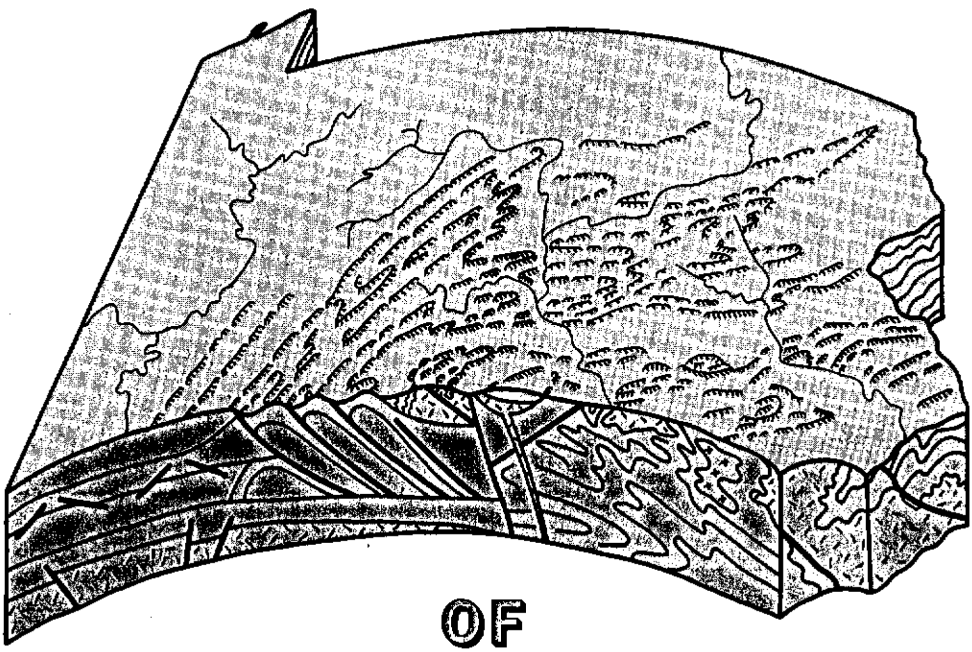
Educational Series 1

ROCKS AND MINERALS



OF PENNSYLVANIA

Commonwealth of Pennsylvania
Department of
Conservation and Natural Resources
Bureau of Topographic and Geologic Survey

Educational Series 1

Rocks and Minerals of Pennsylvania

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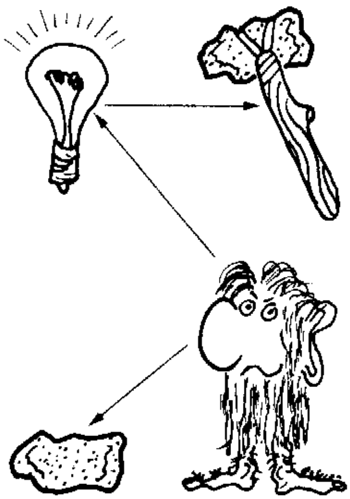
In our increasingly mechanized world, some people speak of the importance of keeping sight of the things that are essential to life. This book deals with one of the most basic of all those things—rocks.

Why rocks? Because rocks are fundamental to our very existence on planet Earth. In fact, without rocks there would be no planet Earth! Nothing that we take for granted, other than the Sun, stars, and space, would exist without rocks.

Rocks are what our earliest human ancestors used to make the things that they needed to survive. Nobody can be sure exactly when someone first made practical use of a rock, but it is not hard to imagine one of the earliest humans picking up a rock and using it as a hammer or a weapon. With time came the idea that a rock could be tied to a stick to make a better hammer, or that certain rocks could be shaped and given sharp edges to make spear points. Eventually, people discovered that certain types of clay, a weathering product of rocks, could be fashioned into containers, such as bowls, pots, and jugs, or could be used to make sun-dried bricks.



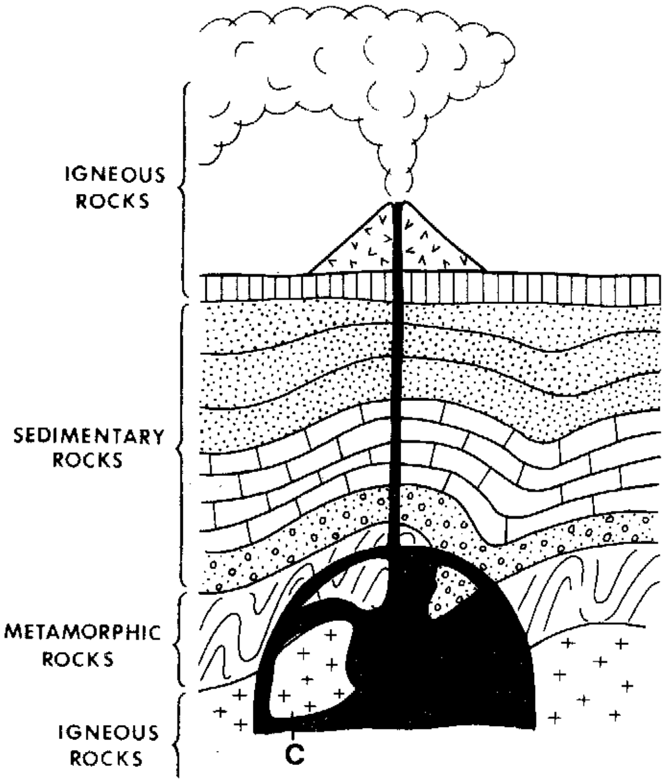
But, you might say, other than forming the planet on which we live, rocks have no relevance to our modern world. Today we make things of steel, glass, and plastic, not rocks. But those materials represent nothing more than a continuation of the early idea that rocks could be modified to better suit a purpose. All of these materials begin with the right kind of rock—rock that will yield iron, quartz, or petroleum, raw materials from which steel, glass, and plastic, respectively, are made.

There are very few activities that do not, in some way, involve rocks. The construction of buildings, highways, monuments, and dams is an example of a few ways in which rocks are still used without much modification. Steel, glass, and plastic are among the products that are derived from rocks after greater modification. But there is another role that rocks play in our lives, and that they played in the lives of our earliest ancestors. As rocks age, they change chemically and break down into fragments that form the basis of soil. This soil provides the nutrients that are required by growing plants, making life on earth possible.

Before we can study rocks, we need some way to classify them. Classification helps us to keep track of the various kinds of rocks by grouping those that are, in some way, similar to each other.

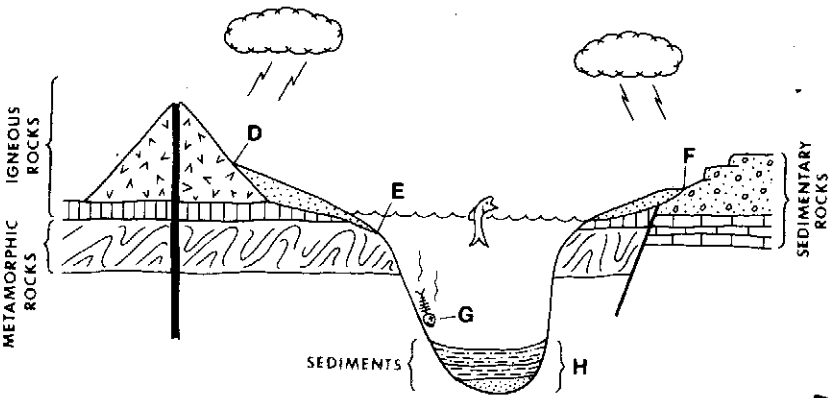
All rocks can be placed in one of three major groups, ***igneous***, ***sedimentary***, or ***metamorphic***, depending on the way in which they are understood to have formed.

IGNEOUS ROCKS form from rock material that has been heated in the interior of the earth to such a high temperature that it has melted. Red-hot liquid moves upward through the earth's crust and cools at or near the surface. If the liquid reaches the surface, a volcano or lava flow forms.



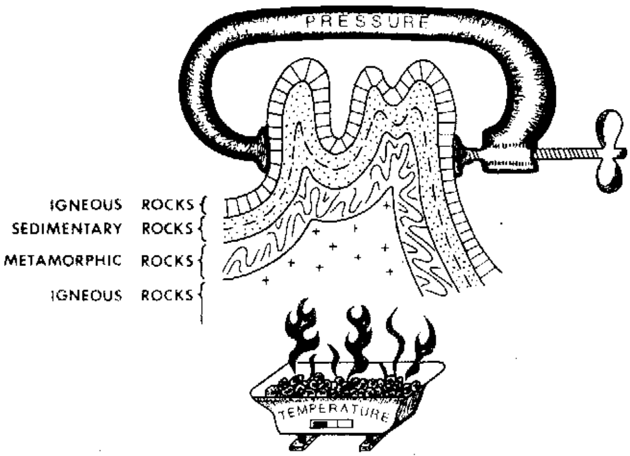
A. Sedimentary rocks are melted to form igneous rocks.
B. Metamorphic rocks are melted to form igneous rocks.
C. Igneous rocks are melted to form more igneous rocks.

SEDIMENTARY ROCKS can form from the accumulation of particles that have worn off older rocks, seashells and other hard fragments of animals, and substances that are dissolved in water and are left behind when the water evaporates. With the passage of long periods of time these sediments become cemented together to form hard rock. Sedimentary rocks commonly form on the seafloor or in lakes.

