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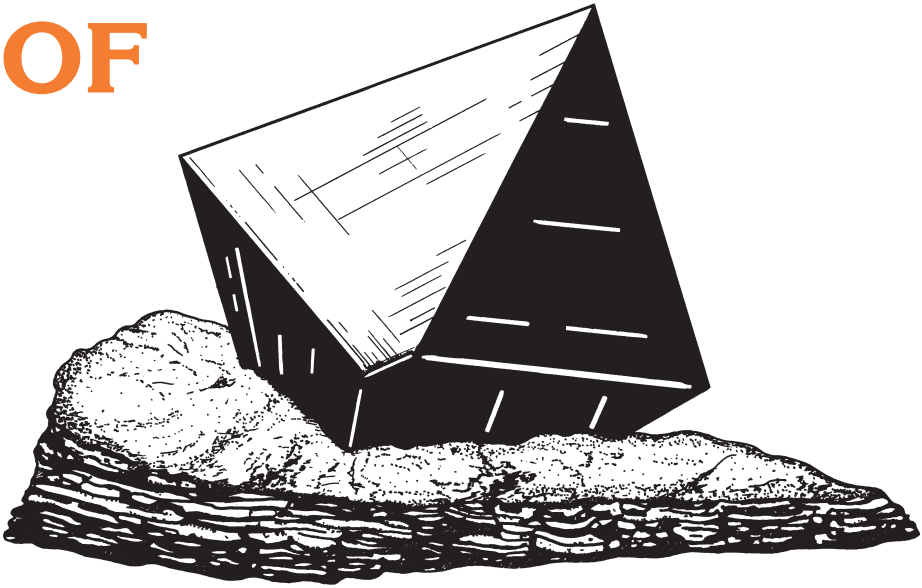
Educational Series 1

ROCKS AND MINERALS OF PENNSYLVANIA



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FRONT COVER: Sketch of magnetite crystal after Lapham, D. M., and Geyer, A. R., 1969, Mineral Collecting in Pennsylvania (3rd ed.): Pennsylvania Geological Survey, 4th ser., General Geology Report 33, p. 40.

Educational Series 1

Rocks and Minerals of Pennsylvania

by John H. Barnes

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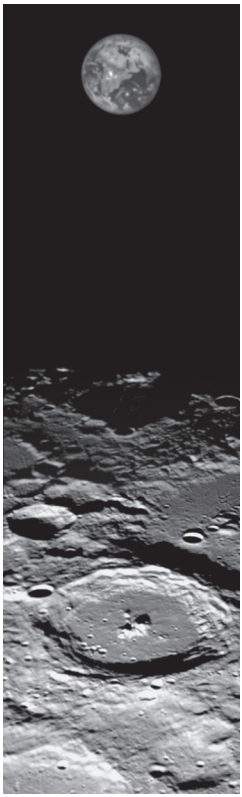
Rocks And Minerals Of Pennsylvania

by John H. Barnes

INTRODUCTION

Rocks are among the most basic things on Earth. They can be found just about everywhere. They do not seem very exciting at first glance. But there is a lot more to rocks than first meets the eye.

Along with air, water, and sunlight, rocks are fundamental to the existence of life on Earth because of the nutrients that they provide to plants through the soil. Beyond that, without rocks there would be no planet Earth on which life as we know it could exist! Nothing that we take for granted, other than the sun, stars, and space, could exist without rocks. Even the moon and the other planets would be gone.



From NASA Clementine mission, March 13, 1994, NSSDC Photo Gallery.

ROCKS IN OUR LIVES. The earliest residents of Pennsylvania depended on rocks as the raw materials for much of what they used. They used iron-bearing minerals as paint pigments. Bowls and other vessels were made of clay and talc-bearing rocks. Arrowheads were fashioned from varieties of the mineral quartz, such as flint, and from hard rocks.

Although we think of such people as living a "Stone Age" existence, the real Stone Age has never ended. Our lives continue to depend on rocks and minerals in ways that we take very much for granted. The steel, glass, and plastic that we use to build things all begin with the right kind of rock—rock that will yield iron, quartz, or petroleum. Modern electronic devices would not be possible without quartz, a raw material for the silicon chips that are at the heart of these devices.

Rocks are important in other ways, too. Rocks carry the clues to understanding the history of the earth. By studying those clues, we can learn how the world became the way it is today, and knowing that, we can also predict what might happen in the future. Those clues also help

us to find the resources that we need, and they can help us understand how our actions are affecting the earth.

Beyond that, rocks are fun to study. Some rocks contain beautiful minerals that are fun to collect, exhibit, and even fashion into jewelry. Others have interesting shapes and colors, or fantastic fossils. There are few activities that do not, in some way, involve rocks and minerals.

THE GEOLOGIC MAP. In the center of this booklet is a colored map of Pennsylvania called a geologic map. The colors represent the age of the bedrock that is found just below the soil. Across the bottom, an explanation shows the names that are given to geologic periods of time associated with the various ages, which are listed in millions of years before present. The common types of rock that formed in Pennsylvania during each time period are noted. We will refer to this map frequently throughout this booklet.

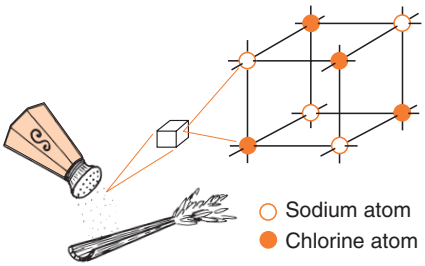
MINERALS

WHAT ARE MINERALS? Nearly all rocks are made of minerals. Minerals can be thought of as naturally occurring chemicals. Each mineral is made up of atoms of chemical elements that are arranged in a particular way. Sometimes the atomic arrangement is reflected in the shape of the mineral.

One of the most common minerals in everyday life is halite. There is probably halite in your kitchen. You will find it in the saltshaker.

If you look closely at halite through a magnifying glass, you will see that most of the individual grains are tiny cubes having straight edges that meet at right angles. This is the shape that halite crystals and broken fragments of halite naturally form, reflecting the arrangement of the atoms in their structure.

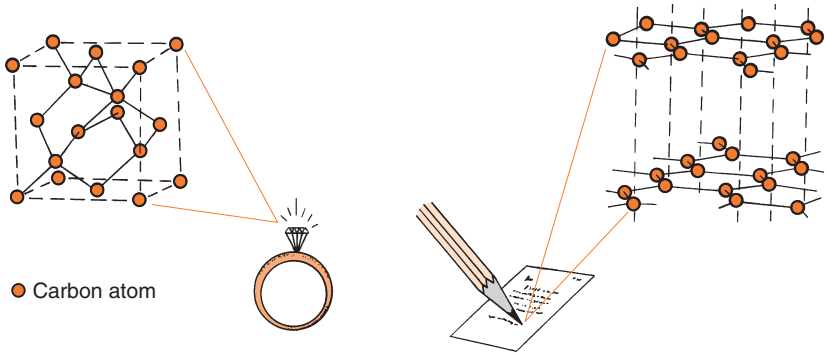
Halite is composed of two chemical elements, sodium (which chemists abbreviate as Na after its Latin name, *natrium*) and chlorine (abbreviated Cl). The atoms of these two elements are arranged in a cubic pattern within the structure of halite. When a piece of halite is broken, it usually breaks in the directions along which it is weakest, parallel to the pattern formed by the atoms. We call this 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 diamonds and pencils have 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. They are so different because the way the atoms of carbon are arranged in 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 why graphite is a good material for making 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.



HOW ARE MINERALS CLASSIFIED? Halite, graphite, and diamond are three of the approximately 3,000 different minerals known worldwide. About 300 minerals are known to occur in Pennsylvania. Each mineral has a particular chemical composition and a unique arrangement of atoms that always give it certain properties, no matter how it formed. Geologists who specialize in the study of minerals, known as mineralogists, usually 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 that have been found in Pennsylvania include sulfur (S), copper (Cu), and very rarely, silver (Ag) and gold (Au).

All of the remaining minerals are chemical compounds, meaning that they consist of a combination of two or more elements. They are classified according to the elements that make up the portion of the compound known as the anion. These elements appear on the right side of the mineral's chemical formula. In halite, NaCl, chlorine forms the anion. Even though all of the chemical elements in a mineral affect its properties, minerals having similar anions tend to have similar properties.

Other than the native elements, the simplest minerals have an anion that consists of only one element. The anion in halite is known as the chloride ion. 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. (All of these are highly reactive elements that chemists refer to as halogens. Note that they are all in the same column in the periodic table shown below.) A halide mineral that is popular among mineral collectors in Pennsylvania is fluorite, or calcium fluoride. This mineral has the formula CaF_2, indicating that for every calcium atom there are two fluorine atoms. It is popular because of its typical bright purple color.

