. Making a subsurface structure map is like making a topographic map, except that the map is of the buried top (or bottom) of a particular target rock formation. In this activity you will learn how to draw a subsurface structure map.

The elevation used on most subsurface structure maps are shown in negative numbers to show how far these values are below sea level. Sea level becomes a *datum,* or a standard reference position known in all wells. The elevation at sea level is zero. If your counselor has access to well data, use that to make a subsurface map. Perhaps your counselor also will have copies of the electric well logs from which this information was taken. Otherwise use the data in the chart on page 51.

PROCEDURES

Step 1—The depth-to-structure values are negative because they are below sea level. To make mapping simpler, add 6,200 feet to each depth in the blank column.

Well Number	Depth to Structure (Subsea) Feet	+6,200 Feet
1	-6,790	590
2	-6,810	610
3	-6,840	640
4	-6,435	235
5	-6,241	41
6	-6,438	238
7	-6,294	94
8	-6,489	289
9	-6,750	550
10	-6,555	355
11	-6,750	550
12	-6,780	580
13	-6,805	605
14	-6,350	150
15	-6,395	195
16	-6,428	228
17	-6,463	263
18	-6,658	458
19	-6,679	479
20	-6,742	542

Step 2—Trace or copy the well location map and label each well with the depth below 6,200 feet you calculated in step 1.

Step 3—Look at the elevations. Decide if you would like to draw contour lines on 50-foot intervals. Find the lowest point.

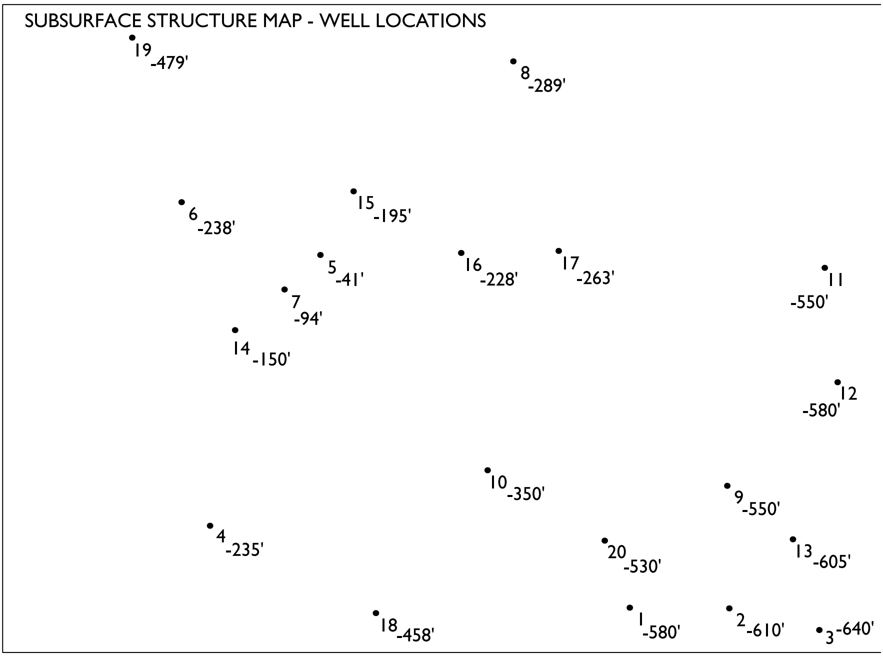
Step 4—You may want to use dashed or light pencil lines until after you have checked the points in step 7. Draw a line between the four lowest points for the –600-foot contour line.

Step 5—Next draw the contour line for –550 feet. Does this line intersect points?

Step 6—Continue sketching in contour lines between points until you reach the highest elevation. Remember, contour lines cannot cross one another.

Step 7—Double-check your contour lines. Make sure, for example, an elevation of –289 doesn't fall between the –300 and the –350 contour lines.

Step 8—Look for a structural high, the place of the highest relative elevation. It looks like a hilltop of a topographic map but actually is the structurally highest point on the map. Since oil and gas are lighter than water, they migrate upward through the rock and collect in a structural high. Label your map where you would expect an oil reservoir to exist.



OBSERVATIONS

1. Is the lowest point well 3 or 5? Why?
2. Are some contour lines spaced out more than others? Where is the steepest section of the formation?

CONCLUSIONS

Three-dimensional surfaces can be clearly seen on a contour map. Drawing a contour map shows hills and valleys that would be difficult to find by reading the well data. A subsurface map is an important geological tool.

Isopach Map. Whenever geologists make a structure map of the *bottom* of the formation, they can calculate the thickness by subtracting the depth of the top from the depth of the bottom. This map showing formation thickness is called an *isopach map* and can help the geologist or engineer determine whether there is enough rock formation present to make a sufficient reservoir for oil or gas.

Offshore Drilling. Oil companies can drill wells on dry land or in deep water. Some *offshore platforms* stand in water hundreds of feet deep, and others drill in water so deep the platform does not even touch the ocean floor. These platforms float like small islands surrounded by water.

Because it is so difficult and expensive to drill offshore, oil companies try to drill more than one well once they set up a drilling platform. They can drill wells in different directions from the same location, using the same hole.

Activity 6: Extraction Tabletop Display

The geologist has located a large oil and gas reservoir. Now what happens? For this activity, make a tabletop display and share either oil and gas extraction or coal extraction information with a small group or your counselor.

PROCEDURES

Step 1—Choose oil and gas or coal as your focus. (Oil and gas often are found together in one reservoir.) Make a three-panel display board. Add one large label in the center that reads either "Oil and Gas" or "Coal." The three labels for the three panels could be labeled "Exploration," "Extraction," and "Processing."

Step 2—With parental permission and a librarian's help, search the public library databases for articles on oil and gas or coal. With parental permission, explore the internet using a search engine for terms like "oil exploration" or "coal mining," for example. By putting the words in quotes, the search engine will pull up only websites that have both words together in the content.

Step 3—Decorate your display board with interesting facts you found on extraction.

Step 4—Give a five-minute presentation on your findings to a small group or your counselor.

OBSERVATIONS

1. Are geologists more involved in exploring for oil, gas, and coal or processing it?
2. What is something you learned in the research you did not know before?
3. Are there oil, gas, or coal reserves in your state? What states do have oil, gas, or coal reserves?
4. Does your home use natural gas? If yes, in what ways?

CONCLUSIONS

The exploration, extraction, and processing of oil, gas, and coal is a fascinating business. Now you understand that by the time you pump gasoline into your car, many people, including geologists, have worked to find, extract, and process the oil for the gasoline.

Activity 7: Visit an Operating Drilling Rig

Would you enjoy working on an oil-drilling rig as a geologist? Complete this activity to find out.

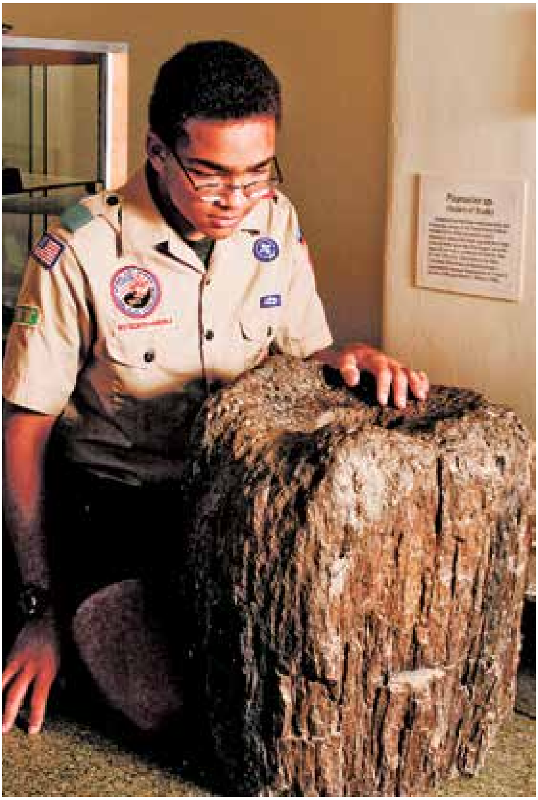
PROCEDURES

Step 1—Ask your merit badge counselor for assistance with finding a geologist who works on a drilling rig. You might locate a geologist in your area by contacting a geological group listed at the end of this pamphlet. With permission from your parent and counselor, telephone or email this contact, explaining you are working on the Geology merit badge and that one of the requirements is to visit with a geologist at a drilling rig.