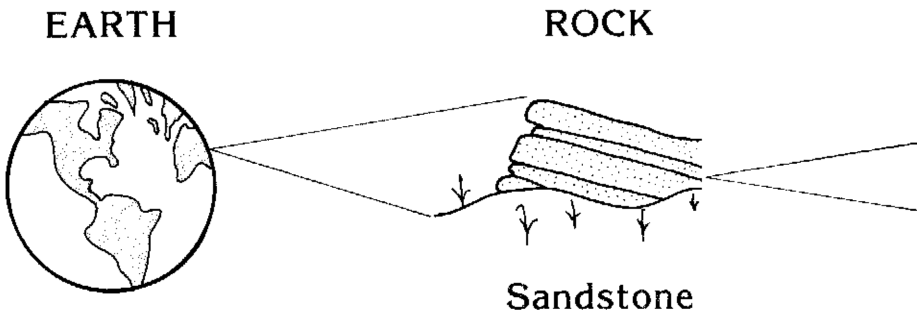


D. Igneous rocks are eroded to form sediments.
E. Metamorphic rocks are eroded to form sediments.
F. Sedimentary rocks are eroded to form new sediments.
G. Skeletal debris accumulates to form sediments.
H. Sediments from the erosion of igneous, metamorphic, and sedimentary rocks collect in a sea or lake, leading to the formation of new sedimentary rocks.

METAMORPHIC ROCKS form when rocks are subjected to great pressure and high temperatures, such as when they are deeply buried. The components of the original rock are rearranged to form new types of rock.

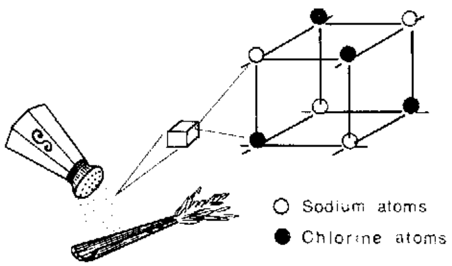


Igneous, sedimentary, and metamorphic rocks that are subjected to high heat and pressure form metamorphic rocks.



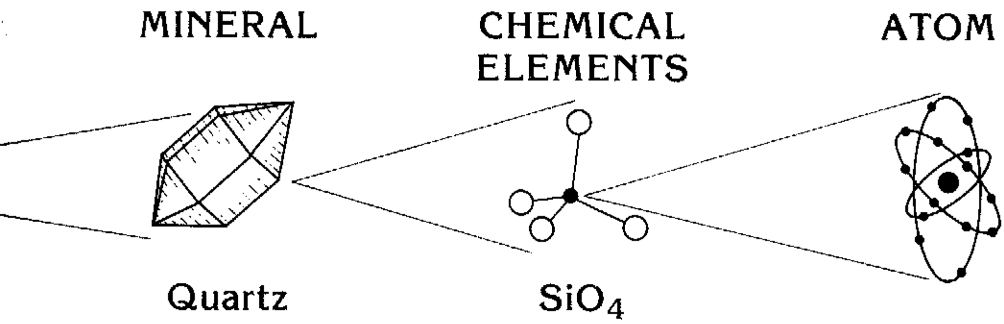
Everything is made of something. The earth, or at least the outer part of the earth, is made of rock. Rock, in turn, is made of minerals. And what are minerals made of? The chemical elements, the same building blocks that make up everything else. Minerals are naturally occurring chemicals. Each mineral has a specific chemical composition, with atoms of various elements arranged in a particular way that is commonly reflected in the shape that the mineral assumes.

One of the most common minerals in everyday life is halite. There is probably halite in your kitchen. You will find it in the salt shaker. If you look closely at salt through a magnifying glass, you will see that the individual grains are not round, as might be expected, or even rough and irregular in shape. Instead, most of them are tiny cubes having straight edges that meet at right angles. This is the shape in which halite crystals naturally form, reflecting the arrangement of the atoms in their structure.



Halite is composed of two chemical elements, sodium (which chemists abbreviate as Na after its Latin name, *natrium*) and chlorine (abbreviated Cl). The atoms of these two elements are arranged in a cubic pattern within the structure of halite, as shown in the diagram. When a piece of halite is broken, its tendency is to break in the directions along which it is weakest, parallel to the pattern formed by the atoms, rather than in any direction that would cut across this structure.

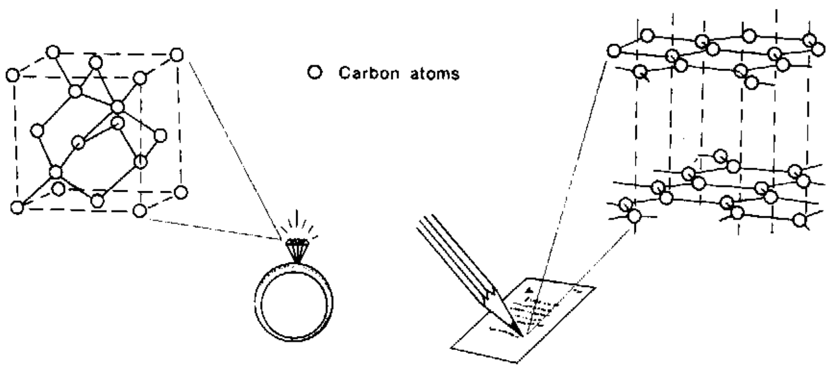
Just as we scientists find it helpful to classify things, we also like to give names to things that we discover. We do this so that we can use just one word to describe something rather than repeating a long descriptive phrase over and over. We call the property of minerals to break in directions that are controlled by their internal structure ***cleavage***.



When a mineral breaks very easily in certain directions, it is said to have ***perfect cleavage.***

Two other minerals that are found in many homes are graphite and diamond. Graphite is mixed with clay to make the "lead" in pencils, which do not contain any real lead at all. Everyone knows that diamond rings and pencils have almost nothing in common. *Almost* nothing. They do have *one* thing in common—carbon. Both diamond and graphite consist entirely of the single chemical element carbon, abbreviated C. Why are they so different? Because the way the atoms of carbon are arranged in the internal structures of these two minerals is vastly different.

In graphite, the atoms are arranged in sheets. Like halite, graphite has perfect cleavage, in this case in the direction parallel to the sheets of carbon atoms. The sheets easily slide over each other, making graphite feel slippery. This is one of the properties that makes graphite such a good material from which to make pencils. The graphite sheets rub off the pencil point and onto the paper. Diamond is so much harder than graphite because the carbon atoms in diamond are arranged in a complex three-dimensional framework. There is no single direction in which a diamond is as weak and easily broken as graphite.



We have mentioned that scientists commonly classify the things that they study, such as rocks and minerals. A person who classifies anything must identify characteristics that consistently distinguish an object from other similar objects. The basis for classifying rocks, by the way in which they formed, cannot be used for minerals. This is because some minerals can form by more than one method. Each mineral does, however, have a particular chemical composition and a unique arrangement of atoms that always give it certain properties, no matter how it formed. Therefore, we classify minerals according to their chemical composition.

The simplest minerals, such as graphite and diamond, contain only one chemical element. Minerals such as these are called ***native elements***. Other native elements include gold (Au), silver (Ag), copper (Cu), and sulfur (S).

The remaining minerals, and there are about three thousand of them, are chemical compounds, meaning that they consist of a combination of two or more elements. We classify them according to the elements that make up the portion of the compound known as the ***anion***. These are the elements that have a negative electrical charge in the compound. Even though all of the chemical elements in a mineral affect its properties, as a general rule minerals having the same anion tend to have certain properties in common.

The simplest of these minerals have an anion that consists of only one element. ***Halite***, which contains sodium (Na) and chlorine (Cl) in equal amounts, is an example. The anion in halite is formed by the chlorine atom and is known as the chloride ion, making halite a chloride mineral known chemically as sodium chloride (NaCl). The chlorides are part of a larger group of minerals called ***halides***. These are minerals that have either chlorine, fluorine (F), bromine (Br), or iodine (I) as the anion. Two other relatively common halide minerals are ***sylvite***, or potassium chloride (having the formula KCl), which some people use as a substitute for table salt; and ***fluorite***, or calcium fluoride (having the formula CaF_2, indicating that for every calcium atom it contains two fluorine atoms), which is popular among mineral collectors because of the colorful crystals that it forms.

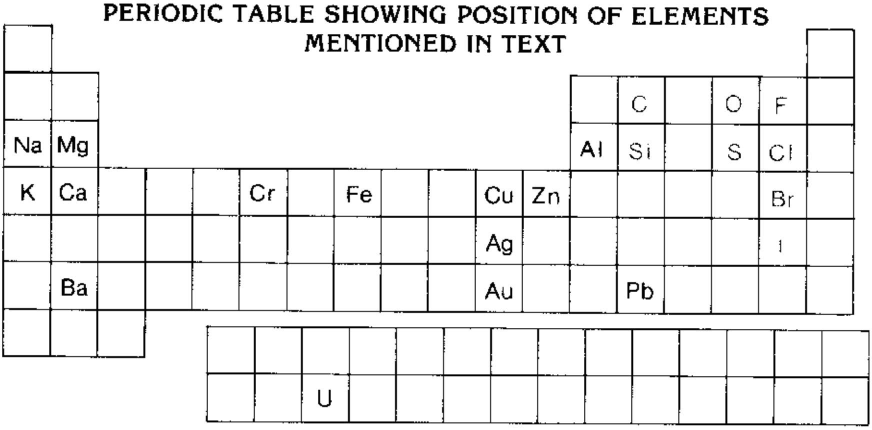
Several other groups of minerals have anions that consist of a single element. The most important of these are the ***oxides*** and the ***sulfides***, which have anions consisting of oxygen (O) and sulfur (S). There are many minerals in these two categories, including some that are important as ores. Among the oxides used as ores are ***magnetite*** (Fe_3O_4) and ***hematite*** (Fe_2O_3), which are ores of iron (Fe); ***chromite*** ($FeCr_2O_4$), from which chromium (Cr) is obtained; and ***uraninite*** (UO_2), a source of uranium (U). Among the better-known sulfides are ***galena*** (PbS), a source of lead (Pb), and ***sphalerite*** ((Zn,Fe)S), from which zinc (Zn) is obtained. Some sulfides are attractive metallic minerals that are favored by mineral collectors. One is the form of iron sulfide known as ***pyrite***

(FeS_2), which has become known as "fool's gold" because of its resemblance to the real thing.

