Earth Materials—Minerals, Rocks, and Mineral Resources

TOPIC 11

How Scientists Study Minerals

Do you think every mineral has a unique chemical composition?

It is the crystal structure that is unique to each mineral and not the chemical composition. Just consider the minerals graphite and diamond, which are both composed of only carbon. It is hard to believe that two minerals with the same chemical composition could be so different: Graphite is one of the softest minerals and diamond is the hardest of the somewhat common minerals. Diamond has a brilliant luster and graphite is greasy to metallic. Graphite is used as a lubricant, while diamond is used as an abrasive. And graphite is an electrical conductor, while diamond is an insulator.

Graphite and diamond are not the only example. Calcite and aragonite are two minerals that are composed of calcium carbonate ($CaCO_3$). There are at least five minerals with the formula SiO_2, with quartz being the most common.

Topic 11: Earth Materials—Minerals, Rocks, and Mineral Resources

Vocabulary

bioclastic sedimentary rocks
chemical sedimentary rocks
clastic sedimentary rock
cleavage
contact metamorphism
crystal shape
crystal structure
extrusive igneous rock
foliation
fossil
fracture
hardness
igneous rock
inorganic
intrusive igneous rock
luster
magma
metamorphic rocks
metamorphism
mineral
mineral crystal
mineral resources
organic
precipitation (of minerals)
regional metamorphism
rock cycle
sedimentary rocks
streak
texture

Topic Overview

Rocks and minerals are the source of much of the material and energy that people want or need. If you make a list of about one hundred objects you used or wanted to use today, most likely 95 to 100 percent of them come from rocks and minerals. Earth materials—minerals, rocks, and mineral resources—are of value to people in many ways. Earth materials fuel our industrial society as extracted fossil fuels. They provide the raw materials for the building of homes and other construction projects. Rocks and minerals make up Earth's solid surface—the lithosphere—that you live on. When Earth's solid surface is weathered and eroded, the end results are the landscape features that people live, work, and play on.

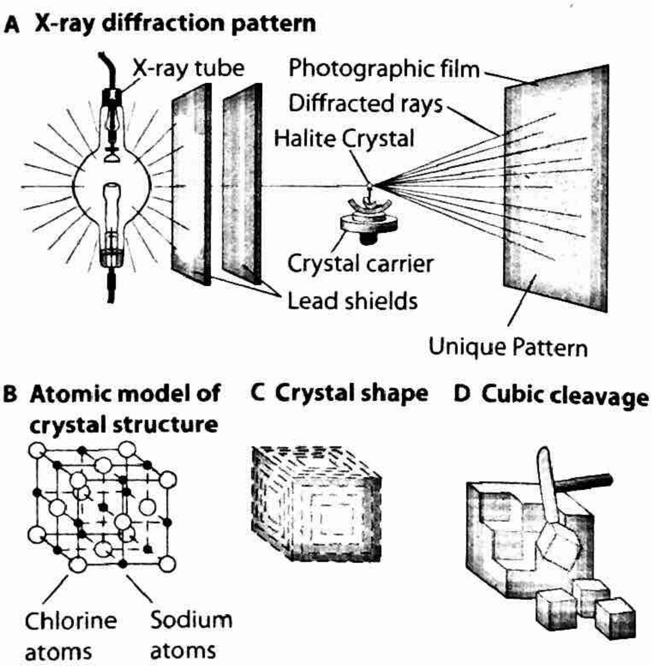


Figure 11-1. Crystal structure and properties of the mineral halite: Halite is the mineral with the formula NaCl (sodium chloride). It is the one mineral of rock salt and common table salt.

Minerals

Minerals have characteristic physical and chemical properties. Some of these properties are color, streak, luster, hardness, density, cleavage and crystal structure.

What a Mineral Is

A **mineral** is a naturally occurring, inorganic, crystalline solid having a definite chemical composition. A mineral is considered to be naturally occurring because it is formed in nature and not made by people. It is **inorganic** because it has not been made by or composed of life forms. Thus fossil fuels or a pearl from an oyster are NOT minerals.