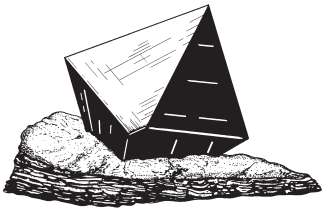
Several other groups of minerals have anions that consist of a single element. The most common of these are the oxides and the sulfides, which have anions consisting of oxygen (O) and sulfur (S). (Note their positions on the periodic table.) Pennsylvania has many minerals in these two categories, including some that have been important as ores. Among

H																	He
Li	Be											B	**C**	N	**O**	**F**	Ne
Na	**Mg**											**Al**	**Si**	**P**	**S**	**Cl**	Ar
K	**Ca**	Sc	Ti	V	**Cr**	Mn	**Fe**	Co	Ni	**Cu**	**Zn**	Ga	Ge	**As**	**Se**	**Br**	Kr
Rb	**Sr**	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	**Ag**	Cd	In	Sn	Sb	Te	**I**	Xe
Cs	**Ba**	La-	Hf	Ta	W	Re	Os	Ir	Pt	**Au**	Hg	Tl	**Pb**	Bi	Po	At	Rn
Fr	Ra	Ac-															

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	**U**											

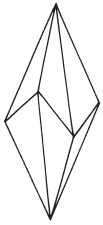
Periodic table of the naturally occurring elements. Chemical elements are arranged according to their properties. Elements that commonly form anions, which are used in mineral classification, are shown in the orange boxes. The elements in bold type are mentioned in the text.

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 (ZnS), 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 called pyrite (FeS_2), also known as "fool's gold."



Magnetite crystal

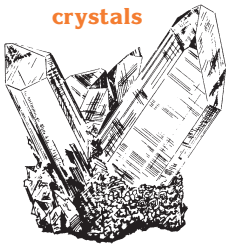
In addition to the sulfides and oxides, there are minerals in which the anion contains both sulfur and oxygen. They are the sulfates (SO_4), one of many groups of minerals that contain anions that are made up of more than one element. Another common mineral group is the carbonate group, which has an 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 rock limestone. Other examples of carbonates and sulfates found in Pennsylvania include dolomite (calcium magnesium carbonate, $CaMg(CO_3)_2$), siderite (iron carbonate, $FeCO_3$), gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$), and barite (barium sulfate, $BaSO_4$). (The "$2H_2O$" in the formula for gypsum is called the water of hydration. Water molecules (H_2O) are incorporated into the structure of some minerals. If the water is not present or is removed, a different mineral is formed. Calcium sulfate without the two water molecules is the mineral anhydrite ($CaSO_4$).)



Calcite crystal

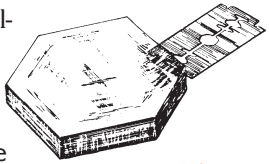
Many minerals belong to a very large and important group called the silicates. These are minerals that contain the element silicon (Si). They are the most abundant of all the minerals and are the principal components of most rocks. The simplest silicates are the ones that are composed only of silicon and oxygen, a combination referred to as silica (SiO_2). One of those minerals, quartz, is one of the most abundant minerals in Pennsylvania. Quartz is very hard and is highly resistant to weathering and erosion. It can occur as beautiful, clear, six-sided crystals called rock crystal. It can also occur as fine-grained masses called chalcedony, forming flint. Various colors of quartz exist and are known by descriptive names such as "smoky quartz" and "rose quartz."

Quartz crystals



In contrast to quartz, most of the minerals that make up clay are also silicates, as are a multitude of other minerals having many different

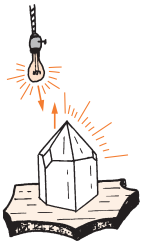
properties. Among other important silicates in Pennsylvania are the feldspars, a complex group of hard, rock-forming silicates containing aluminum (Al), calcium, sodium, and potassium (K). Another important group of silicates is the micas, which are made up of layered sheets that can be easily peeled apart. Micas contain many of the same elements as the feldspars.



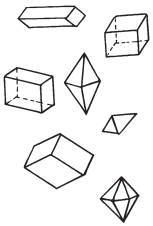
Mica

HOW ARE MINERALS IDENTIFIED? Although a mineral's chemical composition is a good way to classify it, that is something that is not easily determined without access to a laboratory. To identify a mineral away from the laboratory, a geologist makes some observations and performs simple tests that require few, if any, tools.

One of the most obvious things to observe about a specimen is its color. Some minerals can have more than one color, but for others the color is distinctive. For example, the mineral azurite, a copper carbonate, was given its name because of its deep azure-blue color.

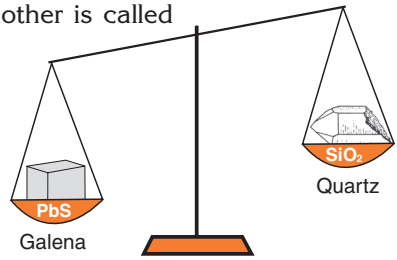


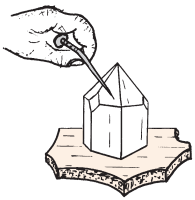
The luster of a mineral adds to its overall appearance. Minerals that appear bright and shiny have metallic luster. Examples include some sulfides, such as pyrite and galena. Most minerals have nonmetallic luster. The brilliant luster of a diamond is said to be adamantine. Many silicate minerals have a luster similar to that of glass; this is called vitreous luster. Other types of nonmetallic luster include resinous, silky, and pearly. Clay minerals have a dull or earthy luster.



Particular shapes help in distinguishing one mineral from another. As described on page 2, the shape of a mineral commonly reflects the arrangement of its atoms, particularly if the mineral was able to grow without being confined by other minerals adjacent to it. The cleavage of a mineral also reflects the arrangement of atoms and affects the mineral's shape. For example, mica can be peeled apart as flat sheets because its atoms are arranged in flat layers.

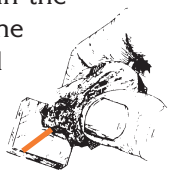
When you pick up a mineral specimen, you might notice that it feels light or heavy for its size in comparison with an average rock. The density of one substance versus another is called its specific gravity. Water has a specific gravity of 1. A substance that is twice as heavy as an equal volume of water has a specific gravity of 2, and so on. Quartz has a specific gravity of 2.65. Galena has a specific gravity of 7.6 and seems very heavy for its size.





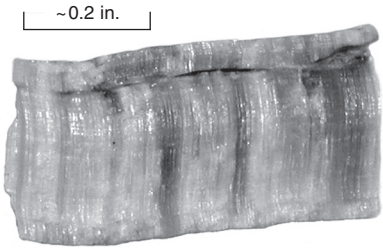
If you have a steel nail or a pocketknife handy, you can use it and a fingernail to determine the relative hardness of a mineral, which also helps in its identification. The hardness of a mineral is measured on a scale from 1 to 10 called the Mohs Hardness Scale. The mineral talc is very soft and has a hardness of 1. Diamond is the hardest known mineral and has a hardness of 10. Your fingernail has a hardness of 2½, so any mineral that you can scratch has a hardness less than 2½, and any mineral that scratches your fingernail has a hardness greater than 2½. Most steel has a hardness of about 5 and is used the same way.

One more simple test that is sometimes used to identify a mineral is to check its color as a powder, which may be different than the mineral's normal color. The color of the powder is called the streak, and a simple way to determine it is to rub the mineral on a small square of white, unglazed porcelain called a streak plate. Unless the mineral is harder than the porcelain (hardness of about 6), a streak of fine powder is left on the plate.



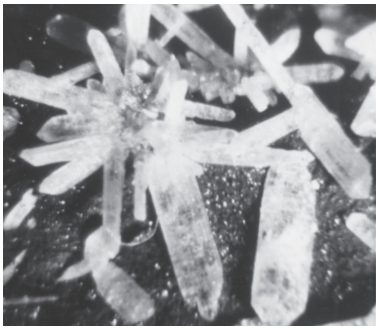
PENNSYLVANIA'S MINERALS. Of the approximately 300 minerals that have been found in Pennsylvania, many are found only in tiny quantities in a few places. The most common minerals probably make up more than 90 percent of the bulk of rocks in the state. There are still more minerals remaining to be discovered in Pennsylvania, possibly including some that have never been found anywhere else in the world.

There are at least eight minerals that *were* found in Pennsylvania before they were found anyplace else. The first was celestine, which is strontium sulfate, a pale blue mineral named from the Latin word for "sky" because of its color. It was found in Blair County by a traveler from Germany named Schütz, who was exploring the wilds of south-central Pennsylvania in 1791. He took a sample back to Germany, where it was studied, and the results were published by the famed mineralogist Martin Heinrich Klaproth in 1797.