In addition to the sulfides and oxides, there are minerals in which the anion contains both sulfur and oxygen. They are the ***sulfates*** (SO_4), and are one of many groups of minerals that contain anions that are made up of more than one element. Another common mineral group is the ***carbonate*** group, which has an anion composed of one carbon atom and three oxygen atoms (CO_3). Among these groups, the most common mineral is ***calcite*** (calcium carbonate, $CaCO_3$), the principal component of the common sedimentary rock limestone. Other examples are ***dolomite*** (calcium magnesium carbonate, $CaMg(CO_3)_2$), ***gypsum*** (calcium sulfate, $CaSO_4$), and ***barite*** (barium sulfate, $BaSO_4$).

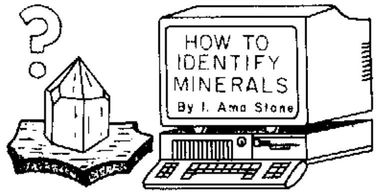
Many minerals belong to a very important group that has yet to be mentioned. Those are the ***silicates***, minerals that contain the element silicon (Si). They are the most numerous and abundant of all the minerals, and are the principal components of most rocks. The simplest silicates are the ones that are composed only of silicon and oxygen, a combination referred to as ***silica*** (SiO_2). One of those minerals, ***quartz***, is probably the most abundant mineral in Pennsylvania. Quartz is very hard, making it resistant to erosion and weathering. Some quartz forms beautiful, clear, six-sided crystals called "rock crystal." By contrast, most minerals that make up clay are also silicates, as are a multitude of minerals having many different properties. Among other important silicates are the ***feldspars***, a complex group of hard, rock-forming silicates containing aluminum (Al), calcium, sodium, and potassium, and ***mica***, another complex group of sheetlike minerals that contain many of the same elements as the feldspars.

PERIODIC TABLE SHOWING POSITION OF ELEMENTS MENTIONED IN TEXT

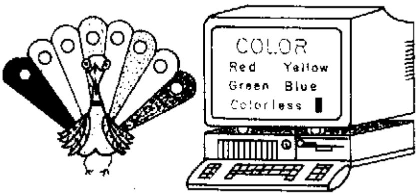


Chemists use the periodic table to group elements with similar properties; the elements that form anions (orange) are found together on the right side. Do you see anything here that suggests that halite and sylvite might have similar properties? How about calcite and dolomite? Copper, silver, and gold?

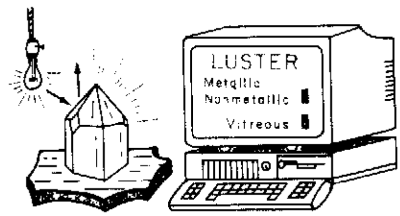
Although chemical composition is a good way to classify minerals, it is something that is not easily determined without expensive laboratory instruments. You probably do not have access to these instruments, and neither do most geologists in the field. Instead, at least for an initial identification, a geologist makes some observations about the specimen and performs tests that require few, if any, tools. Imagine that we have a mineral specimen to be identified. Because we are new at this, a computer will guide us through the process.



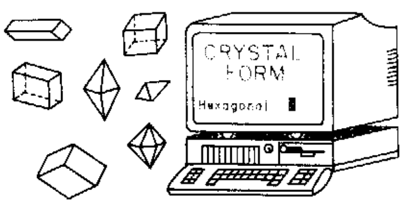
When you look at a mineral specimen, you immediately notice several things. One of the most obvious is its ***color***. Some minerals can have more than one color, but for others the color can be distinctive. For example, the mineral azurite, a copper carbonate, was given its name because of its deep azure-blue color. Pyrite was dubbed "fool's gold" partly because of its color and partly because of the way people felt when they were told what it really was. Our mystery specimen is transparent like glass and has no color, so we say that it is *colorless*.

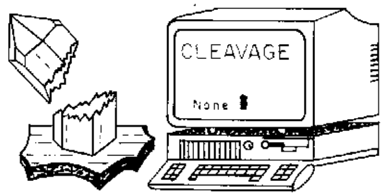


The ***luster*** of a mineral, that is, whether it is bright and shiny like a piece of metal, dull like a lump of clay, or something in between, is another part of its overall appearance. Minerals that appear bright and shiny have metallic luster. Examples include some sulfides, such as pyrite and galena. Other minerals are said to have nonmetallic luster. There are several types of nonmetallic luster. Many silicate minerals have a luster similar to that of glass; this is called vitreous luster. The brilliant luster of a diamond is said to be adamantine. Other types of nonmetallic luster include resinous, silky, pearly, and dull or earthy. Our specimen has a *nonmetallic, vitreous* luster.

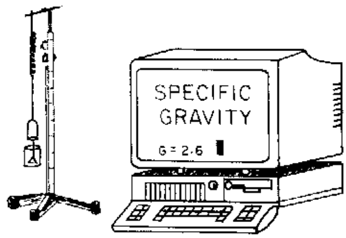


Another property that is obvious when looking at a mineral specimen is its ***shape***. As we noted earlier, the internal arrangement of the atoms that make up a mineral can affect its shape. Our specimen is a crystal that has a six-sided, or *hexagonal* outline. It shows *no cleavage* when it is broken.

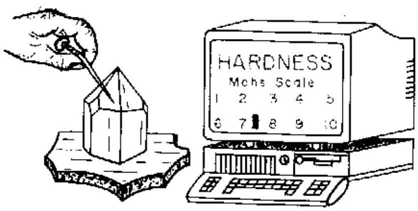




When you pick up a mineral specimen, you will usually notice whether it feels light or heavy for its size in comparison with an average rock. The comparative weight of a substance is its ***specific gravity***. Water has a specific gravity of 1. A substance with a specific gravity twice that of water would have a specific gravity of 2, and so on. Galena, which is lead sulfide, has a specific gravity of 7.6 and seems very heavy for its size. Our mystery specimen has a heft that feels average. If we were to make a precise measurement, we would find that it has a specific gravity of *2.65*.

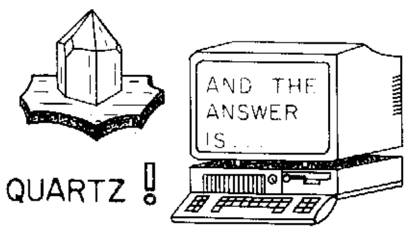


If you have a steel nail or a pocket knife handy, you can use those and your fingernail to determine the relative ***hardness*** of a mineral, which is another important property in its identification. The hardness of a mineral is measured on a scale from 1 to 10, 1 being the softest (the mineral talc) and 10 the hardest (diamond). Your fingernail has a hardness of 2½, so any mineral that you can scratch has a hardness of less than 2½, and any mineral that scratches your fingernail has a hardness greater than 2½. Steel has a hardness of about 5½, and is used the same way. Our mystery specimen cannot be scratched by steel, so we know that it is harder than 5½. If more tests were conducted, they would show that it has a hardness of 7.



One more simple test that is sometimes used to identify a mineral involves a small piece of white, unglazed porcelain, called a streak plate. When a mineral is rubbed across a streak plate, unless the mineral is harder than the streak plate (hardness of about 6), a trail of fine powder is left on the plate. The color of this powder is called the ***streak***, and is sometimes different than the color of the specimen. This is another clue as to its identification. Our specimen is too hard to use with a streak plate, but if we ground a piece of the specimen by some other method we would find that it forms a *white* powder.

So our mystery mineral is *transparent, colorless, vitreous, hexagonal,* and *harder than steel*; it has *no cleavage, average specific gravity,* and a *white streak*. This leads us to the conclusion that the mineral must be *QUARTZ*!



The stage is set. We have talked about minerals, the building blocks that make up rocks. We know that there are thousands of minerals that are classified according to their chemical composition, and that they can be identified by their physical properties.

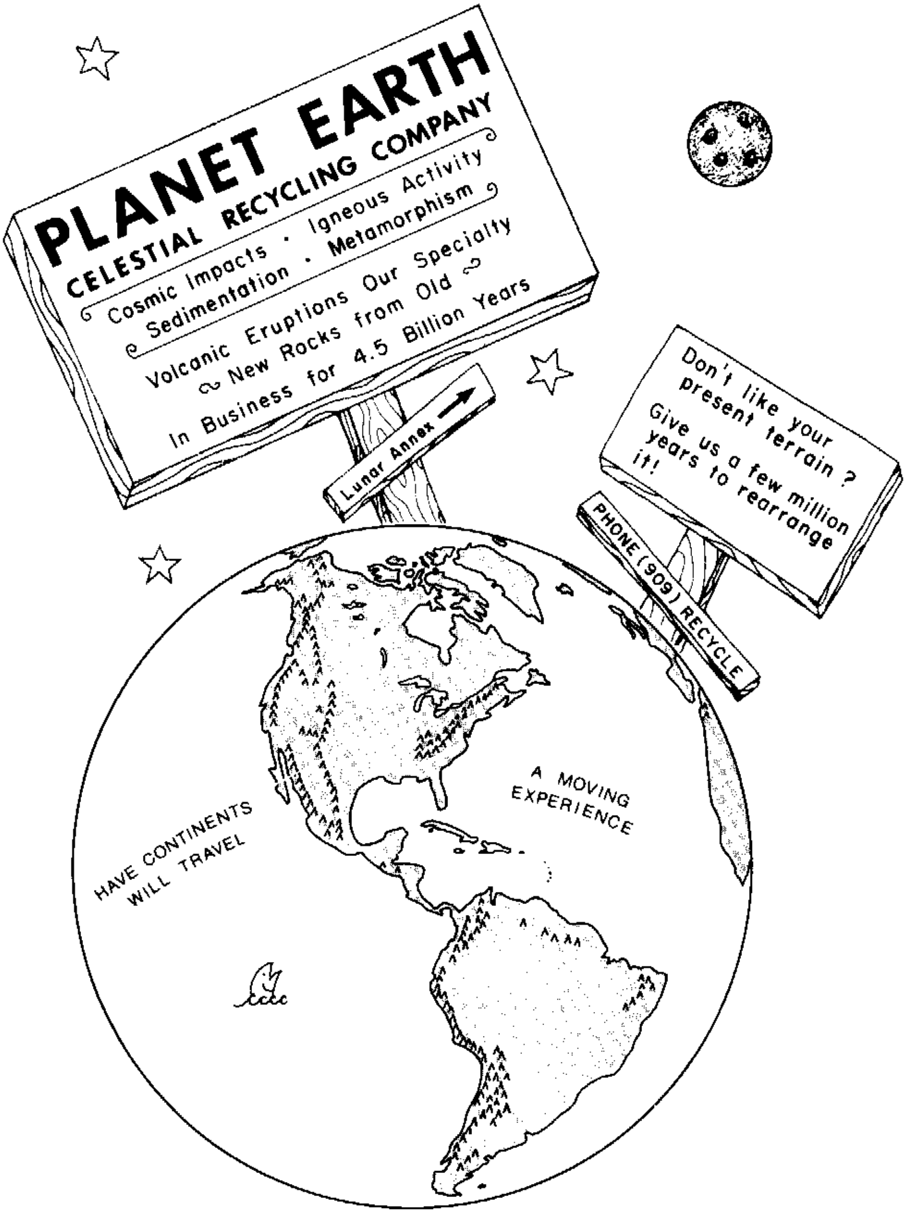
Now, we will see how minerals come together to form rocks. First, though, we are faced with a problem. Where do we begin? At the beginning? Where is the beginning? On pages 2 and 3 there is a diagram that shows the way rocks are classified, into igneous, sedimentary, and metamorphic, according to the method by which they have formed. But that diagram is circular. Where is the beginning of a circle? Even if a circle did have a beginning, we have a second problem. This circle has arrows going in opposite directions. Which direction do we go in telling this story?