A mineral is crystalline because its atoms have a specific arrangement. This arrangement of atoms is called **crystal structure**. Each mineral has its own distinctive crystal structure that can lead to very accurate identifications through the use of X-rays. Figure 11-1 illustrates the crystal structure of a mineral.

All minerals are solids that are composed of one or more chemical elements. The chemical composition of a mineral describes the types and ratios of elements that make up the mineral. Some minerals contain only one element and others are compounds of two or more elements. You can find the characteristics of some minerals in the Properties of Common Minerals in the *Earth Science Reference Tables*.

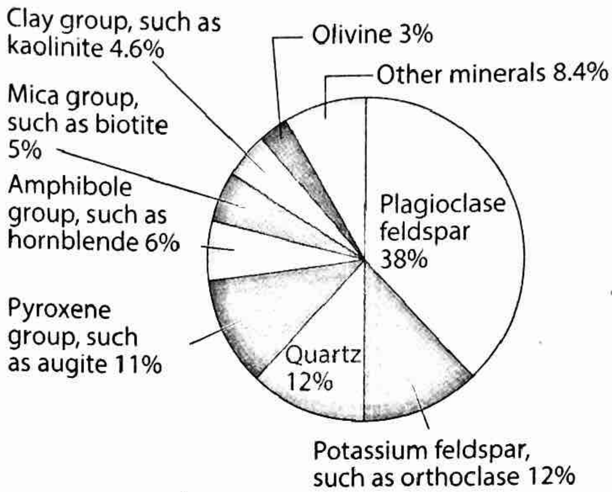


Figure 11-2. Circle graph of the most common minerals of Earth's crust: 90 percent of Earth's crust by weight is composed of eight minerals or groups of minerals—all silicates. These common minerals are called rock-forming minerals.

Relation of Minerals to Rocks

All minerals are rocks, but not all rocks are minerals nor are they all composed of minerals. A rock is any naturally formed solid that is part of Earth or any other celestial body. Though a large percentage of rocks is composed of minerals, many rocks are composed of organic or glassy materials that are not minerals. Glasses are not minerals because their atoms are not arranged in a specific pattern. The majority of rocks are made of two or more minerals—multiple-mineral rocks. Some rocks are composed of only one mineral—single-mineral rocks.

A review of the three schemes for rock identification—sedimentary, metamorphic, and igneous—in the *Earth Science Reference Tables* and Figure 11-2 indicates that only a small number of minerals are commonly found in rocks. These 20 to 30 very common minerals, found in rocks, are called the rock-forming minerals. Many of these rock-forming minerals are listed in the Properties of Common Minerals in the *Earth Science Reference Tables*.

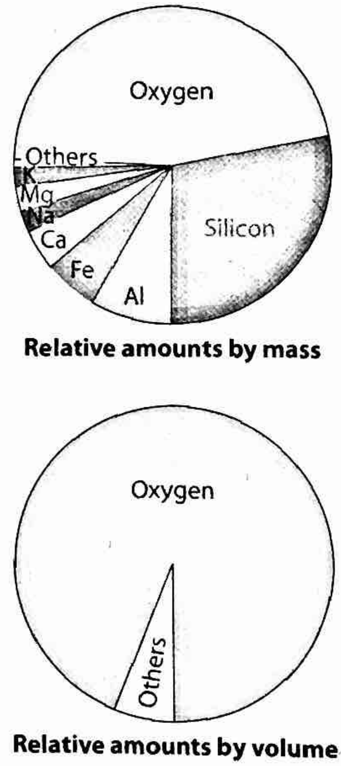


Figure 11-3. Percentages of the chief elements in Earth's crust by mass and by volume: **Volume is the amount of space occupied by the atoms of each element in the solid substances of the crust. Also see Average Chemical Composition of Earth's Crust, Hydrosphere, and Troposphere in the *Earth Science Reference Tables*.**

Element Composition of Earth's Crust

The chemical element composition of Earth's crust is shown in Figure 11-3.