Fibrous sample of celestine

In 1875, a zinc-bearing clay mineral was found in the Saucon Valley of Lehigh County in eastern Pennsylvania and was named sauconite. In 1888, the state mineralogist, Friedrich A. Genth, reported the discovery of a new magnesium carbonate mineral near Lansford in Carbon County, also in eastern Pennsylvania. Like sauconite, it was named after the place where it was discovered and is called lansfordite. Just two years later, Genth and his coworker, S. L. Penfield, reported another new dis-



Photomicrograph of Downeyite crystals

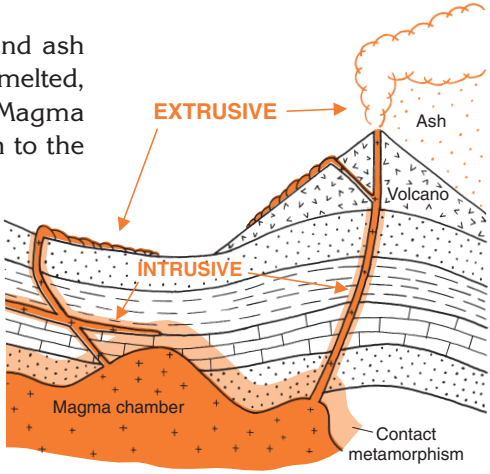
covery not far from Lansford, in a coal mine at Nesquehoning. This mineral is a magnesium bicarbonate that they named nesquehonite.

Following those three discoveries, 87 years passed before another spate of discoveries in eastern Pennsylvania began with the publication in 1977 of the discovery of downeyite, selenium dioxide, which was found on a burning coal waste pile in Forestville, Schuylkill County. It was named for its discoverer, Wayne F. Downey, Jr., who was a high-school student at the time. Next came matulaite, hydrated calcium aluminum phosphate, in 1980. It was found in an iron mine at Hellertown, Northampton County, and was named for its discoverer, Margaret Matula. In 1986, the identification of another new mineral from a burning coal waste pile was announced. This one, from Burnside, Northumberland County, is arsenic selenide-sulfide and was named laphamite in memory of Davis M. Lapham, Chief Mineralogist at the Pennsylvania Geological Survey from 1957 to 1974. The most recent official recognition of a new mineral in Pennsylvania was in 1998. A magnesium-bearing mica found in a serpentine quarry near Easton in Northampton County was named eastonite.

Now that we have seen what rocks are made of, let us look at the rocks themselves. All rocks belong to one of three major groups, igneous, sedimentary, or metamorphic, depending on the way in which they formed. Pennsylvania has rocks that belong to each of these three groups.

IGNEOUS ROCKS

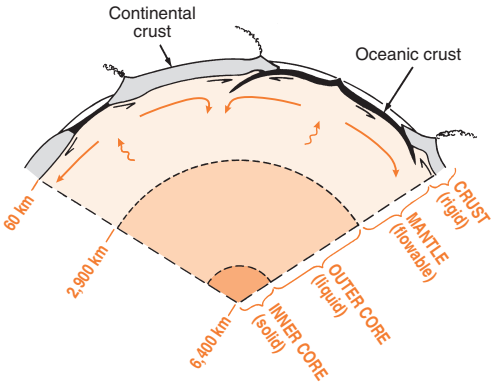
HOW ARE IGNEOUS ROCKS FORMED? No process of forming rocks is as spectacular as the eruption of a volcano. Red-hot liquid rises from the depths of the earth and breaks through to the surface, sometimes with great explosive fury, sometimes more gently, but always putting on a spectacular show. Eventually 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.” Some volcanoes eject solid 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.



The parent of both lava and ash is magma, which is molten, or melted, rock that exists underground. Magma does not always break through to the surface. Sometimes it cools slowly 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.

Based on the various minerals that are 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 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.

Geologists do not fully understand why magma forms in any particular place. The temperature increases with depth in the earth, but so does the pressure. As the pressure increases, the rock must reach a higher temperature before it will melt. Because of that, the temperature does not increase rapidly enough to produce molten rock within the upper 10 kilometers of the earth's crust. 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 a depth of close to 3,000 kilometers, where it meets the earth's outer core. The outer core is so hot that, even under the tremendous pressure at that depth, it consists mainly of liquid iron. Liquid from the core never makes it to the surface, but the great heat of the core is believed to affect the mantle. When mantle material is heated by the core, it becomes less dense and slowly rises in some places until it reaches the cool, solid crust, where it cools, becomes more dense, and descends again. This method of moving



From U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, Wash.

Eruption of Mount St. Helens, May 18, 1980. Photograph by Austin Post, U.S. Geological Survey.

heat from one place to another is known as convection. Molten rock can form when the hot rock from deep in the mantle arrives at shallower depths where the pressure is lower. The molten rock can then be squeezed upward toward the surface, cool, and solidify to form igneous rock.

Some of the magma that originates within the crust is believed to be formed where the denser rock from the part of the crust that is under the oceans is subducted below the lighter rock at the edges of the continents. Water that is carried with the oceanic rock causes it to melt at a lower temperature than normal. If the melted rock reaches the surface, the result is an explosive volcano. A well-known example is Mount St. Helens in the state of Washington, which in 1980 was the site of a large, violent eruption.

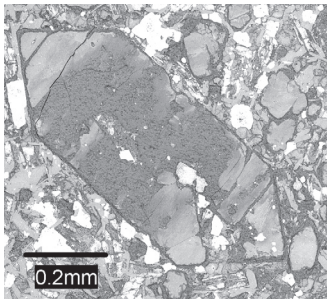
HOW ARE IGNEOUS ROCKS CLASSIFIED? Igneous rocks are classified according to what minerals they contain and the grain size of the minerals. These things can tell us about the circumstances under which an igneous rock formed and the source of the magma that produced it.

The grain size of the minerals in an igneous rock tells us how quickly it cooled. 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 cools very quickly forming a natural glass called obsidian. Other volcanic rocks cool more slowly and have a texture that is fine grained, but not glassy. Intrusive rocks that form deep 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 diabase.

The mineral crystals that are found in igneous rocks do not always have nice, straight outlines. 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 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. Many of these

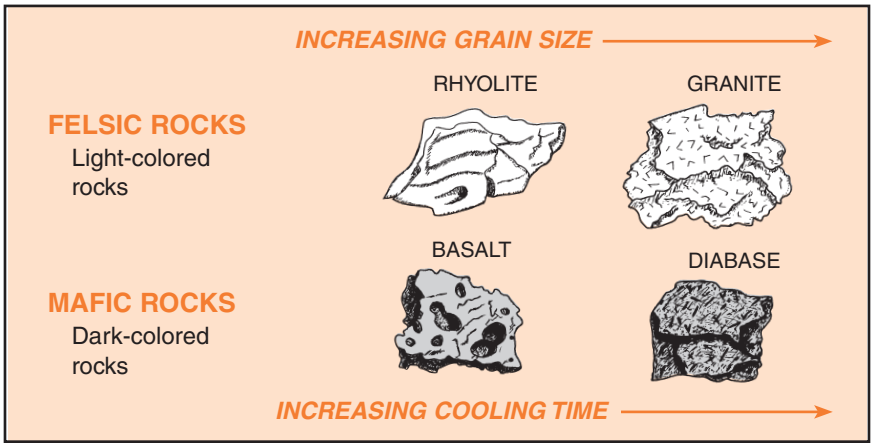
minerals show regular crystal faces. Therefore, we can tell from their appearance which minerals formed first.

There are many interesting stories about the life and times of a magma body that can be told by studying igneous rocks. Sometimes, large, well-formed crystals, known as phenocrysts, are found surrounded by smaller, intergrown crystals of other minerals. The size difference suggests that something must have changed after the larger minerals had some time to grow. Perhaps the magma moved upward and began to cool more rapidly. This would cause the other minerals to crystallize more quickly, forming smaller crystals.



Photomicrograph of an olivine phenocryst

The minerals that are present in an igneous rock give 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. Many felsic rocks form from magma that originated in continental crust. 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, but there are exceptions. Most of the mafic rock found in Pennsylvania formed in continental crust.



Less important effects on the composition of igneous rocks result from the way in which the magma formed. When 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. The last part of a magma to cool can produce a rock having large crystals and rare minerals. Such a rock is called a pegmatite.

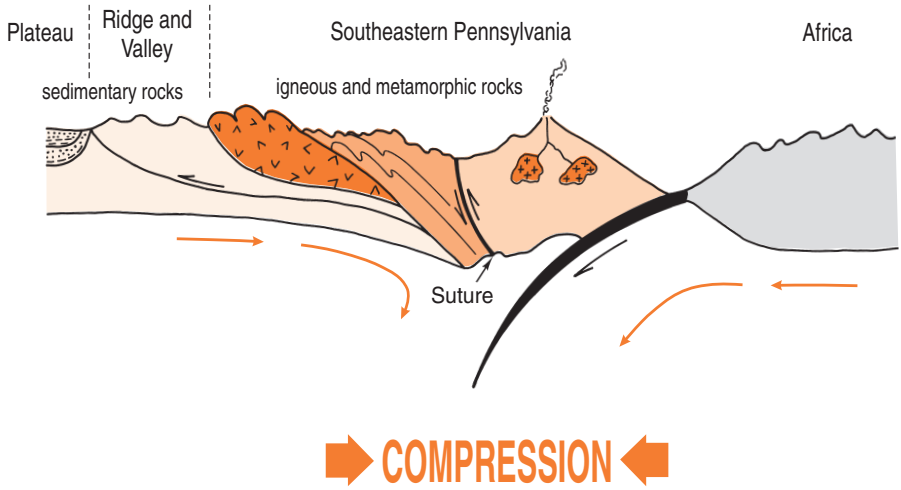
Many possibilities arise from the partial or total melting of different kinds of rock, the partial or total crystallization of the magma, plus the variations in the size of the mineral grains. There are many different types of igneous rock, each with a different story to tell.