A circle is appropriate to represent the formation of rocks because that process is an ongoing story and, like a circle, has no known beginning or end. Every rock that you see was formed from some other rock, and will someday be changed into yet another rock. That could be happening now, slowly, as you watch, or it could happen millions of years from now—but it will happen.

But, you say, everything had to start someplace. True, and there is a beginning to the story of the formation of the rocks—a beginning hidden in mystery. From measuring the decay of radioactive elements in the crust of the earth, scientists calculate that our planet is about 4.5 billion years old. The oldest rocks that have been found, however, are only about 4 billion years old. Because the only way that we can learn about the earth is by studying rocks, we have no direct record of the first 500 million years of the earth's history! An ancient igneous rock in Africa does have an interesting story to tell us, though.

That rock, among the oldest found, is a granite that formed from red-hot molten rock called magma. As the magma rose toward the surface from the depths where it originated, it penetrated a layer of sandstone, a sedimentary rock. Pieces of the sandstone mixed with the magma and were trapped inside when it solidified. Obviously, the sandstone must be even older than the granite, because it had to have formed before the granite to be included within it. Sandstone forms from sand that was eroded from older rocks, so this ancient sandstone is still not as old as the first rocks on earth. What was the first rock? How and when did it form? We may never know for sure. Geoscientists try to learn more about the early history of the earth by searching for still older rocks, by trying to understand the vast part of the earth that is far below the surface, and by studying the moon and other planets. Each discovery provides a few answers and raises new questions.

So, we come into the story of the making of rocks in the middle. The oldest rocks that we have found were made from even older rocks that no longer exist. More rocks are being made right now. New rocks are made from old rocks—the ultimate recycling program. Because we must start somewhere, we will start with the class of rocks that dominates the landscape of most of Pennsylvania, the sedimentary rocks.



In the center of this booklet is a colored map called a ***geologic map***. The colors represent the age of the bedrock that is found just below the soil. Across the bottom, a key shows the name that is given to each period of time and the types of rock that formed at those times in Pennsylvania. In other parts of the world, different types of rock might have formed during those same time periods, rock that did form might have been removed by erosion, or perhaps no rock formed at all.

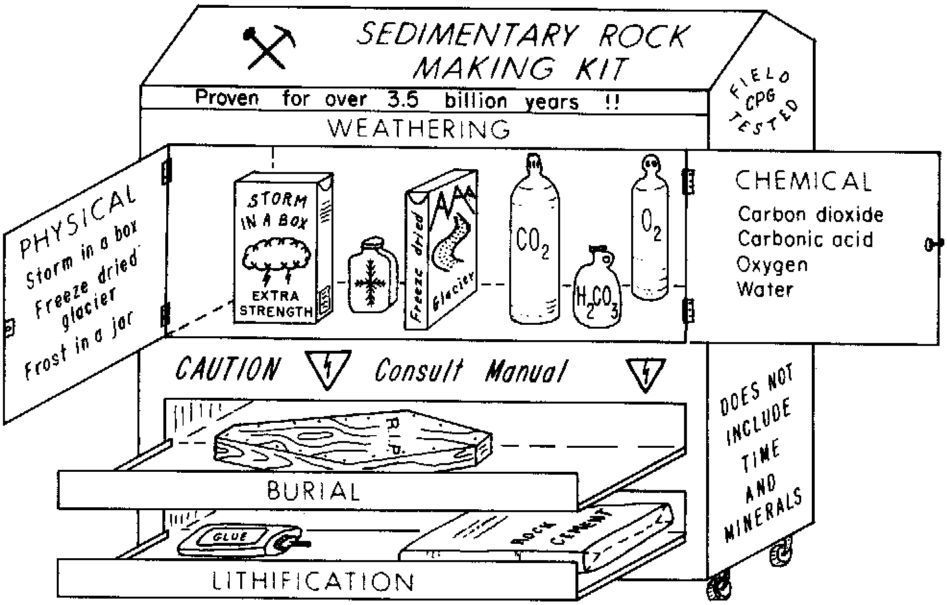
The bedrock that lies just below the soil in most of Pennsylvania is ***sedimentary rock***. The exceptions are the rocks labeled "Triassic" that are colored in red, rocks in southeastern Pennsylvania that are labeled "Lower Paleozoic" and "Precambrian," and an area of Precambrian and Cambrian rock in Adams, Cumberland, and Franklin Counties in south-central Pennsylvania. If we were to drill deeply enough anywhere in the state, we would find rocks that are not sedimentary. In this book, however, we will only talk about the rocks that are near the surface.

As we have said, every rock has formed from something else. Sedimentary rocks are formed from older rocks that have been exposed to the rain, snow, heat, cold, wind, ice, plants, and creatures (two-legged, four-legged, multi-legged, and no-legged) at the earth's surface. We usually think of rocks as being tough. When we expect something to last for a long time, we say that it is "as solid as a rock." But imagine how a car or a house might look if it were exposed to the weather for a million years or so. The same is true for rock that is exposed for a long period of time. It discolors, weakens, and crumbles. In a word, it ***weathers***.

The crumbling of rock is called ***physical weathering***, and can be caused by such things as the freezing and thawing of contained water. Other changes are brought about because certain minerals that form in the depths of the earth, where temperatures and pressures are high, are not stable at the surface. They change slowly by ***chemical weathering***. Usually this change is from a hard mineral such as feldspar to a soft mineral such as clay.

The materials set free by weathering are removed, or eroded, and carried by streams, the wind, or the moving ice of glaciers, until they are deposited somewhere as sediment. Depending on the size of the particles, such sediments might be referred to as clay, silt, sand, or gravel.

Over time, as more sediment accumulates, older sediment becomes buried by younger. If the buried sediment is left undisturbed for a long period of time, perhaps a few million years, processes of ***lithification*** change it to solid rock. The sediment becomes compacted by the weight of sediment that is deposited above it. It can become so deeply buried



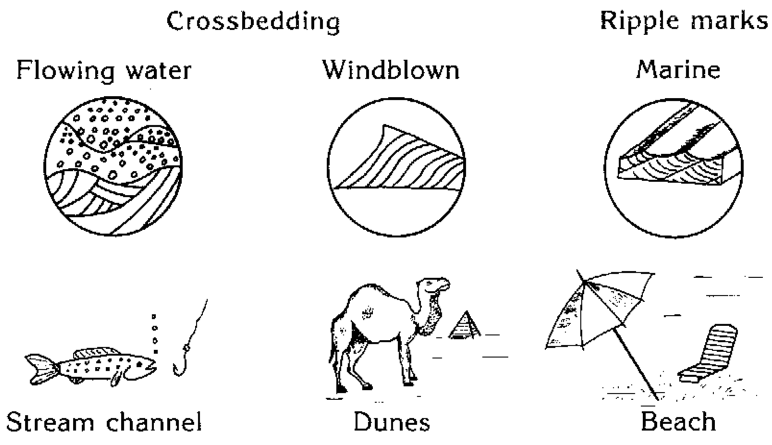
that it is exposed to temperatures that are high enough to cause certain chemical reactions to take place. Water seeping through may deposit substances that harden to form a cement that holds the grains together. The result is a sedimentary rock.

The type of sediment that accumulates in an area depends, in part, on the method of transportation. Slow-moving water or wind can carry only small particles, which eventually settle at the mouth of a stream or in the depths of a lake or the sea to form a clay or silt deposit. ***Shale*** and ***claystone*** form from the lithification of mud and clay. Silt eventually forms ***siltstone***. These rocks are common in most of Pennsylvania. Shale and claystone have individual grains that are so small that they cannot be seen without a powerful microscope. The grains that make up siltstone are slightly larger. Shale has an interesting property known as ***fissility***, making it easy to pry flat layers apart along planes that are known as ***bedding planes***. These bedding planes correspond to the individual layers of clay that were originally deposited in water. Bedding planes are originally flat and horizontal, as the layers of sediment would be when they are deposited in quiet water. For many deposits of shale and other sedimentary rocks in Pennsylvania, however, the bedding planes are tipped upward. This is because the layers of rock were deformed long after lithification.

Sand accumulates where water or wind moves fast enough to carry clay and silt away, but slow enough to allow sand to settle. The sand may finally come to rest on a beach or along the course of a moderately fast moving stream. Windblown sand accumulates to form sand dunes. The sedimentary rock that forms when sand is buried and lithified is ***sandstone***, a very common rock in most of Pennsylvania. The individual grains of sand that make up the rock are easy to see without a microscope. The bedding planes cannot be easily pulled apart as they can with shale, but they often are visible as parallel lines that mark slight changes in the color or grain size.