- The graph indicates that over 99 percent of Earth's crust and its minerals are, by volume and mass, composed of only 8 of the 90 naturally occurring elements found on Earth.
- Silicon is the second most abundant element by mass, but the element potassium is number two in crustal abundance by volume because of its lower density and higher volume.

Mineral Crystal Structure

The crystal structure, or atomic arrangement of the atoms, that comprise minerals is responsible for many of their chemical and physical properties, such as crystal form, breaking pattern, and hardness. Most rock-forming minerals are silicates. Silicate minerals have a structure that results from various arrangements of a tetrahedron-shaped (4-sided) unit of oxygen and silicon called the silicon-oxygen tetrahedron. Figure 11-4 shows how each tetrahedron is composed of one atom of silicon and four atoms of oxygen. It also shows different ways the silicon-oxygen tetrahedron can be arranged resulting in different breaking patterns (cleavage and fracture).

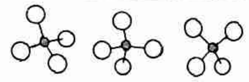
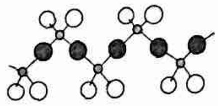
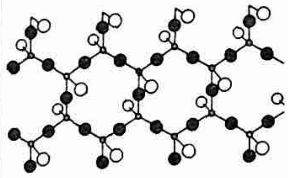
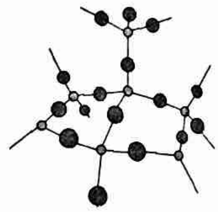
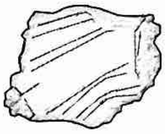
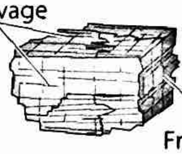
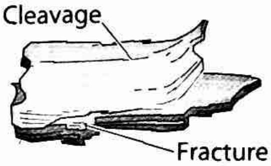
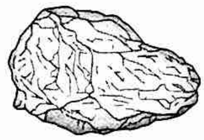
Silicate structure	Key Silicon Shared oxygen Unshared oxygen 			
Silicate structure	Single tetrahedron	Chains of tetrahedra	Sheets of tetrahedra	A network of tetrahedra in three dimensions
Mineral example	Olivine—peridot is gem variety	Pyroxene, such as augite	Mica, such as biotite	Quartz
Cleavage or fracture type	Curved or conchoidal fracture	Two directions of cleavage into blocky or splinter shapes and fracture	One direction of cleavage into sheets and fracture	Curved or conchoidal fracture
Drawing		Cleavage  Fracture	Cleavage  Fracture	

Figure 11-4. Various arrangements of the silicon-oxygen tetrahedron in silicate minerals: The tetrahedra combine with themselves and other elements in different atomic structures. The different combinations affect the physical properties of the minerals—including cleavage and fracture patterns shown in the illustration.

Digging Deeper

Diamond is still the hardest mineral that a person is likely to encounter, but not the hardest in the world. Scientists have recently discovered that wurtzite boron nitride and lonsdaleite, two very rare minerals, are even harder than diamond.

Mineral Formation

Since all minerals are rocks, they form by one of two processes. Minerals form as the result of inorganic crystallization—a process of organizing atoms to form crystalline solids. Minerals also form by recrystallization of atoms from the solids, liquids, and gases associated with various rock- forming environments.

Mineral Properties and Identification

Each mineral has a characteristic set of physical and chemical properties that can be used to help identify it. The crystal structure and the chemical composition of minerals largely determine these properties. Some properties, such as color, are often caused by impurities. The mineral corundum, when pure, is colorless. However, with slight chemical impurities, corundum becomes the blue sapphire or red ruby.

The most accurate method for identifying minerals is by the use of X-ray diffraction instruments (see Figure 11-1) and other machines not available to most individuals. Therefore, simple tests and mineral identification charts are relied on. An example of a mineral identification key, or chart, is found in Properties of Common Minerals in the *Earth Science Reference Tables*.