Step 2—Visit the geologist at work and ask to see what geologists do onsite. Ask to see cutting samples.

OBSERVATIONS

1. What is drilling mud, and what purpose does it serve? What are drill bits and drill pipe?
2. How many barrels of oil does the geologist think the reservoir holds? How many gallons of oil is that? (There are 42 gallons in a barrel of oil.) How much of the oil is expected to be removed or recoverable?
3. Ask the geologist what is the most satisfying part of working on a drilling rig. Was it hard getting a geology degree? Why did the geologist pick this career?



CONCLUSIONS

Visiting a drilling rig gives you a glimpse of what a geologist's daily life can be like.

The magnificent blue Hope diamond, at more than 45 carats, sparkles for visitors at the National Museum of Natural History, Smithsonian Institution, in Washington, D.C.

Minerals: Earth's Treasures

Rocks are a mixture of one or more minerals found on Earth, other planets, moons, and meteorites. Some rocks, like marble, contain only one mineral—calcite. To be considered a mineral, a substance must be naturally occurring, inorganic, and solid with an orderly crystal structure and a well-defined chemical composition.

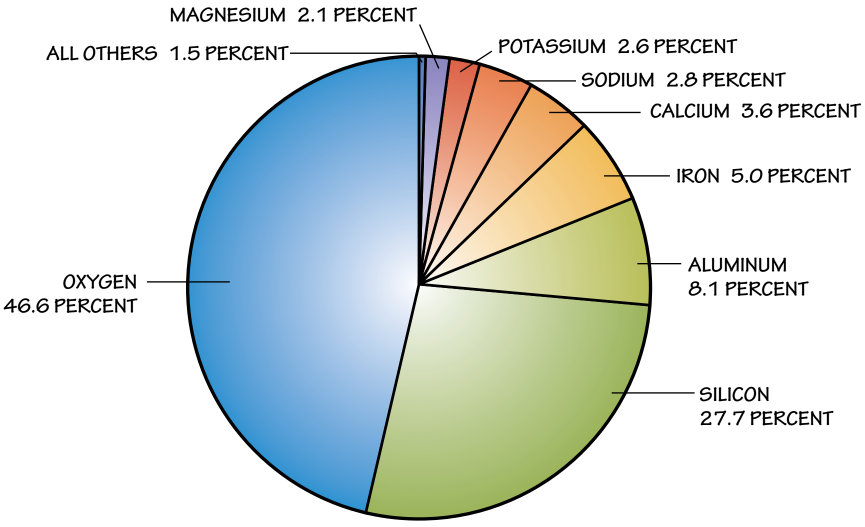
***Gems*—minerals like amethyst that are highly valued for their beauty—are often used in jewelry.**

A geologist who studies minerals is called a *mineralogist.*

Minerals

The most abundant elements in Earth's crust are oxygen and silicon (about 74 percent of Earth's crust). Because these elements combine to form minerals, geologists know that the most common minerals are those composed of the most common elements. It should be no surprise that the most abundant minerals are silicates—compounds of oxygen and silicon. Common silicate minerals include quartz, feldspar, mica, and clay.

These common minerals may be unfamiliar to you because many people are fascinated with the less common minerals, such as metallic, silvery gray, and cubic galena. But identifying minerals is an important step in recognizing the potential economic value of a substance, or even in identifying rocks you find on vacation or in your own back yard. Geologists did not have sophisticated electronic equipment when the first mineralogists were identifying minerals, so they developed a series of *comparative* scales to determine a mineral's physical properties and then to identify the minerals.



Relative abundance of elements in Earth's crust

A comparative scale compares a single property among specimens. For example, one kind of mineral may be darker red than other red minerals in the same rock. So you suspect it is a different mineral from the others. When you compare it to a rock color scale, you can see its color tone is between two values on the scale. Geologists record this scale value in their notes, because later it might be important information. Most minerals can be identified using a combination of two or three of the following eight physical properties: hardness, specific gravity, color, cleavage, fracture, luster, crystal form, and streak.

Hardness

You wouldn't rub your sunglasses across concrete because you know the concrete is harder and will scratch them. In the same way, a mineral is said to be harder than another material if it can scratch, or cut into, it.

The hardness test is a scratching test. Scratch one mineral against another to determine if it will scratch the other. Harder minerals will scratch softer ones. Mineralogists have determined a numerical scale, based on the relative hardness of common minerals. This is called the Mohs' scale.

Mohs' Comparative Scale of Relative Mineral Hardness			
Mineral	Scale of Hardness	Common Use of Mineral	Common Materials With Similar Hardness
Talc	1	Talcum powder	
Gypsum	2	Plaster of paris	Fingernail 2.5
Calcite	3	Cement	Copper penny (pre-1973) 3.5
Fluorite	4	Fluoride in toothpaste	
Apatite	5	Fertilizer	Steel nail 5
Orthoclase	6	Artificial teeth	Knife blade 5.5
Quartz	7	Quartz watch Quartz sand in porcelain	Glass 6 to 7 Streak plate 6.5 to 7 Hardened steel file 7+
Topaz	8	Jewelry	
Corundum (ruby, sapphire)	9	Ruby or sapphire for jewelry or lasers	
Diamond	10	Jewelry and cutting tools	

It is sometimes confusing which material is scratching which, like writing on a driveway with chalk. The chalk is worn down, leaving dust without scratching the concrete, so the concrete would be considered the harder of the two materials.

If you want to know what quartz can scratch, read the Mohs' scale. Quartz has a hardness of 7. This means quartz can scratch anything with a hardness of less than 7. Quartz will scratch a knife blade with a hardness of 5.5 and certainly your fingernail with a hardness of 2.5, but will not scratch a diamond with a hardness of 10. In fact, no other mineral scratches a diamond—it is the hardest naturally occurring material on Earth. (Some minerals found in a meteorite are harder than diamonds.)

This hardness scale would be useful if you found a mineral and wondered if it was fluorite or calcite, which sometimes look alike. Trying the hardness test on a copper penny with a hardness of 3.5 will tell you. Fluorite can scratch a penny, calcite cannot. Why?

The lead sinker is the same size as the aluminum foil ball but weighs more because it has a higher specific gravity.

Specific Gravity

Specific gravity is the weight of a substance compared with the weight of an equal amount of water. A heavy material like lead will have a high specific gravity. A lighter material like aluminum has a lower specific gravity. A geologist uses this relative weight to quickly sort through a collection of minerals, placing heavier ones in one category and lighter ones in another.

Color

Minerals all have a color, and color is possibly the most common—yet least reliable—mineral test. Minerals can have impurities, or elements not normally in its crystal structure, that change its color appearance. The purple amethyst is actually a milky or clear quartz crystal with traces of iron or lithium. Because the color can be misleading, geologists use color as a first-pass comparison before performing other tests.

Calcite forms rhombic forms; salt forms cubes; mica forms sheets; and quartz does not have cleavage, but forms a conchoidal fracture when broken.

Fracture and Cleavage

A mineral is said to *fracture* if, when struck against a hard object, the mineral breaks with uneven, or irregular, surfaces. Some different types of fractures are hackly, uneven, and conchoidal.

A mineral is said to *cleave* if it breaks along smooth surfaces and in regular directions. Minerals that chemically bond to form layers will cleave when broken apart, leaving smoother surfaces. Cleavage can be a definite indicator for mineral identification. Fracture is the apparent lack of cleavage, and that information also is a definite indicator.

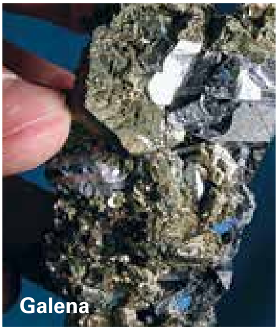
Luster

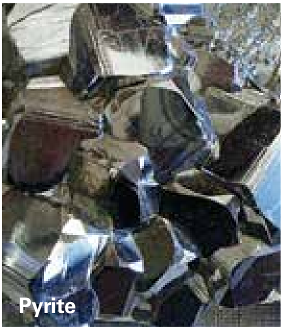
Luster refers to the appearance of the mineral in normal light. Minerals that look like glass are said to have a glassy luster. Minerals with a dull, dirty appearance are said to have an earthy luster. Minerals also can appear waxy, oily, silky, or metallic.