PENNSYLVANIA'S IGNEOUS ROCKS. Igneous rocks that are found in Pennsylvania formed at several widely separated times in the past. The oldest are of many compositions, have complex associations, and probably did not even form here!

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 think happened when the southeastern corner of Pennsylvania was formed.

The earth's crust consists of a number of plates that slowly 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 what is now the east coast of North America hundreds of millions of years ago. The microplates probably had a variety of origins, as is reflected by the different rock types that are found in the southeastern part of Pennsylvania.

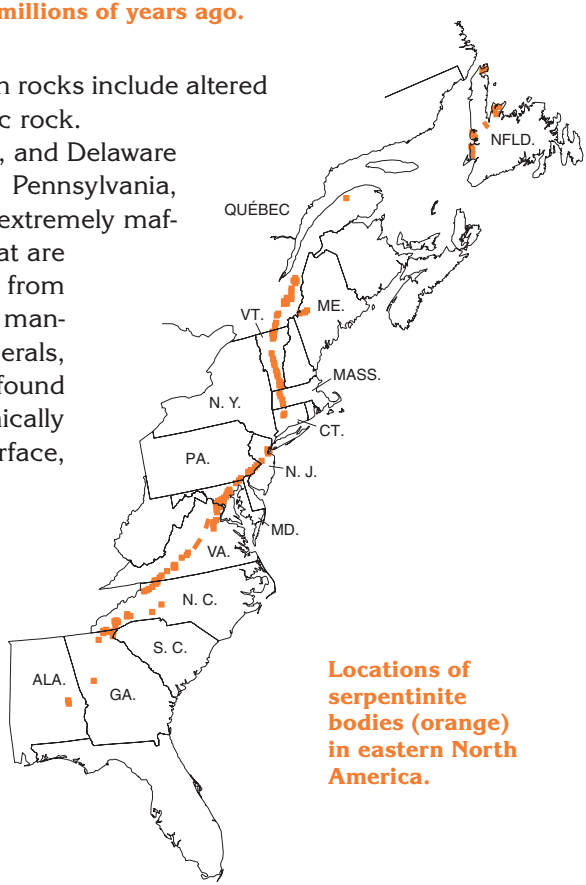
The rocks shown on the geologic map as Lower Paleozoic and Precambrian are among those that were transported into Pennsylvania. They include igneous rocks that were altered from their original form by the heat and pressure generated by the collision of plates. In the southeasternmost part of the state, rocks that were originally intrusive felsic rocks, such as granite and pegmatite, and smaller bodies of mafic rocks, can be found. At South Mountain, in Adams, Cumberland, and Franklin



Simplified diagram of the accumulation of microplates in southeastern Pennsylvania hundreds of millions of years ago.

Counties, the Precambrian rocks include altered rhyolite, an extrusive felsic rock.

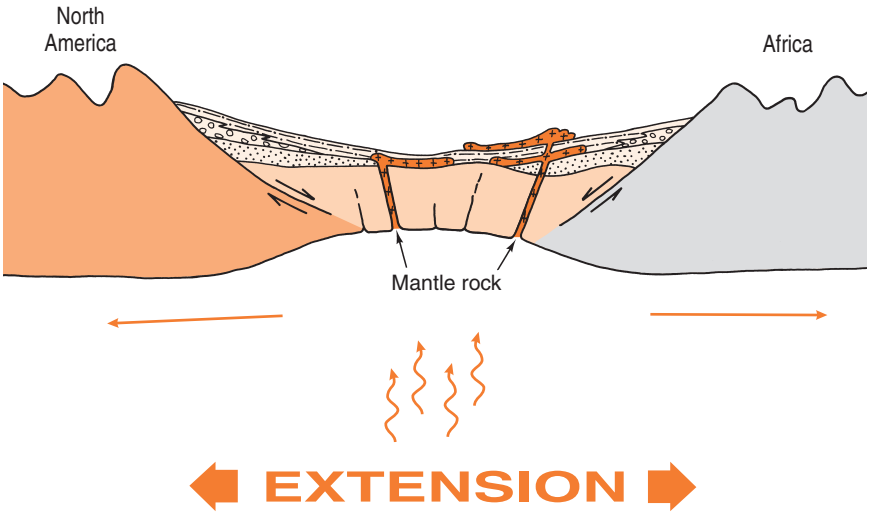
In Lancaster, Chester, and Delaware Counties in southeastern Pennsylvania, there are small bodies of extremely mafic, or ultramafic, rocks that are believed to have formed from magma originating in the mantle. Because some minerals, such as olivine, that are found in these rocks are chemically unstable at the earth's surface, they have been altered to the mineral serpentine, forming a green to greenish-yellow rock called serpentinite. The serpentinite bodies in southeastern Pennsylvania are part of a long belt of serpentinite bodies extending from Newfoundland to Alabama.



Locations of serpentinite bodies (orange) in eastern North America.

A much younger group of igneous rocks, which formed at the beginning of the Jurassic Period, approximately 200 million years ago, cuts across the older rocks of southeastern and south-central Pennsylvania. These igneous rocks are shown in red on the geologic map. They consist of the dark, medium- to fine-grained intrusive rock diabase, which is believed to have formed from magma originating in the mantle.

The origin of the diabase found in Pennsylvania is related to the movement of large, continent-sized plates. North America is believed to have collided with Africa at the end of the Paleozoic Era, during the Permian Period. The diabase is found in a place that was being rifted, or pulled apart, when North America and Africa began separating during the Late Triassic and Early Jurassic. This separation led to the formation of the Atlantic Ocean. The movement of the plates was influenced by gravity and by the mixing of materials caused by convection in the mantle. Where the separation took place, mantle material rose and spread apart; the moving plate on one side carried North America, and the moving plate on other side carried Africa. Magma from the mantle entered the space that separated the two sides, forming igneous rock that, with sediments, filled the widening gap. The rifting eventually shifted eastward, but if it had continued at this site, the land that contains the cities of Philadelphia, Lancaster, and York would now be a part of Africa, and Harrisburg and Reading would be seaports!



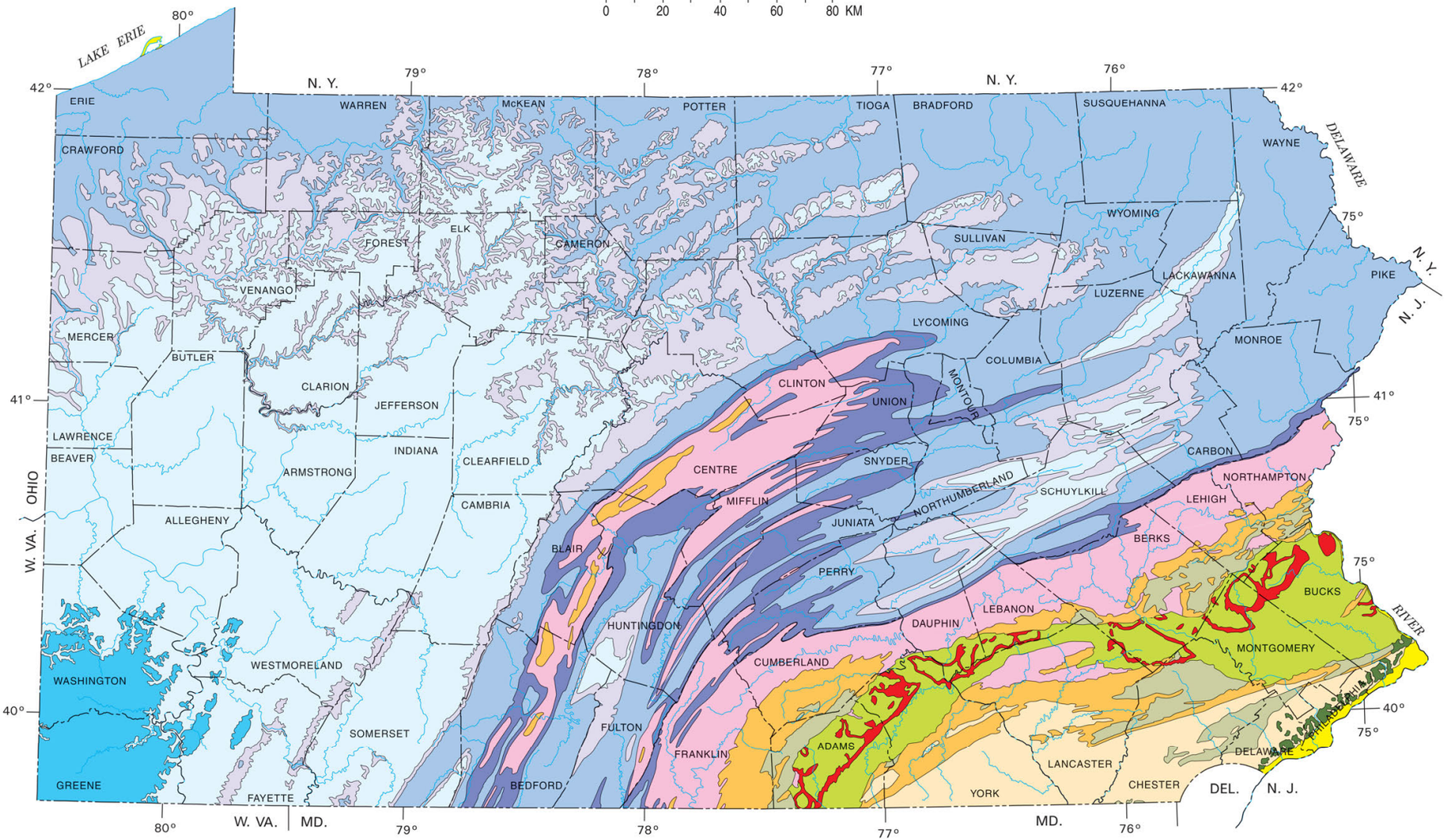
Simplified diagram of the separation of the North American and African plates approximately 190 to 230 million years ago.