Color The color of a mineral is one of its most obvious properties. However, in most cases color is not useful because many minerals have the same color. In addition, the color of many minerals varies due to impurities, and many minerals are clear or colorless when pure. In a few cases however, such as in the yellow of sulfur, the gray of graphite (pencil lead) and galena, or the brassy yellow of pyrite (fool's gold), the mineral's color is usually consistent.

Streak The color of finely crushed residue or powder of a mineral is its **streak**. When you write on a chalkboard, you observe the streak of the rock chalk. The streak of a mineral is usually quite consistent; thus streak color is much more useful than mineral color. For example, the iron ore mineral, hematite, can be various shades of silver-gray to red in color, but the streak is a consistent red.

Luster The shine from an unweathered mineral's surface, or the way a mineral looks in reflected light, is **luster**. There are two broad groups of luster—metallic and nonmetallic. Minerals with a metallic luster, such as pyrite and galena, shine like the surface of a clean stainless steel pot. Most minerals have a nonmetallic luster. There are many types of nonmetallic luster, such as the glassy luster of black hornblende and clear quartz "rhinestone," or the pearly luster of muscovite mica.

Hardness The resistance a mineral offers to being scratched is its **hardness**—the scratchability of a mineral, not how easily the mineral breaks. Diamond is the hardest mineral (see Digging Deeper on page 220), but drop an unmounted diamond on a tile floor and it will likely shatter. On the other hand, if the very soft mineral graphite is dropped, only a small amount will chip off, or cleave.

Figure 11-5 shows the Mohs hardness scale and some other common materials that are often used to determine hardness. Mohs hardness scale is arranged from the softest #1 (talc) to the hardest #10 (diamond). A quick way to determine relative hardness is to use a piece of window glass. If a mineral scratches the glass, the mineral is hard, and if it doesn't, it is soft.

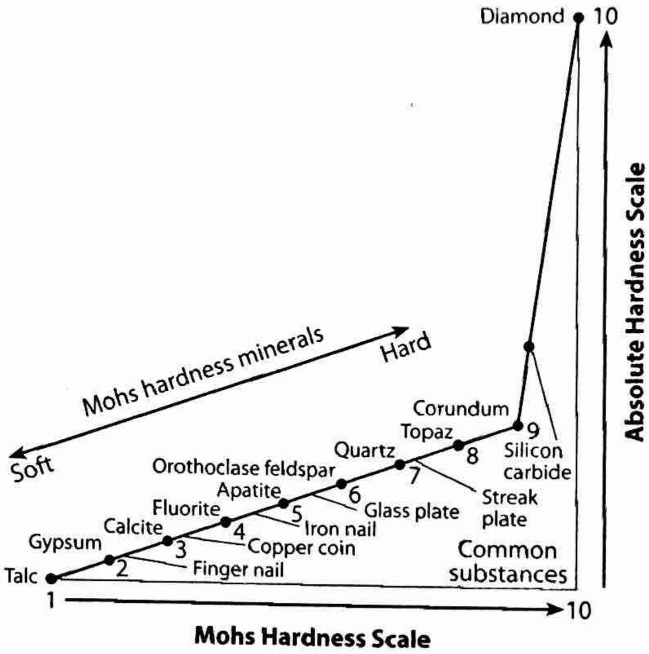


Figure 11-5. Mohs and absolute hardness scale: The differences in the hardnesses on the Mohs scale vary, as shown by the comparison to an absolute scale of hardness. Note that on the absolute scale, the difference of hardness between diamond and corundum—ruby or sapphire—is more than all the way from talc to corundum.

Density Each mineral has a specific density or a small range of densities—for those minerals that vary in mineral composition. Often in mineral studies, density is stated as specific gravity, a value without units. Specific gravity is the density of a mineral compared to the density of water. Specific gravity is a good test to distinguish gemstones, because it doesn't harm the samples like hardness or cleavage tests do. In mining and refining processes, differences in the densities of various minerals allow them to be separated. A common example is the panning of high-density gold.