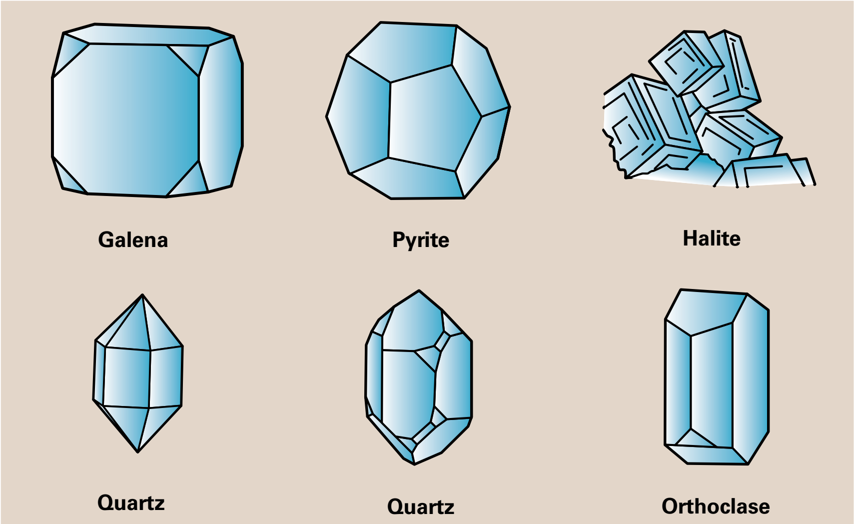
Crystal Form

When a mineral solution is allowed to cool slowly, crystals can grow. A mineral takes a crystal form if it is allowed to grow without constraint, but the lack of a crystal shape does not rule out any particular mineral. Geologists can identify certain minerals by their characteristic crystal shape.

For example, quartz may form in a volcanic steam vent, where the quartz is deposited one molecule at a time on the sides of the vent opening, allowing time for the quartz to form into crystals. Granite forming underground contains quartz, but this quartz is crowded by other minerals and does not form larger crystals.







Some common crystal shapes

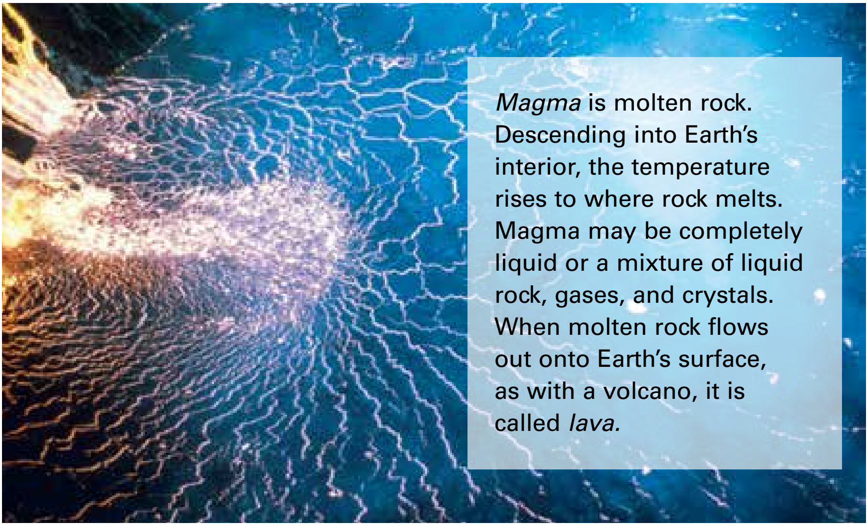
Streak

Streak is the powdery residue left when a mineral is dragged across a piece of rough porcelain. Such a piece of porcelain, which has a hardness of about 7, is called a *streak plate* and is carried in the field or used in the lab. Sometimes a mineral's streak is surprising because its color is different from the rock color. For example, the iron mineral limonite is yellow, but its streak is dark brown, typical of any iron mineral.

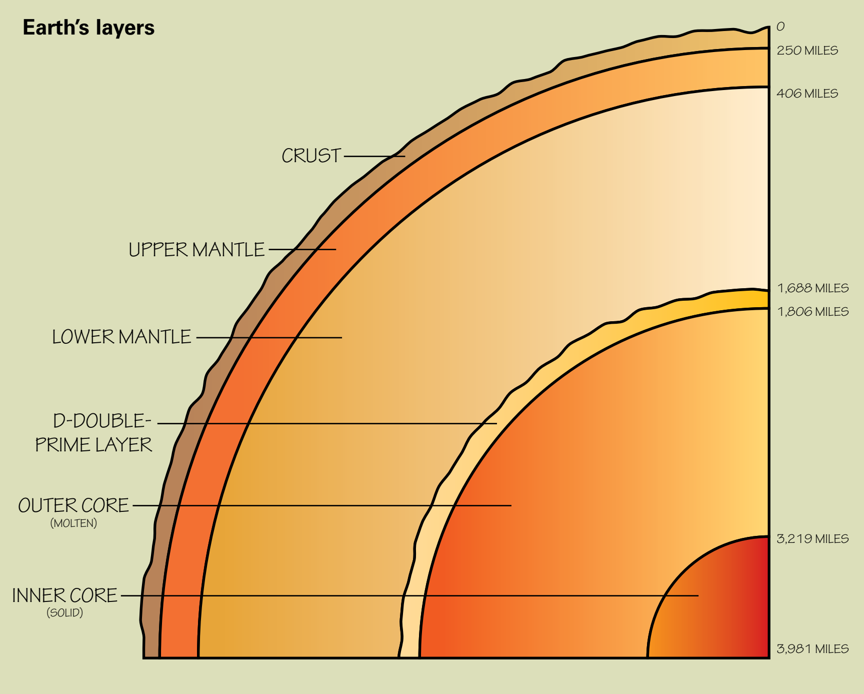
Rocks

A rock is a naturally occurring, solid substance composed of a mineral or a mixture of minerals that form an essential part of Earth's crust. The rocks described below are found worldwide, on every continent and in every ocean basin. There are three basic classes of rocks, classified by the process that forms them: igneous, sedimentary, and metamorphic.

Sedimentary rocks cover 75 percent of the continental landmass, but this is a thin covering, like the skin of an apple, and is only 5 percent of Earth's materials. Igneous and metamorphic rocks comprise the remaining 95 percent. Igneous rocks covered by a thin layer of sediments form the ocean floors.



Magma is molten rock. Descending into Earth's interior, the temperature rises to where rock melts. Magma may be completely liquid or a mixture of liquid rock, gases, and crystals. When molten rock flows out onto Earth's surface, as with a volcano, it is called *lava.*