GEOLOGIC MAP OF PENNSYLVANIA

SCALE 1:2,000,000

0 10 20 30 40 50 MI

0 20 40 60 80 KM



EXPLANATION

QUATERNARY	TERTIARY	* JURASSIC AND TRIASSIC	PERMIAN	PENNSYLVANIAN	MISSISSIPPIAN	DEVONIAN	SILURIAN	ORDOVICIAN	CAMBRIAN	LOWER PALEOZOIC	PRECAMBRIAN
(0–2.6 mil. yrs.) Sand, gravel, and silt.	(2.6–66 mil. yrs.) Sand, gravel, silt, and clay.	(145–252 mil. yrs.) Red sandstone, shale, and conglomerate (green), intruded by diabase (red).	(252–299 mil. yrs.) Cyclic sequences of shale, sandstone, limestone, and coal.	(299–323 mil. yrs.) Cyclic sequences of sandstone, red and gray shale, conglomerate, clay, coal, and limestone.	(323–359 mil. yrs.) Red and gray sandstone, shale, and limestone.	(359–419 mil. yrs.) Red sandstone, gray shale, black shale, limestone, and chert.	(419–443 mil. yrs.) Red and gray sandstone, conglomerate, shale, and limestone.	(443–485 mil. yrs.) Shale, limestone, dolomite, and sandstone.	(485–541 mil. yrs.) Limestone, dolomite, sandstone, shale, quartzite, and phyllite.	(443–541 mil. yrs.) Schist, gneiss, quartzite, serpentinite, slate, and marble.	(older than 541 mil. yrs.) Gneiss, granite, anorthosite, metadiabase, metabasalt, metarhyolite, and marble.

*Cretaceous rocks, which are present in small areas of southern Montgomery County, cannot be shown at the scale of this map.

SEDIMENTARY ROCKS

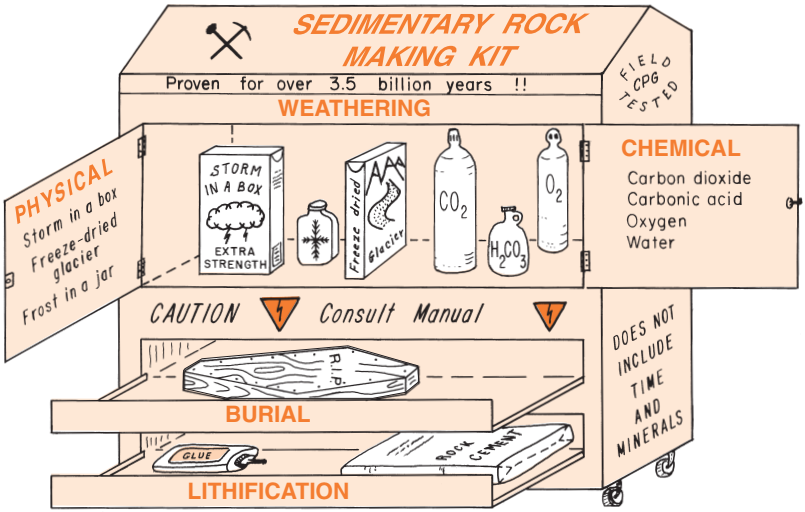
The bedrock that lies just below the soil in most of Pennsylvania is sedimentary rock and is hundreds of millions of years old. The only rocks near the surface in Pennsylvania that are not sedimentary are the Jurassic, Lower Paleozoic, and Precambrian rocks in southeastern Pennsylvania and the Precambrian and some of the Cambrian rocks in south-central Pennsylvania.

WHERE DO SEDIMENTS COME FROM? The particles that make up most sedimentary rocks are worn off of older rocks that have been exposed to the rain, snow, heat, cold, wind, ice, plants, and various creatures at the earth's surface. Imagine how a house or a car might look if it were exposed to the weather for a million years. There probably would be nothing left to see. Rocks *are* exposed to the weather for such long periods of time and gradually wear away.

The crumbling of rock is called physical weathering. It can be a result of cracking caused by the freezing and thawing of water that has seeped into the pores of the rock. Another likely cause of physical weathering is the wearing down of the rock by grains of sand or other sediments transported by wind, glacial ice, surf, or flowing water. Other changes take place in a rock because some minerals that form in the depths of the earth are not chemically stable at the surface. The lower temperature and pressure, and exposure to the atmosphere cause them to change slowly by chemical weathering. The alteration of olivine to serpentine mentioned on page 13 is an example of chemical weathering. More commonly, this change is from a hard mineral, such as feldspar, to an easily eroded soft mineral, such as a clay mineral. The materials set free by weathering can be carried by streams, currents, the wind, or the moving ice of glaciers until they are deposited as sediment.

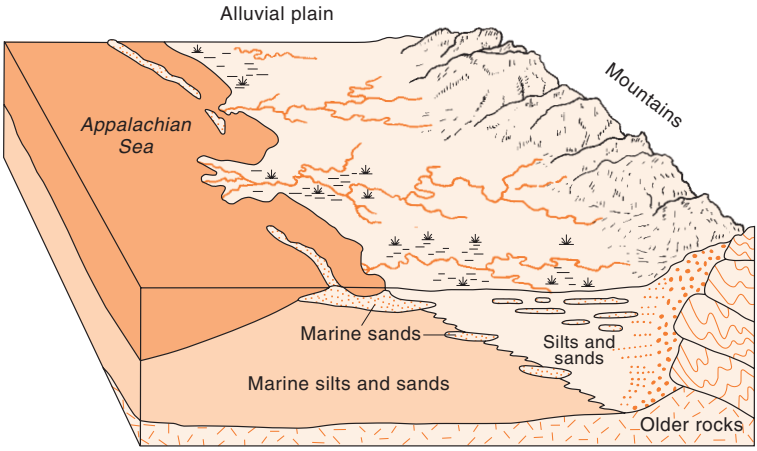
HOW DO SEDIMENTARY ROCKS FORM? Sedimentary rocks most commonly form from materials deposited on the seafloor or in lakes and rivers, but they can form from sediments deposited in nearly any environment. Over time, older sediment becomes compacted by the weight of younger sediment that is deposited above it. Sediments can become so deeply buried that they are exposed to temperatures high enough to cause certain chemical reactions to take place. Water seeping through the sediments may deposit substances that harden to form a cement that holds the grains together. The result is a sedimentary rock. The process of converting sediments to rock is called lithification.

The youngest sediments in Pennsylvania (those of Quaternary, Tertiary, and Cretaceous ages) have not had the time or burial necessary

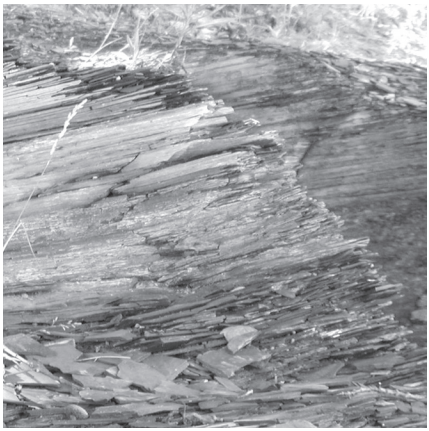


to convert them to rocks. These include the sands along Lake Erie and old river deposits along and near the Delaware River shown on the geologic map. They also include the glacial deposits discussed on pages 18 and 19.

CLASTIC SEDIMENTARY ROCKS. 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, or clasts, which



One of the scenarios in which sediments were deposited in Pennsylvania. Mountains to the east of Pennsylvania contributed sediments that later became sedimentary rocks.