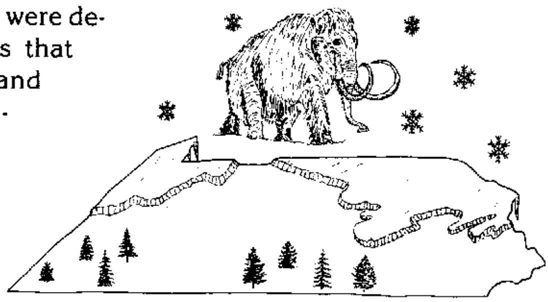
As was true of the finer grained rocks, the bedding planes in a sandstone are not always flat and horizontal. In some places the reason is the same as for finer grained rock; the sandstone was deformed long after lithification. Elsewhere, however, the bedding planes are not flat and horizontal because the sand was not originally deposited in flat, horizontal layers. If you look at the sand in the bed of a stream or near the shore of a large lake or the ocean, you might notice that the surface of the sand has a wavy appearance. This is caused by the current or the waves. If more sand is deposited on top of this surface, the wavy markings can be preserved when the sand is lithified, and are known as ***ripple marks***. When we find these in sandstone, they tell us something about the environment in which the sand was deposited. Another structure that is often seen in sandstones in Pennsylvania is ***crossbedding***; the bedding planes of a crossbedded sandstone curve gracefully and intersect each other. The type of crossbedding indicates whether the sand was deposited in sand dunes by a wind that blew millions of years ago or in the bed of an ancient stream.

PRIMARY STRUCTURES



A fast-moving mountain stream washes away not only clay and silt, but also at least some of the sand, leaving a bed of gravel. Gravel can also accumulate along beaches where the wave action is strong enough to wash away sand. Following burial, a bed of gravel can become lithified, forming a rock called ***conglomerate***. Conglomerate contains angular or rounded pebbles that are cemented together. Sand-sized grains fill the spaces around the pebbles. The pebbles are rounded because they were worn by rubbing against each other and the sand for a long period of time before they were finally buried.

Moving bodies of ice called glaciers can carry everything from clay to boulders mixed together, depositing sediment called ***till***. Although not shown on our colored geologic map, large amounts of till were deposited by huge glaciers that entered northeastern and northwestern Pennsylvania during the "Ice Age," which ended only about 10,000 years ago, just yesterday by geologic standards. These deposits are discussed in Educational Series 6, *Pennsylvania and the Ice Age*. Because the till in Pennsylvania is so young, it is still unlithified.



All of the sedimentary rocks that we have talked about so far form from fragments, or ***clasts***, of older rocks. Geologists call them ***clastic rocks***. Many different minerals can be found in these rocks, but several are common. One type consists of hard, resistant minerals that survive the assaults of chemical weathering, transportation, and lithification. They are removed from old rock by physical weathering and become incorporated into the new rock. Among these are quartz, feldspar, and many other silicates.

Another type of mineral is one that is formed by the chemical weathering of minerals in the original rock. A common product of this process is clay. Mica sometimes survives to exist in a sandstone, but other times it breaks down chemically to form clay. Even feldspar and other hard silicate minerals sometimes suffer this fate.

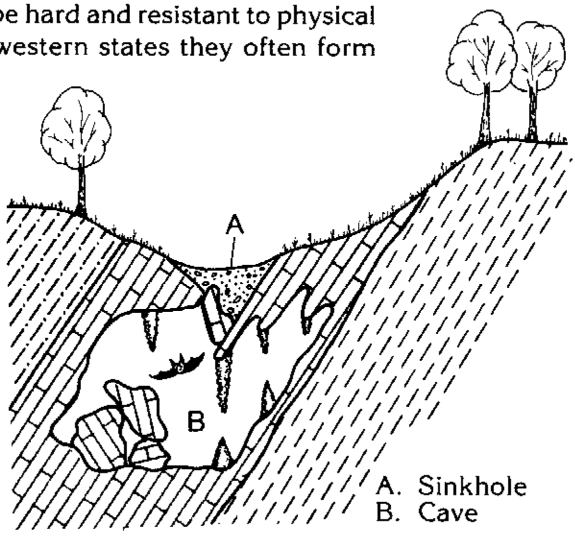
A third type of mineral found in the clastic rocks is one that is formed directly in the sediments. Pyrite sometimes forms in this way as a result of the chemical interaction of materials in the sediment with materials contributed by organisms in the chemical environment that is found at the bottom of a large body of stagnant water.

Clastic rocks are not the only type of sedimentary rock. ***Nonclastic sedimentary rocks*** consist of minerals that are carried in solution by water and are deposited by chemical processes or evaporation. The remains of plants and animals are also prominent components of some nonclastic rocks.

The most common nonclastic sedimentary rocks in Pennsylvania are the ***carbonate rocks***, ***limestone*** and ***dolostone***. The material from which they are formed is manufactured in the sea by animals such as clams, snails, and corals. When they die, their shells mix with other residue on the seafloor and are sometimes preserved as fossils. With time, chemical reactions cement all of this material together to form a hard rock.

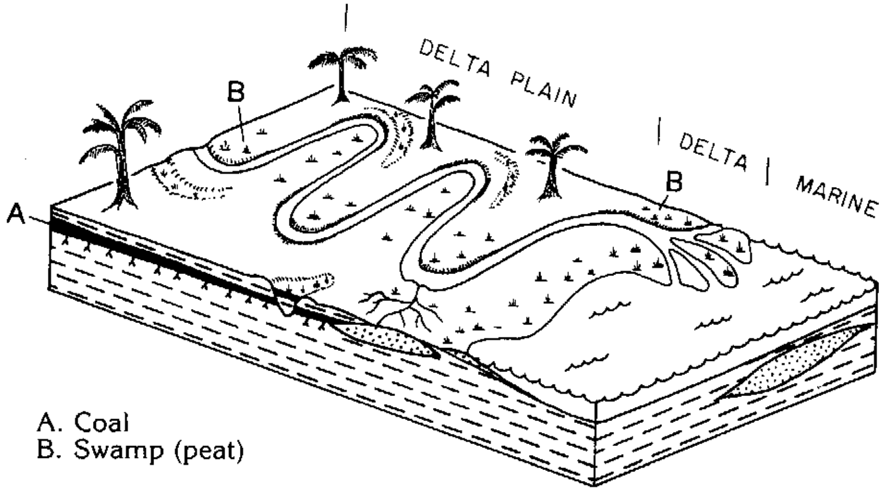
The two most common minerals in carbonate rock are calcite, in limestone, and dolomite, in dolostone. On the geologic map, areas shown as having rocks of Cambrian through Permian age have some carbonate rocks, but carbonates are most prevalent among the Cambrian and Ordovician rocks in the valleys of central and southeastern Pennsylvania.

Carbonate rocks can be hard and resistant to physical weathering. In the dry western states they often form high cliffs. Here in the humid East, however, they are prone to attack by chemical weathering and can literally dissolve over a long period of time. This can pose a problem when they dissolve underground, because the ground above can collapse to form a hole called a sinkhole. This same process of solution, however, is responsible for the formation of beautiful caverns with ***stalactites*** that hang from the ceiling and ***stalagmites*** that rise from the floor. Stalactites and stalagmites are formed by the deposition of calcium carbonate by groundwater. If a drop of this water hangs from the tip of a stalactite and evaporates, a tiny amount of calcium carbonate that was dissolved in the drop is left behind and adds imperceptibly to the length of the stalactite. If the drop falls and then evaporates, the remaining calcium carbonate adds to a stalagmite growing from the floor. If a stalactite and stalagmite grow long enough, they merge to form a column. This might seem like a very slow process, but, compared to many other geologic processes, it is actually very fast!



A. Sinkhole
B. Cave

Pennsylvania is famous for ***coal***. Where does coal fit into rock classification? Coal is a sedimentary rock, but it is different from the rocks that we have talked about because it is not made of minerals. It forms, instead, from plant remains such as wood, bark, and leaves. The plants that formed the coal in Pennsylvania lived in a warm, swampy environment about 300 million years ago. When the plants died, they fell into the stagnant water of the swamps, where they accumulated to form peat. The peat was eventually buried deeply enough to be subjected to the same conditions of heat and pressure that contribute to the lithification of other sedimentary rocks.



A. Coal
B. Swamp (peat)

Most of the coal in Pennsylvania was deposited during a time period that has become known to geologists throughout North America as the Pennsylvanian Period. A smaller amount was deposited later, during the Permian Period. It is found in the areas shown on the geologic map as having bedrock of those ages. Most coal in Pennsylvania is soft coal, or ***bituminous*** coal, and is mined in the large region from Clearfield County westward into Ohio and southwestward into West Virginia. Hard coal, or ***anthracite***, is mined in eastern Pennsylvania, in Lackawanna, Luzerne, Carbon, Schuylkill, Northumberland, and Dauphin Counties. Anthracite was subjected to deeper burial and higher temperatures than bituminous coal, giving it different properties. More information on coal can be found in Educational Series 7, *Coal in Pennsylvania*.

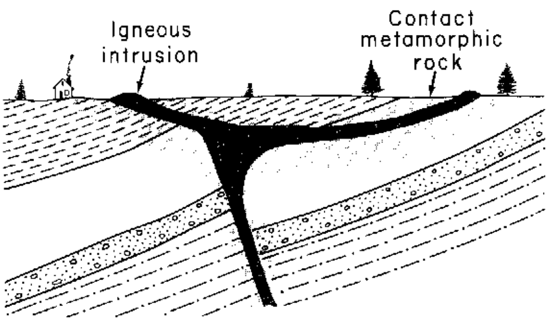
We now know that sediments can be buried to some depth where they lithify to form hard rock. We also know that the effects of burial can vary, an example being the formation of two kinds of coal, bituminous in western Pennsylvania and anthracite in eastern Pennsylvania. Next, we will see what happens when rocks are exposed to even higher temperatures and pressures.