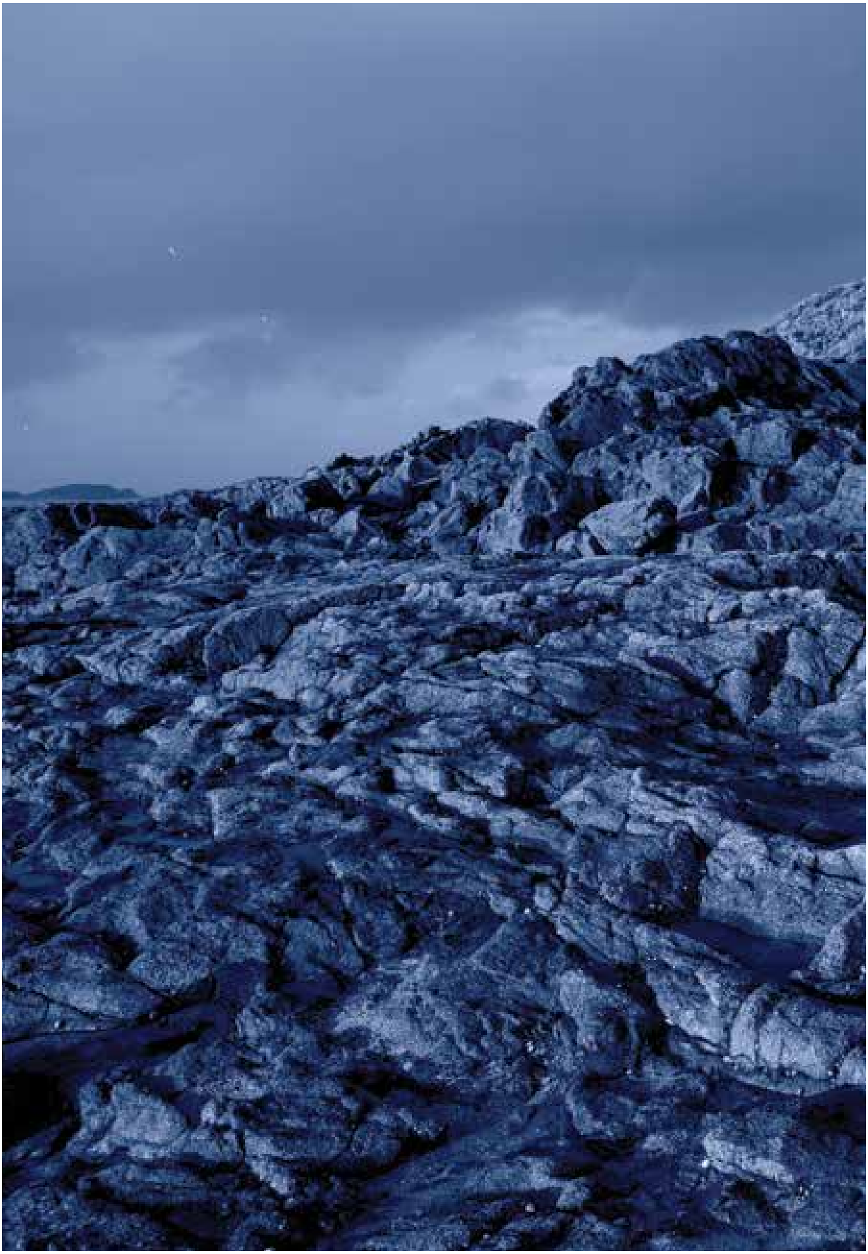


Igneous Rocks

When magma cools and solidifies, it forms igneous rock. There are two basic types of igneous rocks—*extrusive* and *intrusive.*

Sometimes magma reaches Earth's surface as a lava flow, where it quickly cools to form extrusive igneous rock. Many of the minerals that make up extrusive rocks cool very quickly and produce crystals smaller than sugar grains. Extrusive igneous rocks with very small crystal grains are said to be *fine-grained*—basalt is one example. Basalt flows are found in many parts of the western United States, for example, the Columbia River area in Washington and the area around Philmont Scout Ranch in New Mexico. The new rocks formed when Mount St. Helens volcano erupted in 1980 are mostly basalt.

Extrusive igneous rocks form on Earth's surface; intrusive igneous rocks form underground.



Devils Tower in Wyoming is a volcanic neck composed of basalt. The basalt solidified in the vent of an ancient volcano, most of which has eroded away.

When igneous rocks cool so quickly that mineral grains or crystals do not have time to form, the rocks form a volcanic glass called *obsidian.* Obsidian was highly prized by Indians for making arrowheads.

Igneous rocks that cool deeper inside Earth are called intrusive rocks. They have a coarse-grained texture and mineral crystals, or grains, around the size of fingernails. Examples of coarse-grained intrusive igneous rock include *diorite* and *granite.*

Occasionally, igneous rocks called *porphyry* form. Porphyries exhibit two stages of cooling with large crystals (called *phenocrysts*) embedded in a fine-grained groundmass, which makes them look something like a chocolate chip cookie.

Three characteristics of igneous rocks—*texture, color,* and *mineral content*—are useful in understanding their nature and origin.

- Texture indicates the cooling time and possible location (depth) of the igneous rock when it formed.
- Color is useful in understanding the composition of the magma from which the igneous rock formed.
- The mineral content or chemical composition of the rock is used to classify the kind of igneous rock that is found in the field.

Rock texture, or grain size, provides information about the *depth* at which the minerals in the magma began to cool, forming igneous rocks. As an example, if you find a fine-grained igneous rock, you interpret the rock to be an extrusive rock that cooled at or near the surface, as in a volcanic eruption or lava flow. Coarse-grained igneous rocks are intrusive rocks that cooled over very long periods of time. These deep rocks get to the surface when tectonic (mountain-building) forces uplift the area and the material covering the intrusive rock is eroded away by wind and water.

Another important characteristic of igneous rocks is *color,* which indicates the kinds of rock minerals. Lighter colored igneous rocks such as granite are usually formed from *sialic* or *silicic* magmas, rich in quartz and feldspar. Darker colored igneous rocks such as black- or green-colored gabbros or basalts are formed from *mafic* magmas, rich in iron and magnesium.

Sedimentary Rocks

Weathering of rocks exposed at Earth's surface yields two types of materials: solid grains (called *detritus*) and chemicals dissolved in water. Solid grains may be carried away by erosion, usually from running water, eventually to be deposited and buried. Buried sediment may then be compacted and cemented into one of several types of *detrital sedimentary* rocks depending on the texture (size) and composition of the grains.

The second category of sedimentary rocks are the *chemical sedimentary rocks.* This category includes limestones (calcite), chert (silica), and evaporates (salt). Most of these rocks originate from chemicals carried by fresh water to the oceans. Under extreme conditions, some of these chemicals may precipitate directly out of evaporating sea water as halite (salt) or gypsum. However, the majority of chemical sedimentary rocks are limestones or biochemical rocks, formed as various animals (clams, snails, oysters) and algae extract

Grain/Size	Properties	Rock Names	
Gravel (more than 2 millimeters)	Rounded grains		Conglomerate
	Angular grains		Breccia
Sand (1/16 to 2 millimeters)	Quartz grains	Sandstones	Quartz sandstone
	More than 25 percent feldspar		Arkose
	More than 15 percent clay minerals		Graywacke
Silt (1/16 to 1/256 millimeters)	Very fine quartz	Mudstones	Siltstone
Clay/Mud (less than 1/256 millimeters)	Clay minerals		Shale

dissolved minerals, especially calcite, from seawater to form shells and other hard parts. After burial, loose shells may be cemented into one of several types of limestones, such as fossiliferous limestones (larger shells), fossil reefs (corals and other animals), or chalk (microscopic shells).

Coal is also classified as a chemical sedimentary rock. Coal forms from the burial and lithification of plant material deposited in ancient swamps. Initially accumulating as peat, the organic material is compressed during burial into lignite (brown coal) and then into bituminous coal (soft black coal).

Metamorphic Rocks

Metamorphic rocks are the third category of rocks. It seems logical to explain them last because they develop from other sedimentary, igneous, and even metamorphic rocks. Metamorphic rocks result when minerals in rocks are exposed to heat and pressure, or hydrothermal solutions of mineral-rich steam. In most cases, heat and pressure cause the mineral atoms of existing rocks to rearrange, sometimes even producing different minerals. In other cases, new chemical elements are brought by very hot steam moving through existing rock, which can alter the minerals in the rock to form new minerals. Hydrothermal solutions often associated with metamorphic processes penetrate surrounding rocks forming many of the ore deposits found in the world.

Metamorphic rocks can be formed by contact with magma, by heat and pressure associated with burial of sediments, or by squeezing forces. *Foliated,* or layered, metamorphic rocks generally form from existing rocks that have many different mineral grains. For example, during metamorphism, shale (a sedimentary rock consisting of very tiny grains, including both the primary sediment as well as grains of other minerals) can reform into larger grains of the former minerals, giving the rock a layered appearance. Depending on the degree of metamorphism, shale may be altered to form *slate, schist,* or *gneiss,* all of which exhibit foliation but varying grain sizes. Even igneous rocks can be altered by metamorphic conditions. Granite is believed to form gneiss when exposed to metamorphic conditions.

Nonfoliated metamorphic rocks commonly form from *monominerals*—rocks largely composed of one mineral—that are exposed to metamorphism. Limestone, which is largely composed of calcite, becomes *marble* when exposed to metamorphic conditions of heat and pressure. Sandstone, composed of quartz with some feldspar, will be metamorphosed to form *quartzite.*

Collecting Minerals and Rocks

Minerals include a variety of *metallic ores,* which are sources of important metals, and *nonmetallic ores,* which are sources of a variety of products, including building materials and agricultural supplements (like fertilizer). Other minerals and rocks have great appeal as gemstones and for ornamental purposes. Agates and turquoise are of interest to jewelers or rock hounds just as large deposits of magnetite are of interest

The word *metamorphic* means to change form. Think of metamorphic rocks as rocks that have changed or formed with heat and pressure from another rock.

Shale (sedimentary)

Slate (metamorphic)

to geologists searching for iron ore to make steel or good limestone deposits to make crushed rock for highways are of interest to aggregate producers.