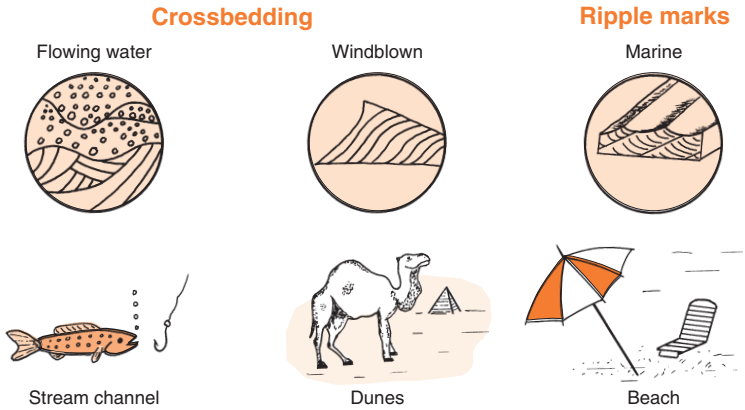
Fissile shale

eventually settle at the mouth of a stream, in the depths of a lake or the sea, or on land to form a clay or silt deposit. Shale and claystone form from the lithification of mud and clay. Siltstone forms from silt. These rocks are common in most of Pennsylvania. Shale and claystone have individual grains that are so small they cannot be seen without a powerful microscope. The grains that make up siltstone are only 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 layers of clay that were originally deposited in the water. Bedding planes in most of these rocks were originally flat and horizontal, as layers of sediment would be when they are deposited in quiet water. In many sedimentary rocks in Pennsylvania, however, the bedding planes are tilted. This is because the layers of rock were deformed long after lithification.

Sand accumulates where the water or wind moves fast enough to carry clay and silt away, but slowly 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. One sandstone formation in particular, the Tuscarora Formation, which was deposited in the Silurian Period, is prominent in central and south-central Pennsylvania. It is the resistant formation that caps many of the ridges that dominate the landscape in that region of the state.

The individual grains of sand that make up sandstone are easy to see without a microscope. The bedding planes cannot be pulled apart as they can in shale, but they are often visible as parallel lines that mark slight changes in the color or grain size. The bedding planes in sandstone are not always flat and horizontal. In some places, this is at least partly because the sandstone was deformed long after lithification, as were the finer grained rocks. It can also be because the sand was not deposited in horizontal layers to begin with. If you look at sand in the bed of a stream or on the shore of a large lake or the ocean, you might notice that the sand has a wavy appearance. This is caused by the cur-

rent or the waves. If more sand is deposited on top of this surface, the wavy markings can be preserved when the sand is lithified. These preserved wavy markings 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.

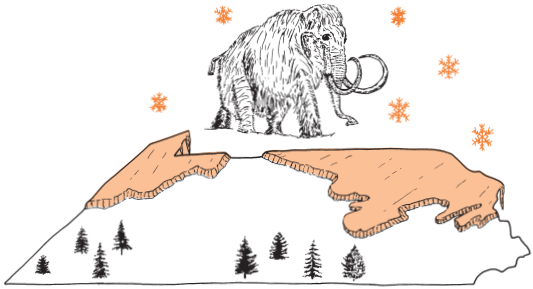


A fast-moving mountain stream washes away not only clay and silt, but also at least some of the sand, leaving a bed of gravel. Gravel also accumulates along beaches where the wave action is strong enough to wash away sand. Following burial, gravel can become lithified, forming a rock called conglomerate.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

Conglomerate

Some sedimentary deposits contain many grain sizes mixed together. They can form by the sudden flow of debris down a slope, either on land or underwater. They also form through the action of glaciers, which can carry everything from clay to boulders mixed together, depositing the mixture as sediment called till. Large amounts of till were deposited by huge glaciers that entered northeastern and northwestern Pennsylvania during the Pleistocene Epoch, commonly called the Ice

Age. These glaciers retreated from the state only about 17,000 years ago, just yesterday by geologic standards. Because the Pleistocene glacial deposits in Pennsylvania are so young, they are still unlithified and are not shown on the geologic map. More information about Pennsylvania's glacial deposits can be found in Educational Series 6, *Pennsylvania and the Ice Age.*



WHAT MINERALS ARE IN CLASTIC SEDIMENTARY ROCKS? All of the sedimentary rocks that we have talked about so far are called clastic rocks because they form from fragments, or clasts, of older rocks. Many different minerals can be found in these rocks, but several types 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 minerals are quartz, feldspar, and many other silicates.

Clastic rocks also contain minerals that were formed by the chemical weathering of minerals in the original rock. A common product of this process is the clay minerals. Mica sometimes survives to exist in a sandstone, but other times it breaks down chemically to form a clay mineral.

A third type of mineral found in clastic rocks is formed by chemical reactions directly in the sediments. Pyrite sometimes forms in this way because of the interaction of materials in the sediment with materials contributed by organisms that live at the bottom of large bodies of stagnant water.

NONCLASTIC SEDIMENTARY ROCKS. There are other completely different kinds of sedimentary rocks known as nonclastic sedimentary rocks. They are made 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.

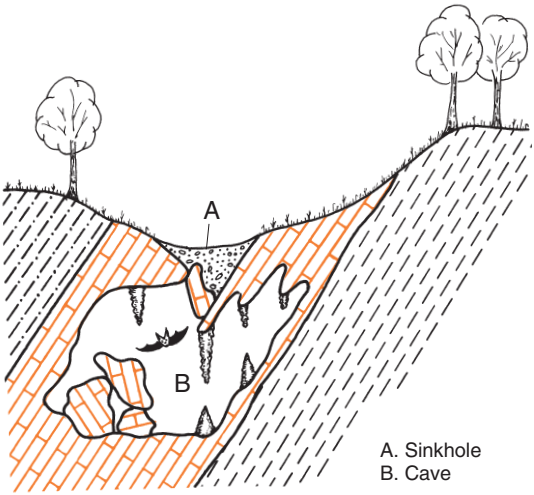
Carbonate Rocks. The most common nonclastic sedimentary rocks in Pennsylvania are the carbonate rocks, limestone and dolomite. Sea-dwelling animals such as clams, snails, and corals manufactured the material from which these rocks formed. When the animals died, their shells mixed with other residue on the seafloor and were sometimes

Limestone containing fossils

preserved as fossils. With time, chemical reactions cemented all of this material together to form a hard rock.

The most common mineral in carbonate rock is calcite, the principal mineral that makes up limestone. The mineral dolomite is the principal component of a rock that is also called dolomite. In our state, carbonates are prevalent among the Cambrian and Ordovician rocks in the valleys of central and southeastern Pennsylvania. There are also important deposits in western Pennsylvania.

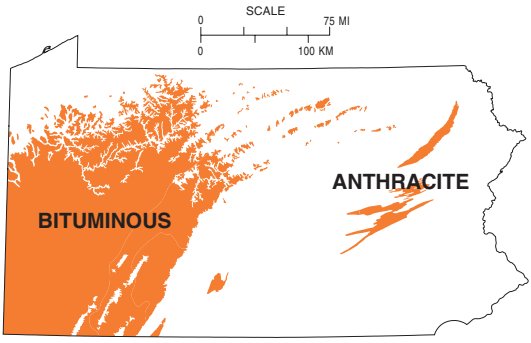
Carbonate rocks are hard and resistant to physical weathering. In the arid western states, limestone forms many high cliffs. Here in the East, the resistant rock that caps the cliff at Niagara Falls is dolomite. But carbonate rocks can also be prone to attack by chemical weathering, especially in a humid climate, 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 sinkhole. Educational Series 11, *Sinkholes in Pennsylvania,* contains more information on this interesting topic. This same process of solution is also responsible for the formation of beautiful caverns having stalactites that hang from the ceiling and stalagmites that rise from the floor. Stalactites and stalagmites are formed by the deposition of calcium carbonate, which is carried in solution by groundwater. If a drop of this water hangs from the tip of a stalactite and evaporates, the 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!



Coal—A Most Unusual Rock. Coal is also a sedimentary rock, but it is different because it is mostly made of materials other than minerals. It forms 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 contributed to the lithification of other sedimentary rocks.

Pennsylvanian-age swamp

Most of the coal in Pennsylvania was deposited during a time that has become known to geologists throughout North America as the Pennsylvanian Period. The deposition continued into the Permian Period that immediately followed the Pennsylvanian. Most coal in Pennsylvania is soft coal, or bituminous coal, and is mined in a large region of western Pennsylvania. Hard coal, or anthracite, is mined in eastern Pennsylvania. Anthracite was subjected to deeper burial and



higher temperatures than bituminous coal, and is harder and shinier. More information on coal can be found in Educational Series 7, *Coal in Pennsylvania.*

METAMORPHIC ROCKS

Sedimentary rocks dominate the surface in most of Pennsylvania, but if we dig deeper, we will find that Pennsylvania's rocks take on a whole different character. The only rock type that is likely to exist everywhere in the commonwealth, from Erie to Philadelphia and from the upper Delaware River to the West Virginia border, is metamorphic rock. In all but the southeast, though, we have to dig a long way down to find it.