When minerals are exposed to temperatures or pressures higher than those at which sedimentary rocks form, they can undergo some dramatic changes! Sometimes they are transformed into completely different minerals, and other times they take on new forms and textures. The rocks in which the minerals reside are transformed into ***metamorphic rocks.*** In fact, the word "metamorphic" is derived from the Greek word meaning "to transform." Metamorphism can be caused by deep burial, by forces that deform rocks during events that cause mountains to rise, or by exposure to heat from a nearby intrusion of molten rock from deep within the earth.

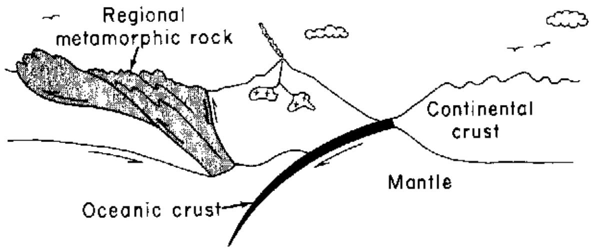
Both the texture and the mineralogy can tell us something about the history of a metamorphic rock. In some metamorphic rocks, minerals are arranged in parallel bands. This characteristic feature, called ***foliation*** or ***schistosity***, can give clues to the direction from which stresses were applied.

The conditions to which metamorphic rocks were subjected during their formation are sometimes indicated by the presence of minerals that form only at certain ranges of temperature and pressure. If the temperature or the pressure gets too high, these minerals are destroyed and others form in their place. If the temperature or the pressure does not get high enough, these minerals do not form at all. ***Garnet*** and ***biotite mica*** are examples of such minerals.

Two major types of metamorphism are recognized. One is ***contact metamorphism***, during which rock is altered by the intense heat of a nearby body of molten rock that has intruded from a greater depth. Among the more common contact metamorphic rocks is ***hornfels***, a hard, fine-grained rock that is really a baked shale. Hornfels is found in southeastern Pennsylvania where shales were altered by igneous intrusions during the Jurassic Period. They are located immediately adjacent to the igneous rocks that are shown in bright red on the geologic map.



The other major type, referred to as ***regional metamorphism***, involves rocks over a large area that have been dramatically transformed by some major event, such as deep burial. Among rocks formed by regional metamorphism, there are three groups that are based on texture. The finest grained rocks, ***slate***, ***argillite***, and ***phyllite***, are believed to result from the metamorphism of shale or claystone. They tend to



be harder than shale, and break parallel to foliation, rather than parallel to bedding as does shale.

Schist is a coarser grained rock and has obvious foliation. It commonly contains layers of mica, which can be peeled apart easily, alternating with layers of other minerals such as quartz and feldspar.

Gneiss and ***granulite*** are the coarsest grained metamorphic rocks. They usually contain more quartz and feldspar than the finer grained rocks, but often have bands of platy minerals such as mica running through them. Some are believed to have formed from the metamorphism of igneous rocks such as granite, although these could be formed from a wide variety of parent rocks.

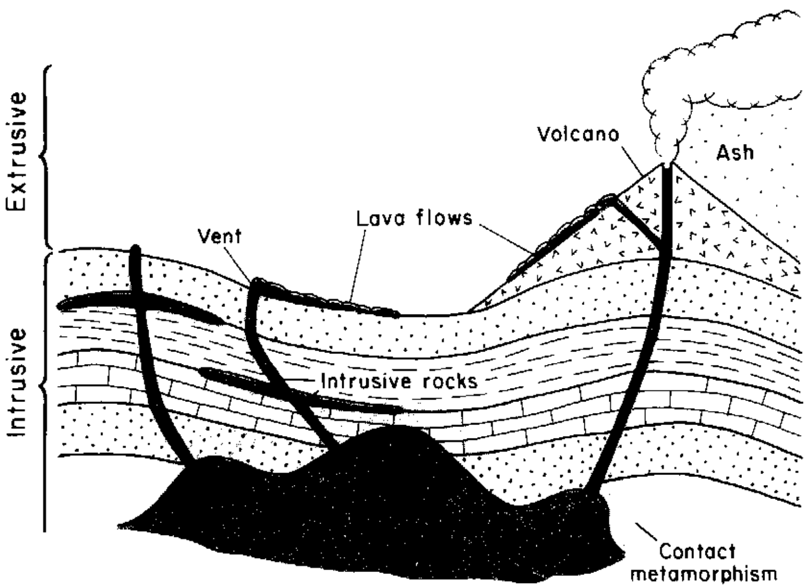
Rocks in Pennsylvania that have been altered by regional metamorphism can be found near the surface in the southeastern part of the state, although at greater depth they probably could be found under the entire state. The metamorphic rocks in southeastern Pennsylvania are quite diverse and are believed to have been derived from both igneous and sedimentary rocks. On the geologic map, they are included among the rocks of Lower Paleozoic and Precambrian age. The metamorphism and diversity of these rocks possibly result from the conditions to which eastern North America was subjected several hundred million years ago.

Although the crust of the earth was once thought to be a single, rigid layer of rock, we now believe that it consists of a number of ***plates*** that move about with respect to each other. The plates come in a variety of sizes, from huge, continent-sized plates to smaller, island-sized microplates. It is believed that a number of microplates collided with, and became attached to, North America over a period of time hundreds of millions of years ago. They may have had a variety of origins, thus accounting for the diversity of rock types in southeastern Pennsylvania.

Large, continent-sized plates can also collide with one another. When they do, the energy that causes them to move is transformed into tremendous pressure that heats and deforms rocks. There is reason to believe that eastern North America has undergone at least two collisions with other continental plates in the past, the most recent being with Africa. The force of these collisions is best seen in southeastern Pennsylvania, where rocks are severely deformed and metamorphosed. In other regions of the state the effects were more limited. Rocks were folded but not metamorphosed in a belt across most of central Pennsylvania. In the northwestern part of the state, few effects of these continental collisions can be seen.

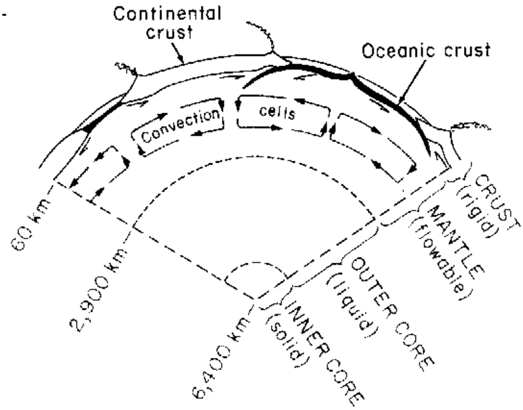
No process of forming rocks is as spectacular as the eruption of a volcano. A red-hot liquid rises from the depths of the earth and breaks through to the surface, sometimes with great explosive fury, sometimes more gently, but always putting on a spectacular show. Eventually the liquid that comes out of the volcano, which is called lava, cools to form solid rock. Rocks formed in this way are called ***igneous rocks***, from the Greek word for "fire." Because people can actually watch them form, igneous rocks are often thought of as "new" rocks, but we have to be careful to remember that the earth is 4.5 billion years old, and that nothing on earth is ever really "new." It is only rearranged. *Everything* is recycled from something else.

Lava emerges from the ground through a hole called a vent. It commonly forms a cone around the vent that can have a steep or gentle slope, depending on the nature of the lava. Some volcanoes eject solid, glassy fragments called ash or cinders, which can quickly build a steep-sided cone. At the other extreme, lava might be so runny that it flows easily across the landscape and never builds a cone. All of the rock that forms from lava or volcanic ash is called ***extrusive rock***, because it formed as a result of the extrusion of hot, molten rock onto the surface.



The parent of both lava and ash is ***magma***, which is molten rock that exists underground. Magma does not always break through to the surface. Sometimes it slowly cools and solidifies underground. The bodies of igneous rock formed in this way can range from a few inches wide to several miles across. This type of rock is called ***intrusive rock***, because it intruded whatever rock was present below the surface, but got no farther.

Based on the various minerals that can be present in igneous rocks, we believe that certain kinds of magma come from different depths. Some of it probably originates in the crust, the part of the earth that is nearest the surface and extends down to a depth of 10 to to 60 kilometers. Other magma is believed to form in the mantle, which is the portion of the earth that is directly below the crust, and may come from depths greater than 100 kilometers.



Continents and oceans recycled here.

Geologists do not fully understand why magma forms in any particular place. It is known that temperature increases with depth in the earth, but not rapidly enough to produce molten rock within the upper 100 kilometers. This is because pressure also increases with depth, and, as pressure increases, the rock must reach a higher temperature before it will melt. At a depth of 10 to 60 kilometers, the solid crust of the earth gives way to the mantle, which is believed to be soft and able to flow very slowly. The mantle extends to depths close to 3,000 kilometers, where temperatures in the earth's outer core are so hot that, even with the tremendous pressure that exists at that depth, rock exists as a liquid. That liquid never makes it to the surface, but the great heat of the core is believed to affect the mantle, causing it to mix slowly by rising in some places, then cooling and settling in others, similar to the movement of water that is being heated in a pan on the stove. This method of moving heat from one place to another is known as ***convection***. When the heat arrives at shallower depths in the mantle where the pressure is lower, molten rock can form. That molten rock, in turn, could move upward toward the surface, cool, and solidify to form igneous rock.

Magma that originates at much shallower depths, within the crust, is believed to be formed where the convection currents in the mantle drag rock from the portion of the crust that is under the oceans down below the edges of continents. Water that is carried with the crust causes it to melt at a lower temperature than would normally be the case, the result being explosive volcanoes such as Mount St. Helens in the state of Washington, which was the site of a violent eruption in 1980.