Our ancestors searched for good deposits of obsidian, chert, and flint for arrowheads. Explorers coming to the New World were motivated by the desire to find gold. Today geologists look for rocks and minerals to understand how Earth continually changes and are searching other planetary surfaces to understand their geologic processes.

When you collect rock specimens or study rocks and minerals, you have the opportunity to hold earth history in your hands and to recognize earth processes at work.

Listing of common rocks and minerals, and where to find them		
Rock or Mineral	**Common Name**	**Where to Obtain Them**
Limestone	Road aggregate or chat	Building supply store
Volcanic scoria or pumice	Lava rock	Landscaping supplies
Marble	Marble chips	Landscaping supplies

Use this chart to get started on requirement 3a of the mineral resources option.

Everyday Uses of Rocks

Some geologists use rocks and minerals to give them clues about earth processes and about the history of Earth. Other geologists study rocks and minerals to find new ways to use them.

Almost every city has a nearby source of earth materials used in manufacturing, construction, energy production, agriculture, and even recreation. A rock quarry or sand-and-gravel operation produces materials for construction of roads or buildings. Can you think of one you have seen? Crushed limestone is the most commonly mined or quarried material in the United States. Millions of tons of limestone are used each year in the manufacturing of cement or crushed rock called *aggregate*. This aggregate is used in road concrete, highway asphalt, and even loose gravel for driveways and roads. Other mining operations range from coal, gypsum, ore, and salt, to oil production and fertilizer manufacturing. Mining or mineral extraction is found throughout the United States.

If you examine where you live, your home, the sidewalks and roads, your school, your place of worship, Scout camp, sports fields, even silverware, nearly everything around you is a product of mining or contains products derived from mining.

Road Building

Road building is one way geology affects you every day. First of all, government planners and construction companies employ geologists and civil engineers. These professionals can tell them the best places to build highways, bypasses, highway exits, and streets. The geologist or engineer checks the location to be sure it offers a sound foundation for a road bed.

The selection of materials is also important because there must be a balance between selecting the best materials for the job against the cost of purchasing and transporting the materials. For example, we may have a ready supply of river gravel in the community but no limestone to make cement for concrete. It is not acceptable to build a high-speed interstate highway out of loose gravel, so we pay a higher cost to bring cement to the site from hundreds of miles away. Often it is more cost-efficient to repair and resurface a highway rather than to build a new one. If a geologist has access to limestone supplies and oil refinery petroleum, the geologist might recommend resurfacing a concrete roadway with asphalt.

What kinds of road materials are used in your area? Look at the highway closest to your home, look at the street that you take to school, and look at your own driveway or the parking lot of a nearby business. What are they made of, and where did the materials originate?

Activity 8: Road Construction Materials in Your Community

Now that you understand the types of rocks that make up Earth, explore how roads are built in your community. In this activity you will identify the three most common road-building materials in your community, how they are produced, and how they are used in road construction.

PROCEDURES

Step 1—With the help of your counselor or parent, call or visit a construction engineer or a concrete or construction business listed in the yellow pages.

Step 2—Take notes as you ask what the business uses as its three most common road construction materials.

Step 3—Ask how these three materials are produced and how these three materials are used in road construction.

Earth History: The Story Rocks Tell

The story of geology, the history of Earth, is divided into chapters much like a book. The story is filled with the mystery and adventure of what happened to former lands and seas, plants and animals. This merit badge pamphlet attempts to look at the different chapters that tell the story of Earth. After earning this merit badge, you will have a better understanding of the history of Earth's crust and the evolution of life on Earth.

Events Revealed by the Geological Record

Climate Change

Earth's climate has fluctuated throughout history. This includes several ice ages, the harshest of which began about 715 million years ago and lasted at least 100 million years. This event is referred to as the Snowball Earth period (or Cryogenian Glaciation). Most of Earth was covered in snow and ice.

The most recent glaciation (the Pleistocene Glaciation) began about 2.5 million years ago and is ongoing. It consists of several alternating glacial and interglacial intervals. We are currently in an interglacial interval that began about 12,000 years ago. During the last glacial interval, sea level fell almost 400 feet below its present level.

Alternatively, during much of Earth history global climates were warmer than today, such as during the Cambrian Period and most of the Mesozoic Era. One brief and exceptionally hot event occurred 56 million years ago. Referred to as the Paleocene-Eocene Thermal Maximum (PETM), global mean temperatures rose to 73°F (today the global mean temperature is 60°F). Data indicate the increase in temperature was due to a massive release of carbon dioxide into the atmosphere, but the source of the carbon dioxide is still being investigated.

In the 1980s and 1990s, scientists became concerned about the accumulation of carbon dioxide in the atmosphere. Carbon dioxide is a byproduct of the combustion of petroleum and coal, which are fuels for cars, airplanes, and power plants. While the average temperature of Earth's atmosphere has fluctuated for hundreds of years, including a "Little Ice Age" (ending about 1850), the input of carbon dioxide due to human activity began increasing at the beginning of the European Industrial Revolution (about 1760). This input began to manifest itself as increasing atmospheric temperatures by about 1910.

Carbon dioxide in the atmosphere traps infrared radiation reflected from Earth's surface and converts it into heat, causing atmospheric temperatures to rise. The Intergovernmental

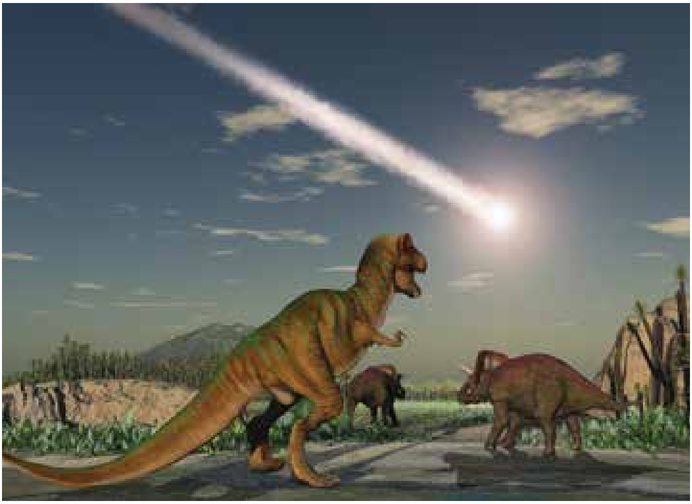
Panel on Climate Change has speculated that the average temperature could rise 1.5°C by 2100. Potential impacts include the melting of glaciers, rising sea levels, reduction of polar sea ice, and changing weather patterns.

Extinction of Dinosaurs

In the 1970s, Walter Alvarez, along with his father, Nobel Prize winner Luis Alvarez, and chemists Frank Asaro and Helen Michel began investigating sediments in Italy. Samples collected from outcrops spanning the Cretaceous-Paleocene boundary were found to have elevated levels of the element iridium. Iridium is extremely rare on Earth's surface, so the scientists began to ask what why the iridium was present.

Speculation focused on objects from outer space—meteors—that would bring the iridium to earth. In time, geologists were able to identify the impact site, a 93-mile-wide crater located near Chicxulub, Mexico. The crater had been covered by sediments but the basic structure was identified. In addition to the iridium, shocked quartz, a form of quartz that has a microscopic structure different from normal quartz, was found in the area of the crater.