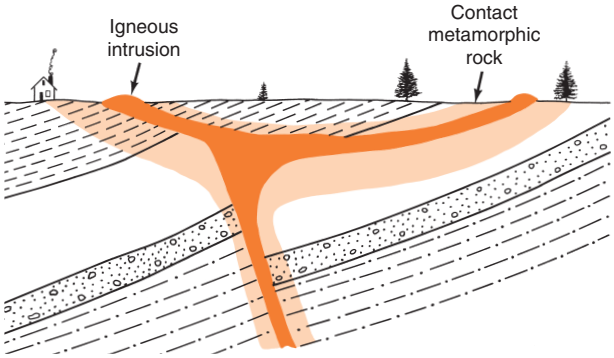
HOW DO METAMORPHIC ROCKS FORM? Metamorphic rocks form from existing rocks that are exposed to temperatures or pressures higher than those at which sedimentary rocks form. When rocks are exposed to such conditions, they can undergo some dramatic changes! Sometimes the minerals they contain are transformed into completely different minerals, and other times they take on new forms and textures. The word "metamorphic" is derived from the Greek word meaning "to transform."

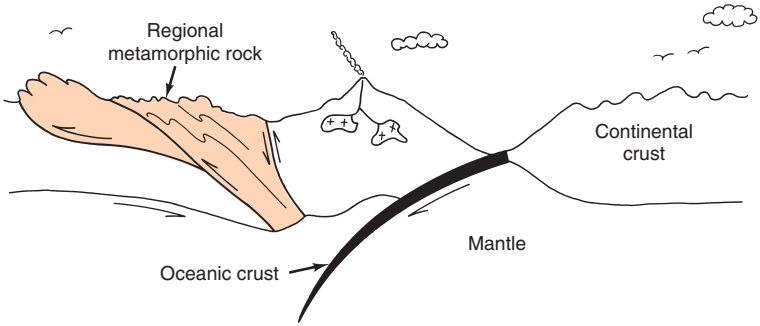
Both the texture and the mineralogy can tell us something about the history of a metamorphic rock. In some metamorphic rocks, minerals are arranged in parallel bands. This characteristic feature, called foliation, can give clues as to the direction from which stresses were applied. The presence of minerals that form only at certain ranges of temperature and pressure can indicate the conditions to which metamorphic rocks were subjected during their formation. If the temperature or the pressure gets high enough, certain minerals are destroyed and others form in their place.

Foliated metamorphic rock

There are two major types of metamorphism. One is contact metamorphism, during which rock is altered by the intense heat of a nearby body of magma. Among the more common contact metamorphic rocks is hornfels, a hard, fine-grained rock that is really baked shale. Hornfels is found in southeastern Pennsylvania where shales were altered by igneous intrusions at the beginning of the Jurassic Period. Contact metamorphic rocks are located adjacent to the igneous rocks that are shown in red on the geologic map.

The other major type of metamorphism is regional metamorphism. It involves rocks over a large area that have been transformed by some major event, such as deep burial or mountain building.





Sketches illustrating the creation of metamorphic rock next to a magmatic intrusion (left) and where two continental plates collide (below).

The finest grained metamorphic 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.

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

Coarse-grained metamorphic rocks include gneiss and marble. Gneiss usually contains more quartz and feldspar than do the finer grained metamorphic rocks, and it often has bands of platy minerals such as mica running through it. Some gneiss is believed to have formed from the metamorphism of igneous rocks such as granite, although it could be formed from a wide variety of parent rocks. Marble is predominantly calcite and forms from the metamorphism of limestone.

PENNSYLVANIA'S METAMORPHIC ROCKS. Rocks that have been altered by metamorphism are found near the surface only in the southeastern part of Pennsylvania, although they probably occur at greater depth under the entire state. The metamorphic rocks in southeastern Pennsylvania are quite diverse and most were derived through regional metamorphism of both igneous and sedimentary rocks. On the geologic map, they are included among the rocks labeled as Cambrian, Lower Paleozoic, and Precambrian age.

In part, the diversity of metamorphic rocks in southeastern Pennsylvania comes from the accumulation of microplates that collided with the North American continent, as was described on page 12. 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 the rocks. Eastern North America has undergone at least two collisions with other continental plates, the most recent being with Africa during the Permian Period. The force of these collisions caused the rocks in southeastern Pennsylvania to become severely deformed and metamorphosed.

FOR MORE INFORMATION

This booklet provides only a brief introduction to Pennsylvania's rocks and minerals. There are many books containing more detailed information on the properties and identification of rocks and minerals in general and in Pennsylvania. Some relevant publications of the Pennsylvania Geological Survey are listed on page 30.

You can get information on what can be collected near your hometown from members of the rock and mineral clubs that are found throughout the state. A list of mineral-collecting clubs around the state can be found through our website at dcnr.state.pa.us/topogeo/collecting/rocks/index.htm.

The remainder of this booklet contains a list of some of the more common or interesting minerals that are found in Pennsylvania. The following three books, which served as sources for this list, contain much more information:

Gordon, S. G., 1922, **The Mineralogy of Pennsylvania:** Academy of Natural Sciences of Philadelphia Special Publication 1, 255 p.

Montgomery, Arthur, 1969, **The Mineralogy of Pennsylvania—1922–1965:** Academy of Natural Sciences of Philadelphia Special Publication 9, 104 p.

Smith, R. C., II, 1978, **The Mineralogy of Pennsylvania—1966–1975:** Friends of Mineralogy, Pennsylvania Chapter, Inc., Special Publication 1, 304 p.

SOME MINERALS FOUND IN PENNSYLVANIA

NATIVE ELEMENTS

GOLD: Au. Gold color. Metallic luster. High specific gravity. Very rare as tiny flakes, many barely visible, which can be found by panning in streams.

COPPER: Cu. Reddish-brown. Metallic luster. Irregular masses. Found at South Mountain in Adams, Cumberland, and Franklin Counties, where it was locally prospected.

SULFUR: S. Yellow or reddish-yellow. Resinous luster. Irregular masses. Rarely found in some limestones. Fine, delicate crystals also form by sublimation from gases emitted by coal-mine fires.

GRAPHITE: C. Black. Metallic to dull luster. Scaly, radiating, or earthy masses; rare tabular crystals. Very soft, will mark paper. Found in marble in southeastern Pennsylvania.

SULFIDES

GALENA: PbS. Gray. Metallic luster. Very dense. Cubic crystals and masses. Scattered deposits in southeastern and central Pennsylvania. Formerly mined in those areas.

SPHALERITE: ZnS. Yellowish-brown and other colors. Usually resinous luster. Mostly irregular masses. Dense. Often found in deposits with galena. Was formerly mined in eastern and central Pennsylvania.

CHALCOPYRITE: $CuFeS_2$. Brass-yellow. Metallic luster. Mostly found as irregular masses in large iron deposits in southeastern Pennsylvania. Also found in small quantities in other areas of the state.

WURTZITE: ZnS. Brownish-black. Resinous luster. Found as small crystals in limestone in western Pennsylvania. Some of the wurtzite is found in barite-filled cracks in siderite concretions, which are rounded masses of minerals that are distinct from the minerals in the surrounding rock.

PYRITE: FeS_2. Pale-yellow. Metallic luster. “Fool’s gold.” Crystals and irregular masses are found in small quantities in many sedimentary rocks statewide. Some larger quantities are associated with iron deposits in southeastern Pennsylvania.

OXIDES AND HYDROXIDES

MAGNETITE: Fe_3O_4. Black. Metallic luster. Attracted to magnets. Crystals and irregular masses. Large deposits in Lebanon and Berks Counties served as the principal ore mineral of iron mines. Also found in small quantities in rocks and surficial deposits statewide. Can be collected from sand in many streams by using a magnet.

CHROMITE: $(Mg,Fe)Cr_2O_4$. Black. Metallic luster. Irregular masses and small crystals. Was mined for chromium in southeastern Pennsylvania. Southern Lancaster County was the world's leading source of chromium in the 1800s. Chromite is found in sand in streams in areas of serpentine bedrock.

HEMATITE: Fe_2O_3. Irregular masses are typically red and earthy; crystals can be gray and have metallic luster. Was used as an iron ore in colonial times in eastern Pennsylvania. Found in small quantities in sedimentary rocks statewide. Thought to be what makes Triassic and some other sedimentary rocks red.

GOETHITE: FeO(OH). Commonly yellowish-brown and earthy irregular masses. Principal mineral in "limonite," which is a mixture of iron oxides. Limonite formed from the oxidation of pyrite has the same form as the pyrite crystals. Was mined for iron in small operations from colonial times to the late 1800s in eastern and central Pennsylvania.

HALIDES

HALITE: NaCl. Normally white. Vitreous luster. Soluble in water. Salty taste. Large, deep, subsurface deposits of halite are found in northern and western Pennsylvania. Rocks consisting primarily of halite are called evaporites. Some sedimentary rocks in Pennsylvania contain casts of halite crystals that dissolved long ago.

FLUORITE: CaF_2. Purple is the common color in Pennsylvania. Also colorless, white, green, blue, or yellow. Vitreous luster. Small crystals and cleavage fragments are found in several locations in south-central and eastern Pennsylvania.

CARBONATES

CALCITE: $CaCO_3$. Colorless and transparent, white to gray and opaque, other colors; may be yellowish. Vitreous luster. Found as crystals in some places. The principal mineral forming large limestone deposits in many areas of the state. Also forms marble in the regions of metamorphic rock in southeastern Pennsylvania.