Cleavage The tendency of a mineral to break along the zones of weakness and form smooth to semi-smooth parallel sides, or surfaces, is called **cleavage**. Cleavage surfaces can often be distinguished from sides without cleavage by having a shinier or more brilliant luster (smooth surfaces reflect better). If a mineral lacks preferred zones of weakness in the crystal structure, then it will demonstrate uneven breaking surfaces called **fracture**. For example, some types of fracture are irregular (earthy), fibrous (splintery), and curved (conchoidal). The curved surfaces in a type of quartz called flint make this

Memory Jogger

Recall that density is the ratio of the mass of an object to its volume. Therefore, an element that has a lower density than another element has a smaller mass per volume than an element with higher density.

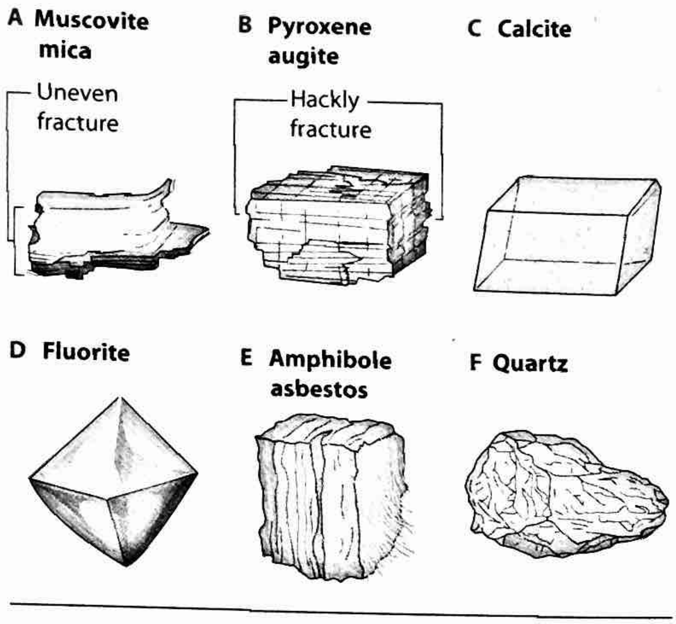


Figure 11-6. Types of cleavage and fracture: (A) shows one direction of cleavage and some uneven fracture. (B) shows two directions of cleavage and a hackly (bumpy) fracture. (C) shows three directions of cleavage. (D) shows four directions of cleavage. (E) shows fibrous fracture. (F) shows curved fracture.

material very useful in making knives and arrowheads. Often a mineral will have both cleavage and fracture on different sides, such as the silicates hornblende and the feldspars. (See Figures 11-4 and 11-6)

Crystal Structure The outward geometric shape of a mineral, the crystal form, or **crystal shape,** reflects the crystal structure—orderly arrangement of the atoms in the mineral. It is only when individual mineral grains have the room to freely grow that this crystal shape, with its smooth sides or faces, can take shape. This is the reason most mineral samples found in nature don't illustrate the crystal forms; the use of crystal form in mineral identification is limited. Another problem is that even though the internal crystal structure of minerals is unique, the outward crystal shape, such as the cubic shape of halite, galena, and fluorite, isn't unique. Also, any mineral can have many different crystal shapes.

Other Mineral Properties Besides physical properties, some chemical properties of minerals are also used for identification. One of these chemical properties is the reaction of a mineral with acid. When a small amount of dilute hydrochloric acid is placed on a mineral or rock containing calcite (CaCO3), the mineral or rock will bubble (effervesce)—giving off carbon dioxide. The mineral dolomite can be distinguished from calcite, because dolomite will bubble in acid only after the mineral is powdered.