Calculations indicate the meteor might have been 6 to 7 miles (10 kilometers) in diameter. Such a meteor impact would have a tremendous impact on the earth's climate and biologic processes. Scientists believe the dust generated by the impact

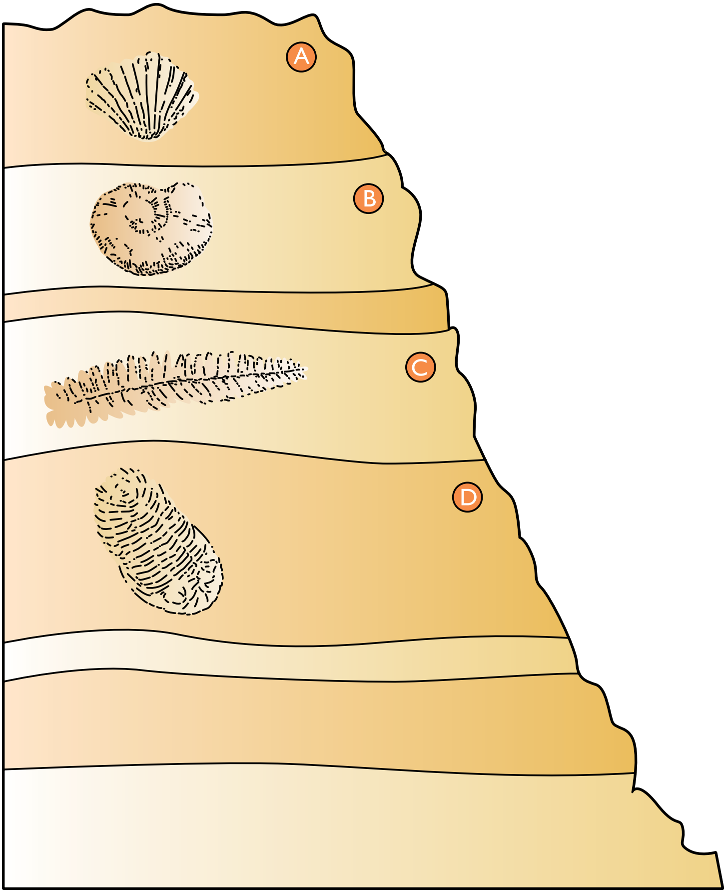


substantially reduced the sunlight, cooled the planet, and halted photosynthesis. The disruption and reduced food supplies led to the mass extinction of approximately 75% of life on Earth, including the dinosaurs. A contributing factor to this extinction appears to have been a concurrent outpouring of massive lavas (flood basalts) in India. This volcanism, which lasted several thousand years, released enormous amounts of carbon dioxide and sulfurous gases into the atmosphere.

Reviewing the geologic record, scientists have identified four additional mass extinctions in the past 540 million years. These extinctions were generally caused by massive volcanic eruptions, although major ice ages and sea level changes may have contributed. All these causes are related to changes in global climates.

Determining the Earth's Age

Scientists use two basic techniques—*relative dating* and *absolute dating*—to estimate the age of a rock layer or a fossil. Relative dating is the most basic technique, based on the observation that most rocks are laid down in roughly horizontal layers, with the oldest layer at the bottom and the youngest layer at the top. This allows geologists to say that one rock layer is older or younger than another layer, but it does not identify the actual age of the rock. Because this technique tells

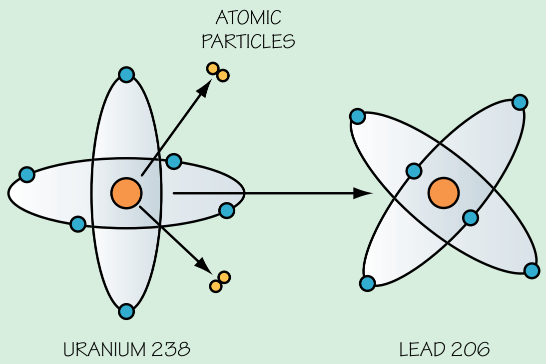


Using relative dating, geologists know that rock in layer C is older than rock in layer B but younger than rock in layer D.

only the relative age of a rock layer in comparison to the layers above and below it, it is called *relative dating*.

Scientists also use *absolute dating* to determine the age in years of certain rock types. Absolute dating is measured by calculating the *radioactive decay,* or degeneration of an element's atomic structure through time, as they phase from one element form (isotope) to another (like potassium to argon, uranium to lead, or the different isotopes of carbon). Using sophisticated laboratory equipment, scientists can estimate an element's *half-life*—the time needed for half of a sample to decay by losing atomic particles.

When uranium 238 loses atomic particles and becomes lead 206, it is called radioactive decay. The number 238 is the total protons plus neutrons in the nucleus of this uranium isotope.



HALF-LIFE

Radioactive decay is a process in which the nucleus of an atom loses some atomic particles over a period of time. As those particles leave the nucleus, the atomic number changes, and the element degrades into a daughter product, sometimes creating a totally different element. For example, some isotopes of uranium can decay into lead over a period of time. Some scientists are convinced that measuring the amount of decay that has occurred in a rock sample can give us a way to measure time.

There are four relatively abundant radioactive isotopes that occur in rocks: two isotopes of uranium (U238 and U235), rubidium (Rb87), and potassium (K40). We can measure the ratio (the relative amount) of different isotopes to others: uranium isotopes to other uranium isotopes, rubidium to strontium, uranium to lead, and potassium to argon. This ratio allows a rock to be dated based on the isotope's half-life. Imagine a 1-gram sample of uranium 238. In theory, it would take 4.5 billion years for half, or 0.5 grams, of it to decay to lead 206.

Common Radioactive Atomic Half-Lives Theory

Atom	Billion Years
Uranium 238	4.5
Uranium 235	0.7
Rubidium 87	47.0
Potassium 40	1.3
Carbon 14	5,730 years

A geologic map shows the common ages and types of rocks on Earth's surface. Ask your counselor to show you a geologic map of the area in which you live and, using the map legend and descriptions, discuss how to estimate the age of the surface rocks in your area.

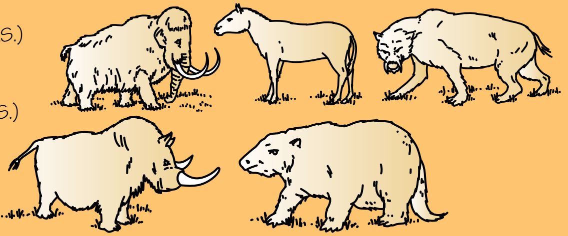
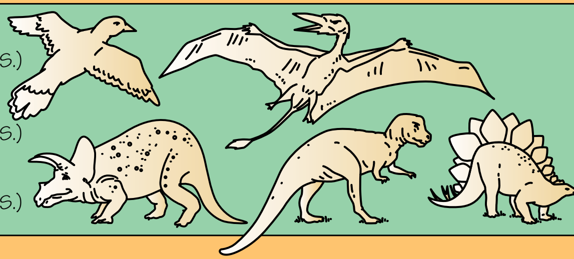
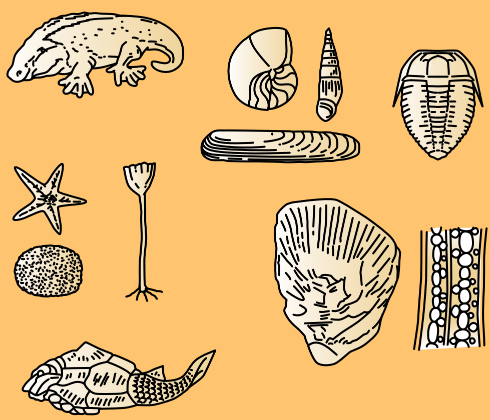
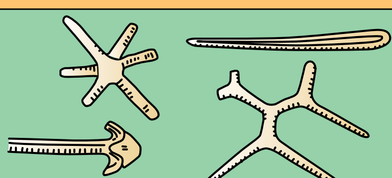
Fossils Give Clues to the Past

Have you ever wondered why we are all so interested in fossils? Is it because big, scary creatures like *Tyrannosaurus rex* or saber-toothed tigers fascinate us? That's certainly part of it, but most fossils are not the remains of big, scary creatures. Much of our fascination with fossils is because they are the closest things people have to a time machine, a way to go back into prehistoric times and to see Earth's plants and animals of long ago. The study of fossils is called *paleontology,* and the geologist who studies fossils is a *paleontologist.* The paleontologist reconstructs the past by combining the knowledge of modern animals and plants with what is known about the remains of ancient animals and plants from fossils.

A **fossil** is the remains or impression (imprint) of a plant, animal, or shape, such as a shell, bones, leaf, or even a footprint, that was created or formed during a past geologic age.

Geologic time is organized into eras. Each era represents a time during which certain lifestyles dominated Earth. Eras cover long intervals of time, so geologists find it useful to further divide the eras into shorter time intervals called *periods.*

Geologic Time Scale Theory

Era	Period and Approximate Duration	Characteristic Life
Cenozoic	QUATERNARY (2.6 MILLION YRS.) TERTIARY (63 MILLION YRS.)	
Mesozoic	CRETACEOUS (79 MILLION YRS.) JURASSIC (56 MILLION YRS.) TRIASSIC (51 MILLION YRS.)	
Paleozoic	PERMIAN (47 MILLION YRS.) PENNSYLVANIAN (24 MILLION YRS.) MISSISSIPPIAN (36 MILLION YRS.) DEVONIAN (60 MILLION YRS.) SILURIAN (25 MILLION YRS.) ORDOVICIAN (41 MILLION YRS.) CAMBRIAN (56 MILLION YRS.)	
Precambrian Time	PROTEROZOIC EON (2 BILLION YRS.) ARCHEAN EON (1.5 BILLION YRS.) HADEAN EON (500 MILLION YRS.)	