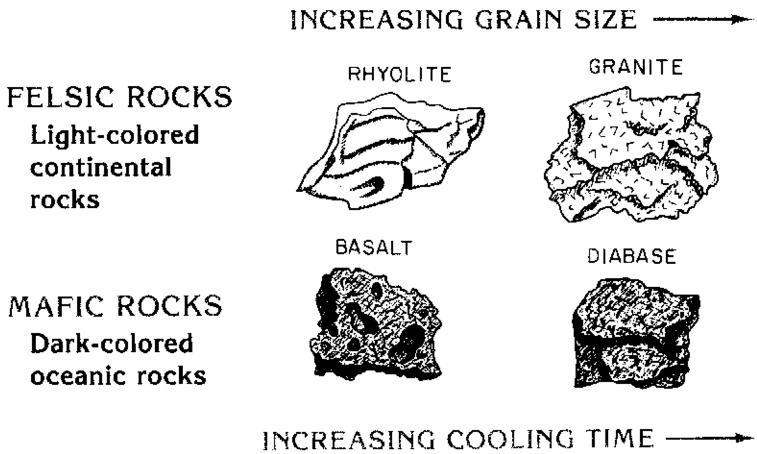
Divide and classify! That is the necessary prelude to the fun of understanding nature. Minerals are classified by chemistry. Rocks are classified according to how we understand them to have formed. Like the other rock types, igneous rocks are further divided and classified according to mineralogy and texture, and sometimes in additional ways. Among the igneous rocks, the mineralogy and texture can tell us about the circumstances under which the rock formed and the source of the magma that produced it.

The texture, or grain size, of an igneous rock tells us about its cooling history. In general, the more slowly the magma cooled, the more time there was for each mineral crystal to grow, and the larger each crystal could get. At one extreme are rocks that form from volcanic eruptions in places where lava could cool very quickly, perhaps by flowing into the sea, forming a natural glass called ***obsidian***. Other volcanic rocks cool more slowly and have a texture that is fine grained, but not glassy. ***Basalt*** and ***rhyolite*** form in this way. Intrusive rocks that form underground cool so slowly that crystals are large enough to be easily seen without magnification. Examples of this type of rock are ***granite***, ***gabbro***, and some ***diabase***.

The mineral crystals that are found in igneous rocks do not always have nice, straight outlines that reflect their internal structure. This is because their neighbors often interfere with their growth, and there is no room for the characteristic crystal faces to develop. However, the minerals that form an igneous rock do not all crystallize from the magma at the same time. If the cooling is slow, the earliest minerals to form are free to grow surrounded by nothing but liquid. These minerals often do show regular crystal faces.

There are many interesting stories about the life and times of a magma body that can be told by studying the texture of igneous rocks. Sometimes, large, well-formed crystals, known as ***phenocrysts***, are found surrounded by smaller, intergrown crystals of other minerals. We know that crystal size is related to the rate at which the magma cooled and the time available for the crystal to grow. The size difference suggests that something must have changed after the larger minerals had some time to grow. Most likely, the magma moved upward and began to cool more rapidly. The other minerals then crystallized more quickly, forming smaller crystals.

As the texture of an igneous rock tells us something about how magma cooled, the mineralogy gives us clues to the source of the magma. Based on what minerals are present, igneous rocks are divided into two categories, ***felsic*** and ***mafic***. Felsic rocks are dominated by minerals that are light in color, such as quartz, feldspar, and mica. The extrusive rock rhyolite and its intrusive counterpart granite are examples of felsic rocks. Mafic rocks are dominated by minerals that are dark



in color, such as amphibole, pyroxene, and olivine. Examples include the extrusive rock basalt and the intrusive rocks gabbro and diabase.

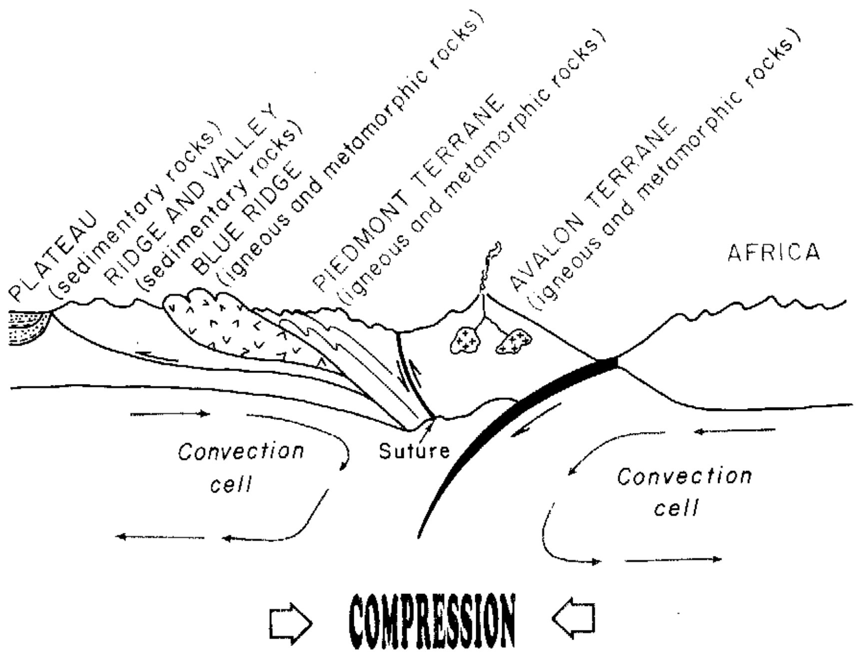
The composition of an igneous rock is related to three things: the source of the magma, the way in which the magma formed, and the way in which the rock crystallized from the magma. The most important of these is the source. In general, felsic rocks form from magma that originated in continental crust, and mafic rocks form from magma that originated at a much greater depth, in the earth's mantle. Mafic rocks are commonly found in oceanic crust.

Less important effects on the composition result from the way in which the magma formed. When a rock melts to form magma, occasionally only some of the original minerals will melt because different minerals have different melting points. The composition of the igneous rock that eventually forms from the magma will be affected by this factor. It will also be affected by the reverse process—some minerals crystallize from magma sooner than others. If the minerals that crystallize first are denser than the magma, for example olivine or pyroxene, they may settle toward the bottom of the magma chamber and form a rock rich in those minerals. Less dense minerals, such as feldspar, may drift upward through the magma, forming a rock rich in those minerals. The remaining magma will eventually solidify and form a rock having yet a third composition. The result will be layers of rock with different compositions, all formed from the same magma.

With the many possibilities that arise from the partial or total melting of different kinds of rock, and the partial or total crystallization of the magma, plus variations in the texture, it should not be surprising that there are many different types of igneous rock, each with a different story to tell. In Pennsylvania, several types are represented, and we will describe these next.

Igneous rocks have formed in Pennsylvania at several widely separated times in the past. The oldest are of many compositions and have complex associations. They are not truly igneous anymore, having been transformed into metamorphic rocks. Among these are metamorphosed rhyolite on South Mountain, in Adams, Cumberland, and Franklin Counties in south-central Pennsylvania. In the southeastern part of the state, a large area labeled on the geologic map as having rocks of Lower Paleozoic and Precambrian age contains metamorphosed felsic rocks, such as granite, and smaller bodies of metamorphosed mafic rock. In Lancaster, Chester, and Delaware Counties are small bodies of extremely mafic, or ***ultramafic***, rocks that are believed to have formed from magma originating in the mantle. Because some minerals, such as olivine, that are found in these rocks are unstable at the earth's surface, they have been severely altered to the mineral serpentine, forming a rock called ***serpentinite***.

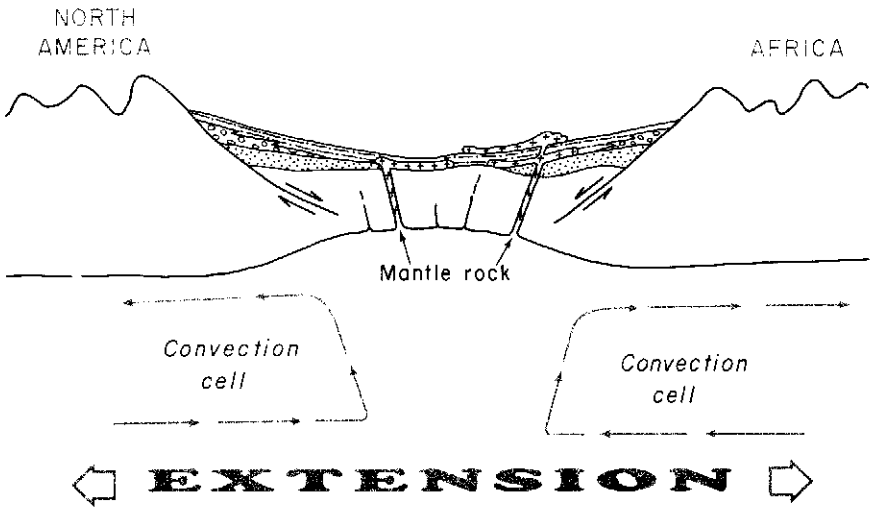
The complex associations of rocks in the southeast support the idea that the region is one dominated by microplates, as was mentioned on page 19. Imagine a checkout counter at a supermarket, with many different items placed on the conveyor as it moves toward the checker. As the items are checked off, they are sent to the end of the counter, where they are all piled together in a heap—bars of soap next to cans of peas squeezed against a box of cornflakes. This is similar to what geologists now think happened when the southeasternmost part of



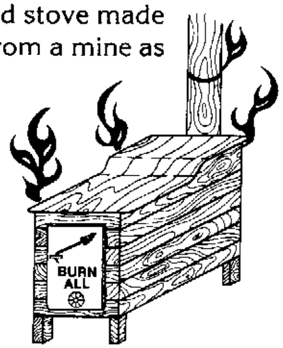
Pennsylvania was formed. Many small landmasses were carried toward what is now the east coast of North America hundreds of millions of years ago. They eventually piled up against each other, giving southeastern Pennsylvania a varied assortment of rock types.