DOLOMITE: $CaMg(CO_3)_2$. Colorless and transparent, white to gray and opaque, other colors; may be yellowish. Vitreous luster. Found as crystals and masses. Forms large deposits of dolomite rock in many areas, especially in south-central and southeastern Pennsylvania.

SIDERITE: $FeCO_3$. Yellowish-brown to reddish-brown. Vitreous luster. Widespread occurrence as nodules in the coal-producing regions of western Pennsylvania. Some crystals. Also found in several places in eastern Pennsylvania.

SULFATES

CELESTINE: $SrSO_4$. Pale blue or colorless. Vitreous luster. Fibrous masses and small crystals. The world's first discovery of celestine was in Blair County in 1791. Proposals have been made to designate celestine as Pennsylvania's state mineral.

GYPSUM: $CaSO_4 \cdot 2H_2O$. Colorless or white. Vitreous or pearly luster. Small crystals found in small scattered deposits associated with shales and carbonate rocks. Probably exists in larger subsurface deposits associated with evaporites.

MELANTERITE: $Fe^{2+}SO_4 \cdot 7H_2O$. White. Vitreous luster. Metallic taste. This and some other sulfates are commonly seen as powdery coatings or small crystals on shale. Forms from the oxidation of pyrite in the shale.

BARITE: $BaSO_4$. White to gray, blue, red, or brown. Vitreous luster. High specific gravity. Found as irregular masses and crystals. Most common in southeastern and south-central Pennsylvania.

PHOSPHATES

APATITE GROUP: Carbonate-fluorapatite ($Ca_5(PO_4,CO_3)_3F$), fluorapatite, ($Ca_5(PO_4)_3F$), and carbonate-hydroxylapatite ($Ca_5(PO_4,CO_3)_3OH$) are probably the most common members of this group in Pennsylvania. Various shades of green, white, brown, and red. Subresinous to vitreous luster. Apatite minerals are found in a number of places. Fluorapatite is found as tiny crystals in igneous and metamorphic rocks of southeastern Pennsylvania. Carbonate-fluorapatite has been reported in fossilized bone from sedimentary rocks in central Pennsylvania.

WAVELLITE: $Al_3(PO_4)_2(OH,F)_3 \cdot 5H_2O$. Colorless, white, or green. Vitreous or pearly luster. Radiating clusters of crystals are found in south-central and southeastern Pennsylvania.

SILICATES

QUARTZ: SiO_2. Commonly colorless and transparent; many other colors possible. Vitreous luster. Varieties include amethyst, chalcedony (flint or chert), jasper, smoky quartz, and rose quartz. Very abundant in most sedimentary, metamorphic, and igneous rocks statewide. Crystals are found in numerous locations.

FELDSPAR GROUP: Plagioclase (a continuous series of compositions ranging from albite, $NaAlSi_3O_8$, to anorthite, $CaAl_2Si_2O_8$) and orthoclase and microcline (both $KAl(Si_3O_8)$) are the most common feldspars in Pennsylvania. Various shades of white, gray, pink, and other colors. Vitreous luster. Abundant in many sedimentary, metamorphic, and igneous rocks statewide.

KAOLINITE GROUP: Kaolinite is the most common member of this group, which includes dickite and halloysite. All three have the same chemical formula: $Al_2Si_2O_5(OH)_4$. They exist as microscopic particles in clay, are normally whitish, and have an earthy texture. The main difference between the three minerals is their form—dickite has larger plates than kaolinite, and halloysite occurs as rolled-up tubes.

SERPENTINE GROUP: Antigorite ($(Mg,Fe^{2+})_3Si_2O_5(OH)_4$) and clinochrysotile and lizardite (both $Mg_3Si_2O_5(OH)_4$) are the most common members in Pennsylvania. They are normally green with a waxy or silky luster. Clinochrysotile is commonly fibrous; antigorite and lizardite are massive. Serpentine minerals make up the bulk of the altered ultramafic rock serpentinite, which is found in Delaware, Chester, and Lancaster Counties. They are also in metamorphic rocks in Northampton County.

MICA GROUP: In Pennsylvania, the most common members are muscovite ($KAl_2(AlSi_3)O_{10}(OH)_2$) and biotite ($K(Mg,Fe^{2+})_3AlSi_3O_{10}(OH)_2$). Muscovite is colorless or pale shades of green or brown; biotite is darker. Both have a vitreous or pearly luster and are easily separated into very thin, flexible sheets. Mica is abundant in many sedimentary, metamorphic, and igneous rocks statewide. Large sheets of muscovite are found in some rocks in southeastern Pennsylvania. The weathered form of mica, illite, is a clay mineral and a major component of shale.

CHLORITE GROUP: Clinochlore ($(Mg,Fe^{2+})_5Al(Si_3Al)O_{10}(OH)_8$) and chamosite ($(Fe^{2+},Mg,Fe^{3+})_5Al(Si_3Al)O_{10}(OH,O)_8$) are the most commonly found chlorites in Pennsylvania. Both tend to be green or brown. Vitreous to earthy luster. Large specimens can be easily separated into very thin sheets that are easily bent. Chlorite is abundant in metamorphic rocks, some of which contain large sheets. It is also abundant as a clay mineral in shale.

AMPHIBOLE GROUP: There are approximately 125 minerals in this group by latest count. Among the more common ones that are found in Pennsylvania are two hornblende minerals, ferrohornblende and magnesiohornblende ($Ca_2[(Fe^{2+},Mg)_4(Al,Fe^{3+})]Si_7AlO_{22}(OH)_2$), and actinolite ($Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$). The hornblendes are usually dark green to black and have a vitreous luster. They form short columnar crystals in the metamorphic rocks of southeastern Pennsylvania. Actinolite is white or green, has a vitreous luster, and forms long, thin crystals. It is also found in the metamorphic rocks of southeastern Pennsylvania.

PYROXENE GROUP: The most common pyroxenes in Pennsylvania are thought to be augite ($(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$) and diopside ($CaMgSi_2O_6$). Both minerals are white to dark green or black. Vitreous luster. Short crystals or massive forms. Pyroxenes are important minerals in the mafic rocks of southeastern Pennsylvania, especially in the Jurassic diabase, where they make up half the rock.

TOURMALINE GROUP: Schorl ($NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$) is the most common species of tourmaline found in Pennsylvania. Black. Vitreous luster. Occurs as crystals found in metamorphic rocks of southeastern Pennsylvania. It is also found as tiny, radiating grains in many sandstones.

OLIVINE GROUP: Forsterite (Mg_2SiO_4) and fayalite ($Fe^{2+}_2SiO_4$) are the two most common species of olivine. Normally olive-green. Vitreous luster. Olivine in Pennsylvania commonly has a composition between those of forsterite and fayalite, but is closer to forsterite. It is found in southeastern Pennsylvania, where most of it has altered to serpentine. Small grains of olivine can be found in many serpentine deposits.

GARNET GROUP: Almandine ($Fe^{2+}_3Al_2(SiO_4)_3$) is one of several kinds of garnet found in Pennsylvania. Red color most common, but can be other colors. Vitreous to resinous luster. Garnets are found as crystals or irregular forms in the metamorphic rocks of southeastern Pennsylvania. Garnet sand can be panned from many streams in the glaciated regions of northwestern and northeastern Pennsylvania.

ZIRCON: $ZrSiO_4$. Colorless or brown. Vitreous or adamantine luster. Occurs as crystals. Very small zircons are found in the igneous and metamorphic rocks of southeastern Pennsylvania and in many sedimentary rocks statewide. Because they are highly resistant to erosion, even the zircons found in sedimentary rocks commonly show their crystal form. Tiny zircons can be panned from streams throughout the state.

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OTHER SURVEY PUBLICATIONS OF INTEREST TO ROCK AND MINERAL ENTHUSIASTS

Berg, T. M., Edmunds, W. E., Geyer, A. R., and others, compilers, 1980, **Geologic map of Pennsylvania** (2nd ed.): Pennsylvania Geological Survey, 4th ser., Map 1, scale 1:250,000, 3 sheets.

Berkheiser, S. W., Jr., **Fetid barite occurrences, western Berks County, Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 84, 43 p.

Lapham, D. M., Barnes, J. H., Downey, W. F., Jr., and Finkelman, R. B., 1980, **Mineralogy associated with burning anthracite deposits of eastern Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 78, 82 p.

Lapham, D. M., and Gray, Carlyle, 1973, **Geology and origin of the Triassic magnetite deposit and diabase at Cornwall, Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 56, 343 p.

Rose, A. W., 1970, **Atlas of Pennsylvania's mineral resources—Part 3, Metal mines and occurrences in Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 50, pt. 3, 14 p.

Smith, R. C., II, 1972, **Zinc and lead occurrences in Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 72, 318 p.

Smith, R. C., II, and Hoff, D. T., 1984, **Geology and mineralogy of copper-uranium occurrences in the Picture Rocks and Sonestown quadrangles, Lycoming and Sullivan Counties, Pennsylvania:** Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 80, 271 p.

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