Approximate age of Earth: more than 4 billion 600 million years

For example, today sharks live in the ocean. Shark teeth are distinctive, not like your teeth or the teeth of other mammals. When paleontologists find a shark tooth in a rock layer, they know that the rock layer was deposited on an ocean floor. As paleontologists study the rock layer that held the shark tooth, they may find more fossils and gather other geologic information. Together the fossils and other information allow the paleontologists to piece together an idea of the ocean the shark lived in. Also based on the size of the fossil tooth compared to today's shark teeth, the paleontologist can closely estimate the shark's size.

Fossils act like time machines for geologists, allowing them a peek into the past.

What other animals lived there? Was the water deep or shallow? Was the bottom sandy or was it a hard reef made of coral? If this was the ocean, where was the land? You can't go back in time, but you can use your knowledge of modern oceans and modern life, with your knowledge of fossils, to compare ancient times with the present.

What makes an animal or plant turn into a fossil? If you are at summer camp and a raccoon dies near your tent, it probably won't turn into a fossil. As it lies on the ground, vultures, beetles, flies, and other scavengers eat it. Even the bones are destroyed. By the time you return to camp the next summer, no trace of that raccoon will remain. It will never become a fossil.

The key for any animal or plant to become a fossil is that it must be buried soon after death. If a raccoon falls into a stream or river, the river sands or mud will bury it quickly. Even if the soft tissues of the animal are decayed, its bones may be preserved and the layers of sand and mud covering the bones protect it from being destroyed. Unfortunately, animals that live on land have a poor chance of becoming fossils. There are very few situations where they are quickly buried. There are places where animals have been buried in a river, as at Dinosaur National Monument in Utah, or in a tar pit, as at La Brea Tar Pits in Los Angeles. However, these places are not common.

Only a fraction of plants and animals die and fall in a place with the right conditions for fossils to form. Yet even with the low chance of becoming a fossil there are billions of fossils in the world, from big dinosaur bones to tiny microfossils.

Ocean animals like clams, snails, and corals have a greater chance of becoming fossils than land animals, partly because sediments quickly bury them on the ocean floor, but also because they have hard shells.

The shells of clams, snails, and other shell-bearing animals can be preserved as fossils. Plants and even soft-bodied worms can form impressions in soft mud that preserve the shape of these organisms after the mud turns to rock. Sometimes, after the shell has been buried in soft mud, it will dissolve, leaving the shape of the shell preserved as a mold in the rock.

Measuring Time Using Fossils

Many geologists commonly speak of the age of a rock or fossil in millions or even billions of years. People have a life span of only about 60 to 100 years, so a million or a billion years is almost impossible to imagine. How can you determine the age of something that old?

Geologists refer to the *abundant fossil record* as that time when numerous and different life forms appeared on Earth at the same time. Before the Cambrian Period, most life forms were single-celled organisms like amoeba, bacteria, or plankton. At the beginning of the Cambrian (beginning of the Paleozoic Era), many life forms appeared in the world ocean and most of them were complex, multicelled organisms (animals and plants that developed several types of specialized cells within their bodies, each performing a specialized function). These organisms were no longer living on photosynthesis (like a plant) or by absorbing nutrients from surrounding water (like an amoeba or bacteria). These animals and plants were evolving and becoming larger and more complex.

Once buried, the grains of sediment cover the plant or animal and accumulate. If the plant or animal has "hard parts" like a shell or woody trunk, they can support the weight of overlying sediments. Then the mud will create a *mold* around the fossil. As the sediments harden into rock, the molded impression also hardens and its outline may still be seen, even if the fossil is dissolved away.

Sometimes you can find an animal fossil that has undergone *replacement* of its original shell material with a new, secondary mineral. This occurs long after burial when the original shell material is slowly dissolved away by groundwater. Then one molecule at a time seeps in to fill the void.

Relative dating is most common for fossils. After examining thousands of different fossils and comparing the rocks in which they are formed with rocks dated by radioactive means, paleontologists have determined an age range for most fossils and the rocks that contain them.

Make a fossil with plaster of paris. Find an animal footprint in soft mud. Pour plaster of paris over the footprint. When it hardens lift your "fossil" out of the mud. This may be a part of a Scout nature study. Make a plant fossil by pouring plaster of paris in a disposable tray, like an aluminum baking tin, and then press a fern or other leaf into it.

Life Through Time in the Fossil Record

The fossil record suggests that life has changed through time. You may find that none of the species in the fossils you collect are alive today. Many plants and animals may have evolved and thrived under a specific set of environmental conditions. This set of conditions is a *paleoenvironment*. When conditions change the plant or animal is no longer able to compete for food and dies off. If the conditions change across a wide enough area the plant or animal may become extinct. One circumstance that could have caused extinctions occurred during a time when widespread glaciation killed plants. When plants die, plant-eating animals starve and also die. The plant and animal species alive today are only a fraction of all the species that have been alive during Earth's history.

Suppose you discover fossils of marine animals that lived in the tropical ocean waters near your home. The ocean may have extended over the land where you now live. This suggests that when the fossilized animals were alive, your home's climate was warmer.

Fossil records suggest that during certain relatively short time periods massive extinctions occurred. During these events, not only could individual species become extinct, but even entire ecosystems. Five major mass extinctions have occurred since the beginning of the Paleozoic Era. The two largest extinction events occurred at the end of the Paleozoic and Mesozoic eras, respectively.

Of course, not all species of plants and animals died out at the end of the Paleozoic. Sharks originally appeared during the Paleozoic Era and have remained essentially unchanged since then. The record shows many new species developed during the next era, the Mesozoic. The Mesozoic Era is most commonly thought of as the age of dinosaurs, although many other plants and animals were present during that time.

The final era is the Cenozoic Era, which started at the end of the Mesozoic and continues through today. The word *Cenozoic* means recent life. The last 2.6 million years of the Cenozoic Era include a distinctive paleoenvironmental feature, known as the *Ice Age.* Scientists believe it was a time when periods of extremely cold climate allowed the widespread development of glaciers in the Northern Hemisphere (the north half of the planet Earth). In North America, widespread sheets of ice, measuring hundreds or thousands of miles across, spread southward from the North Pole and filled the continent from the Appalachian Mountains in the east to the Rocky Mountains in the west. These sheets of ice extended as far south as Kansas and the ice measured more than a mile thick in some places. See the section in this pamphlet about glaciers.

During this Ice Age, many plants and animals adapted to the new living conditions. Mammoths and mastodons were common in North America and may have been hunted for food. The climate south of the ice sheets was rainy, and insects thrived. Bats and birds thrived by eating the abundance of insects.

Interpreting the Past With Fossils

Every animal and plant species tends to be found within the habitat in which they are best adapted to survive. Environmental conditions vary from one habitat to the next. For example, the forest floor of a tropical rainforest is usually humid from frequent rain and has little sunlight. Many smaller plants grow thickly and cover the forest floor. A plant adapted to survive on a rainforest

The fossil record suggests, despite what many people think, that all dinosaurs did not live at the same time. The familiar ***Apatosaurus*** (formerly called ***Brontosaurus***) lived in the late Jurassic period, which many scientists believe ended about 140 million years ago. ***Tyrannosaurus rex*** lived during the late Cretaceous period, which these scientists theorize ended about 66 million years ago. Accordingly, they believe the last of the tyrannosaurs lived about 74 million years after the extinction of ***Apatosaurus***.

floor might not be able to survive in an open field where it is hot and dry, or in a desert. Likewise, a plant from a sunny field probably could not survive long in the moist shady floor of the rainforest. The amount of sunlight and the amount of moisture limit where particular plants can survive.

An animal living in the ocean also must be adapted to its environmental conditions. One major environmental factor is ocean salinity, the amount of salt dissolved in the water. Far from land, salinity remains constant and fish and other animals have adapted to this *open marine* environment. Near shore, rivers pour into the ocean, bringing freshwater. This freshwater reduces the ocean salinity at the mouth of the river. At this point salinity is less than normal ocean salinity. This water is called *brackish.* Animals living in brackish water are able to adapt to changes in salinity. Many fish that survive in brackish water cannot survive in the higher salinity of the open ocean or in a freshwater river or lake.