A much younger group of igneous rocks, which formed during the Jurassic Period, less than 200 million years ago, cuts across this older assortment. They are shown in bright red on the geologic map, and consist of a dark, medium- to fine-grained intrusive rock, diabase. Diabase is a mafic rock that is believed to have formed from magma originating in the mantle. It has a different mineral composition than the older ultramafic rocks that have altered to serpentinite.

The origin of the diabase found in Pennsylvania is related to the movement of large, continent-sized plates. We have mentioned that North America is believed to have collided with Africa in the distant past. The diabase is found in a place that was being rifted, or pulled apart, when North America and Africa were separating, forming the Atlantic Ocean. The force that might have brought the plates together and that later pulled them apart could have been the movement of convection cells in the mantle. The separation would have taken place where two cells rose and spread apart, each side dragging a part of the crust with it; North America on one side, Africa on the other. Magma from the mantle entered the space that separated the two sides, forming igneous rock that, with sediments, filled the widening gap. If rifting had continued at this site, instead of several hundred miles to the east, the land that contains the cities of Philadelphia, Lancaster, and York might now be a part of Africa, and Harrisburg and Reading would be seaports!

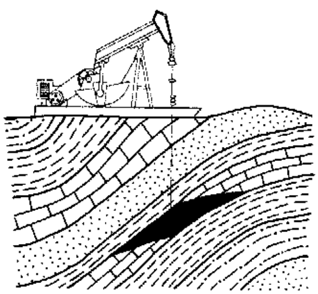


When we see a home that is heated with a wood stove, rather than using coal, gas, oil, or electricity, we might think the owner is independent of the mining and energy industries. But, in thinking that, could we be overlooking some things? What is the wood stove made of? Probably not wood! Probably iron, extracted from a mine as iron ore. The house might be made of wood, but what holds the wood together? Nails—more iron! If the house is made of brick, the bricks were made of shale or clay. The glass for the windows is made of quartz sand. The interior walls and ceilings probably are made of plaster or dry wall, each of which is made of more mined products, such as gypsum. We could continue through this house, talking about the chimney, the appliances and tools, the plumbing, the electrical wiring, the light bulbs and fixtures, and on and on. All of these things are made from products that must be mined from the earth. This brings us back to the tremendous importance of rocks and minerals to our welfare. As was pointed out at the beginning of this booklet, our lives depend on rocks every day in ways that we take very much for granted.



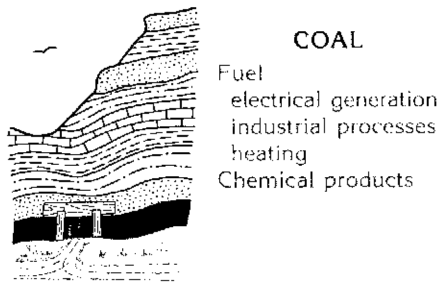
In Pennsylvania, the earliest mining took place long before recorded history. The native peoples used iron-bearing minerals and other colorful substances as paint pigments. Bowls and other vessels were made of clay and talc. Arrowheads were fashioned from varieties of quartz, such as flint.

Soon after their arrival from Europe, colonists began mining clay in the new city of Philadelphia to manufacture bricks for their homes. Soon, raw materials such as lime, iron, copper, and lead were being mined in the Philadelphia area and beyond. By the time of the Revolution, Pennsylvania had become a major center for mining among the American colonies. By the mid-nineteenth century, nickel, zinc, chromium, and coal were added to the list of commodities mined in Pennsylvania. The discovery of petroleum at Titusville in 1859 opened a new means of extracting riches from the earth. All of these resources played a major role in transforming the United States from an agricultural nation to its status at the beginning of the twentieth century as an industrial giant.



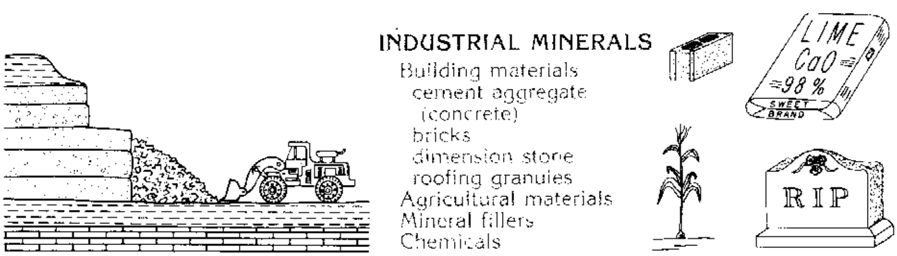
OIL AND GAS
Lubricants
Chemical products
plastics
fertilizers
Fuel

As Pennsylvania approaches the end of the twentieth century, there are no longer any metal mines in operation. The last, a zinc mine, closed



in 1983. But the state has enormous reserves of coal that continue to be mined. Pennsylvania is also a major supplier of commodities such as limestone, which is made into agricultural lime, cement, and other construction materials; sandstone and sand-and-gravel deposits that are also used for construction materials and in the manufacture of glass and other products; diabase, which is shaped and polished for use in monuments and buildings; and slate, which is used in making such diverse products as roofing shingles, billiard tables, and turkey calls. In 1988, not counting coal, the total production of mined materials in Pennsylvania passed 1 billion dollars, making this the ninth largest state in the production of such commodities.

The biggest change to affect mining in recent times is the change of attitude on the part of society. As recently as the 1920's, the pollution of air and water and the destruction of the original landscape were considered a small price to pay for the prosperity that mining brought. Today, we have gained a greater respect for the earth and have introduced mining procedures that cause less pollution. When a mine ceases production, the land is reclaimed for other uses. In the past, we knew that we could not live without mining. More recently, we have learned that we cannot live without respecting and caring for our earth. Both activities are essential. Our challenge is to obtain what we need from the earth while protecting the environment and assuring that adequate resources will be available for future generations.

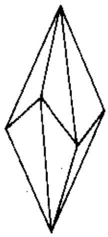


Through this book we have tried to give you an introduction to the origin, study, and practical use of the rocks and minerals that are found in Pennsylvania. We hope that you have gained a better appreciation of the role that rocks play in our everyday lives and of the fascinating story that they can tell us about the history of planet Earth. We also hope that you will pursue this topic further, perhaps by visiting a museum that has an exhibit related to geology, or by reading books and magazines on geology that can be found in your local library or bookstore.

Some of the more common minerals that can be found in Pennsylvania, as well as a few that are less common but interesting, are shown here. The drawings illustrate ideal crystals of these minerals. Many of them are more commonly found in irregularly shaped pieces. Colors of some minerals can vary considerably.

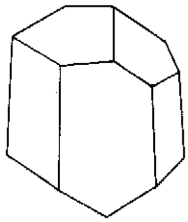
The symbols that are used for chemical elements are as follows:

Al — Aluminum	Fe — Iron	Na — Sodium	Si — Silicon
B — Boron	H — Hydrogen	O — Oxygen	Zr — Zirconium
C — Carbon	K — Potassium	Pb — Lead	
Ca — Calcium	Mg — Magnesium	S — Sulfur	



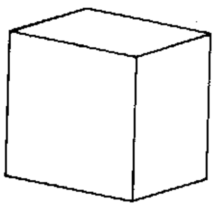
CALCITE

$CaCO_3$
Color: white, yellow, others
Luster: vitreous
Specific gravity: 2.7
Hardness: 3
Streak: white to gray
Main component of limestone; the material of fossil shells.



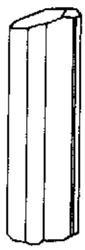
FELDSPAR GROUP

$[x]AlSi_3O_8$
Color: white, pink, others
Luster: vitreous to pearly
Specific gravity: 2.6
Hardness: 6
Streak: white
Large, common group; [x] can be K, Ca, Na, or other element.



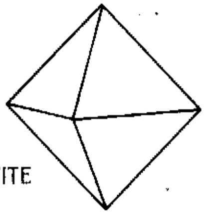
GALENA

PbS
Color: gray
Luster: metallic
Specific gravity: 7.6
Hardness: 2½
Streak: dark gray
Bright and silvery with perfect cubic cleavage.



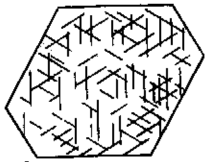
HORNBLENDE

$NaCa_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$
Color: dark green-brown, black
Luster: vitreous
Specific gravity: 3.0–3.4
Hardness: 6
Streak: white
Common member of a large group known as the amphibole group.



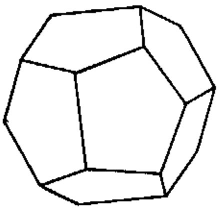
MAGNETITE

Fe_3O_4
Color: black
Luster: dull metallic
Specific gravity: 5.2
Hardness: 6
Streak: black
Common as sand-sized grains; attracted to a magnet.



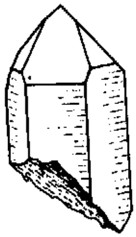
MUSCOVITE

$KAl_2(AlSi_3O_{10})(OH)_2$
Color: colorless, gray, brown
Luster: vitreous to pearly
Specific gravity: 2.8
Hardness: 2½–4
Streak: white
Member of the mica group. Easily cleaves, making flakes.



PYRITE

FeS_2
Color: brass-yellow
Luster: metallic
Specific gravity: 5
Hardness: 6–6½
Streak: brownish black
Found as rounded globules, cubes, and pyritohedrons.

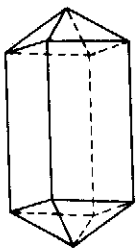


QUARTZ

SiO_2
Color: colorless, many colors
Luster: vitreous
Specific gravity: 2.65
Hardness: 7
Streak: white
Rock crystal, jasper, agate, flint, and amethyst are varieties.

TOURMALINE

$NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Color: black, brown, others
Luster: vitreous
Specific gravity: 3
Hardness: 7½
Streak: white
Common as long crystals having a triangular cross section.



ZIRCON

$ZrSiO_4$
Color: brown, others
Luster: vitreous to adamantine
Specific gravity: 4.6
Hardness: 7½
Streak: white
Common in sandstone as extremely tiny crystals pointed at both ends.

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