Many other chemical and physical properties are used to identify minerals. Many of the properties only apply to a few minerals and will often be the key to a mineral's identification. For example, some minerals such as thin pieces of muscovite and biotite micas are flexible. This means that they can be bent and will snap back to their original shape. Other properties used for identification are found in Properties of Common Minerals in the *Earth Science Reference Tables.* Ⓡ

Digging Deeper

A few minerals have very fine lines—called striations—on cleavage surfaces and on the faces of their crystal form. These striations can be used to distinguish the mineral plagioclase feldspar from the potassium feldspars such as orthoclase. Striations are an outward expression of the internal arrangement of the atoms within a mineral.

Review Questions

1. A mineral CANNOT be
(1) organic
(2) crystalline
(3) a solid
(4) formed in nature

2. Which rock is usually composed of several different minerals?
(1) rock gypsum
(2) limestone
(3) quartzite
(4) gneiss

3. Only a small number of Earth's minerals are commonly found in rocks. This fact indicates that most
(1) minerals weather before they can be identified
(2) minerals have properties that are difficult to identify
(3) rocks have a number of minerals in common
(4) exposed surface rocks are mostly igneous

4. The data table shows the composition of six common rock-forming minerals.

Mineral	Composition
Muscovite Mica	$KAl_3Si_3O_{10}$
Olivine	$(FeMg)_2SiO_4$
Orthoclase	$KAlSi_3O_8$
Plagioclase	$NaAlSi_3O_8$
Pyroxene	$CaMgSi_2O_6$
Quartz	SiO_2

The data table provides evidence that

(1) the same elements are found in all minerals
(2) a few elements are found in many minerals
(3) all elements are found in only a few minerals
(4) all elements are found in all minerals

5. What are the four most abundant elements, by volume, in Earth's crust?

(1) oxygen, potassium, sodium, and calcium
(2) hydrogen, oxygen, nitrogen, and potassium
(3) aluminum, iron, silicon, and magnesium
(4) aluminum, calcium, hydrogen, and iron

6. Diamonds and graphite are both minerals that are composed of the element carbon. Diamond has a hardness of 10, while graphite has a hardness of 1. Based on your knowledge of earth science, what is the most probable cause of this difference in hardness?

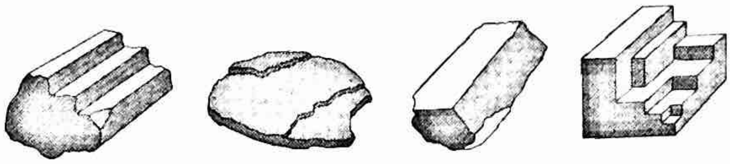
7. Minerals are composed of

(1) one or more rocks
(2) only one rock
(3) one or more chemical elements
(4) only one metal

8. The cubic shape of a mineral crystal is most likely the result of that crystal's

(1) hardness
(2) density distribution
(3) internal arrangement of atoms
(4) intensity of radioactive decay

9. The following diagrams represent four different mineral samples.



Which mineral property is best represented by the samples?

(1) density
(2) cleavage
(3) hardness
(4) streak

10. Minerals are identified on the basis of

(1) the method by which they were formed
(2) the type of rock in which they are found
(3) the size of their crystals
(4) their physical and chemical properties

11. A six-sided mineral crystal is a very hard mineral called

(1) hornblende
(2) orthoclase feldspar
(3) quartz
(4) biotite mica

12. The relative hardness of a mineral can best be tested by

(1) scratching the mineral across a glass plate
(2) squeezing the mineral with calibrated pliers
(3) determining the density of the mineral
(4) breaking the mineral with a hammer

13. What property would a mineral have if it appears like a new quarter in reflected light?

(1) a metallic luster
(2) metallic element composition
(3) magnetic
(4) a high density

14. Which property of the mineral diamond allows diamond powder to be used to shape gems for jewelry?

(1) crystal shape
(2) cleavage
(3) luster
(4) hardness

15. What information about a mineral is needed to determine its density?

(1) shape and volume
(2) shape and mass
(3) volume and mass
(4) volume and hardness