In the ocean, scientists have observed that different *marine* animals live in particular environments. Geologists study fossils of these animals and their paleoenvironment. Knowing this information about paleoenvironments helps geologists to pinpoint areas where valuable minerals or hydrocarbons may exist.

Marine Animal Environments

Where an animal lives tells us how it eats and survives. *Pelagic* animals are those that either swim or drift in the water near the surface. Since pelagic animals swim or float, they must eat things that swim or float. Some plants are pelagic and live near the surface where they can catch the sunlight.

Benthic animals are those that live on the bottom of the ocean. A benthic plant, like all plants, requires sunlight for

The most common benthic animal are the corals, which build rigid skeletons in community structures called *coral reefs.*

photosynthesis. Since sunlight filters through water only to a limited depth, benthic plants live in shallow water. A benthic animal can stay in one place and wait for food to float past, which a clam would do. Or it can live like a starfish crawling along slowly eating other benthic animals. Because these animals will die if washed out to sea in a storm current, most have adapted some sort of anchor to help them stay in place.

Littoral animals live along the shore line bounded by the levels of high and low tide. This is called the intertidal zone. Tide pools are littoral environments where they are under water and out of water part of the time.

Not all animals that live in water live in the ocean. Those living in rivers live in a *fluvial* environment, and animals living in lakes live in a *lacustrine* environment.

Because animals tend to live in very specific environments, their fossil remains give us a lot of information about the history of the area. A coral reef tends to create a barrier between the shore and the open sea, so frequently a quiet water lagoon is located between the reef and the shore. Knowing this geologists can predict in which direction rocks will be deposited in the open ocean, versus rocks onshore. This will enable geologists to draw a *paleogeographic map,* or a map showing the ancient geography at the time of sediment deposition.

Field Trips Are for Learning About Geology

Geologists love to take field trips to see rock collections. A museum or university geology department are the best places to see how geologists organize and categorize their collections, especially when the collections are used to educate.

To complete the requirements for the earth history option, each Scout is encouraged to visit a museum or university geology department. Remember to call ahead and make an appointment with a curator or professor so that person can set aside enough time to properly show the fossil and mineral collections. The people who work in such places enjoy having the public visit and most will happily take time for you. Be sure to ask questions and have them show you how they clean and prepare a freshly discovered fossil for display.

If there is not a museum or university department nearby, your counselor may be able to provide addresses of local buildings that used fossiliferous rocks as building stones. Visit these buildings and treat them like fossil dig sites.

1. Sketch the building's fossils in your notebook or photograph them and tape photos into your notebook with written descriptions of the fossil and anything else you observe.
2. Observe the type of rock that contains the fossils (is it sandstone or limestone), and observe whether the rock grains are very fine or more coarse. Finer grains help preserve fossils in greater detail. Can you describe the paleoenvironment of deposition from looking at these rocks? Remember that finer grained sediments occur in calmer water, whereas coarser sediments occur where there is a current, as in a stream or beach. Also remember that certain kinds of plants and animals live in certain kinds of paleoenvironments and their very presence is a clue to the ancient environment. Write your thoughts in your notebook and discuss your observations with your counselor.

If you happen to be on vacation or away from home for some reason, you may discover a rock outcropping worth exploring. Take notes, photographs, and sketches of what you see there. When you return home, you and your buddy can meet with your counselor and discuss what you found at the outcrop.

If a visitation is not practical for you, create a display or presentation on your state fossil instead. Your research at the library and online (with your parent's permission) will pay off with an amazing presentation. Remember, if your state does not have a state fossil, you may select a state fossil from a neighboring state.

A geologist collects samples at an active field site.

Careers in Geology

Even if you are not interested in a career in geology, it is good to learn more about our Earth. Knowledge of geology makes Earth even more interesting. A walk or drive is more fun if you know why and how the hills and valleys formed, how the waves on a beach sort and distribute sand, how sand someday will be a solid rock and carry oil, gas, and water, how part of the land is always on its way to the sea, and where the minerals come from that are used to make the things you use every day.

To learn more about geology take an earth science course in high school, or two or more college courses in geology.

Geology is a wide field with many career choices. Hydrogeologists help find water underground and can plan how much to use so you will not run out. Geological engineers advise where to build a dam, where bridge abutments and piers may be built safely, where buildings will have solid foundations, or where tunnels can be built without collapsing.

Many geologists are involved in the exploration of and/or the production of natural resources, like oil and gas, coal, iron ore, copper, gold, and countless other minerals.

A professional geologist must earn at least a four-year college degree (bachelor's degree) in geology, geophysics, environmental geology, or geological engineering. In many fields a master's degree (two years beyond a bachelor's degree) may be necessary. To teach at a college or university, or to do research, a doctorate is required (three to seven years beyond a bachelor's degree).

Aside from geology courses, all geologists should take fundamental science courses such as chemistry and physics, and also mathematics. Some fields will require specialized courses. Writing skills are always important, as geologists must write reports about their discoveries and tell others what they have found. Virtually all geologists use computers extensively in their work.

Geology is fun. Geologists enjoy their profession and like the challenge and adventure. Geologists were the first environmentalists. They enjoy working outdoors and in out-of-the-way places that are hard to reach and where it is difficult to live. Geologists like to solve puzzles and like to grapple with geological problems, using evidence you may—or may not—be able to see.

For more information on careers in geology, or to find what schools offer geology or geology related degrees, contact the American Geological Institute. Many professional societies also have career information. See the resources section at the end of this pamphlet.





Geology Resources

Scouting Literature

Archaeology, Chemistry, Collections, Drafting, Energy, Engineering, Environmental Science, Landscape Architecture, Mining in Society, Nuclear Science, Oceanography, Orienteering, Soil and Water Conservation, Surveying, Sustainability, and *Weather* merit badge pamphlets

With your parent's permission, visit the Boy Scouts of America's official retail website, www.scoutshop.org, for a complete listing of all merit badge pamphlets and other helpful Scouting materials and supplies.

Books

Altman, Linda Jacobs. *The California Gold Rush.* Enslow Publishers Inc., 2012.

Dixon, Dougal. *The Practical Geologist.* Simon & Schuster Inc., 1992.

Gaines, R., H. Skinner, E. Foord, B. Mason, and A. Rosenzweig. *Dana's New Mineralogy.* Wiley-Interscience, 1997.

Hyne, Norman J., Ph.D. *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production.* PennWell Corp., 2012.

Johnson, Carl. *Fire on the Mountain.* Chronicle Books, 1994.

Lamb, Simon, and David Sington. *Earth Story: The Forces That Have Shaped Our Planet.* Princeton University Press, 2003.

Lambert, David, and the Diagram Group. *The Field Guide to Geology.* Checkmark Books, 2006.

Mayor, Adrienne. *The First Fossil Hunters: Paleontology in Greek and Roman Times.* Princeton University Press, 2000.

Monroe, James S., and Reed Wicander. *The Changing Earth: Exploring Geology and Evolution,* 7th ed. Cengage Learning, 2015.

Pough, Frederick H. *Rocks and Minerals.* Houghton Mifflin Harcourt, 1998.

Stewart, Iain. *Journeys from the Centre of the Earth: How Geology Shaped Civilization.* Random House, 2005.

VanCleave, Janice. *Rocks and Minerals.* John Wiley & Sons Inc., 1996.

Organizations and Websites

American Association of Petroleum Geologists
1444 S. Boulder Ave.
Tulsa, OK 74119
Toll-free telephone: 800-364-2274
www.aapg.org

American Geosciences Institute
4220 King St.
Alexandria, VA 22302-1502
Telephone: 703-379-2480
www.americangeosciences.org

American Petroleum Institute
1220 L St. NW
Washington, DC 20005-4070
Telephone: 202-682-8000
www.api.org

The Geological Society of America
P.O. Box 9140
Boulder, CO 80301-9140
Telephone: 303-357-1000
www.geosociety.org

Paleontological Research Institute
1259 Trumansburg Road
Ithaca, NY 14850
Telephone: 607-273-6623
www.priweb.org

Society of Exploration Geophysicists
8801 S. Yale Ave., Suite 500
Tulsa, OK 74137-3575
Telephone: 918-497-5500
www.seg.org

U.S. Geological Survey
www.usgs.gov

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