CHAPTER 2

MINERAL IDENTIFICATION

MATERIALS NEEDED

- **Pencil**
- **Hand lens**
- Set of mineral samples
- Equipment for determination of mineral properties: streak plate, copper penny, glass plate or steel knife, magnet, dilute hydrochloric acid

Note: Abbreviations of common chemical elements are inside the back cover!

INTRODUCTION

Most of the Earth is made of rocks, and rocks are made of minerals. Just as you had to learn the alphabet before you could read, you need to learn about minerals before you can understand rocks. The first step is to learn how to identify minerals. Chapter 1 shows that minerals have a number of rather easily determined physical properties, and that different minerals have different properties. This chapter explains how to use these properties to identify minerals. First, the text describes the most important (common) minerals found on Earth, and then it prepares you to go from observing the physical properties of an unknown mineral to an accurate identification of that mineral. You will see these same minerals over and over again through the next three labs, so it is worth taking extra care to learn them.

More than 3000 minerals are known to exist, yet only a comparative few are common. The **rock-forming minerals** are the most abundant minerals found in rocks at the Earth's surface. **Minor minerals** may be important constituents of certain rocks, but they are not common in most rocks. **Accessory minerals** are commonly present in rocks, but generally in only small amounts. **Ore minerals** have economic value when concentrated and are mined for the elements they contain. Table 2.1 lists some of the more important minerals within each of these groups; descriptions follow.

ROCK-FORMING MINERALS

FELDSPARS (K, NA, AND CA AL-SILICATES)

As a group, the feldspars are by far the most abundant minerals in the Earth's crust. They are the principal constituents of many kinds of igneous and metamorphic rocks and are abundant in some kinds of sedimentary rocks. Feldspar is fairly easy to identify due to its two good cleavages that intersect at essentially 90°, a Mohs hardness of 6, and a vitreous luster. There are two principal varieties of feldspar—plagioclase and potassium feldspar.

Plagioclase has a variable chemical composition, ranging from sodium aluminum silicate ($NaAlSi_3O_8$) to calcium aluminum silicate ($CaAl_2Si_2O_8$). The color varies as well: sodium-rich varieties tend to be light colored—commonly white, cream to buff, or light gray—whereas calcium-rich varieties tend to be gray to dark gray (Fig. 2.1). However, **striations,** not color, are the distinctive feature of plagioclase (see Fig. 1.20, Chapter 1). Unfortunately, not every plagioclase cleavage shows striations.

Potassium feldspar is a general name that includes several varieties of $KAlSi_3O_8$ (e.g., *orthoclase, microcline, sanidine*). It comes in white, cream, light gray, and even green, but salmon pink is a common and often distinctive color (Fig. 2.2). Some varieties contain semi-parallel veinlets (Fig. 1.21), which, as discussed in Chapter 1, are not to be confused with the striations in plagioclase.

The principal use of feldspars, especially potassium feldspar, is in the production of porcelain and ceramics. Some varieties of Ca-rich plagioclase (called labradorite) show a play of dark blue iridescent colors as the angle of reflected light changes. These are used for ornamental purposes, as is an unusual green variety of microcline known as *amazonite.*

TABLE 2.1
SOME IMPORTANT MINERALS

*Rock-Forming Minerals**	*Accessory and Minor Minerals*	*Ore Minerals*
Potassium feldspar	Pyrite	Native Copper
Plagioclase feldspar	Magnetite	Graphite
Quartz	Corundum	Sulfur
Hornblende (an amphibole)	Halite	Galena
Augite (a pyroxene)	Fluorite	Sphalerite
Biotite	Apatite	Chalcopyrite
Muscovite	Garnet	Pyrite
Chlorite	Sillimanite	Hematite
Talc	Kyanite	Magnetite
Clays (e.g., kaolinite)	Topaz	Chromite
Olivine	Staurolite	Goethite
Calcite	Epidote	Malachite
Dolomite	Beryl	Azurite
Gypsum	Tourmaline	Barite
Halite	Serpentine	
	Opal	

*In order of decreasing abundance in the Earth's crust.

QUARTZ (SiO_2)

Quartz is one of the most abundant minerals in the crust of the Earth and is common in soils, rocks, and even atmospheric dust. It is hard and tough, so it survives well on the Earth's surface, and it occurs in a wide variety of colors and forms.

Distinctive properties are hardness (H = 7), conchoidal fracture, and vitreous to somewhat greasy luster, but color varies. Quartz comes in several varieties. Well-formed crystals of colorless *rock crystal quartz,* purple *amethyst,* and dark grey *smoky quartz* are common in rock shops, but not in your backyard. Masses of coarsely intergrown quartz crystals with no well-defined crystal faces occur as white (or iron-stained) *milky quartz* (Fig. 2.3), which is common in many areas, or the rarer pinkish *rose quartz* or grayish *smoky quartz* (Fig. 2.3). Extremely fine-grained varieties of quartz, collectively termed *microcrystalline quartz,* include varicolored

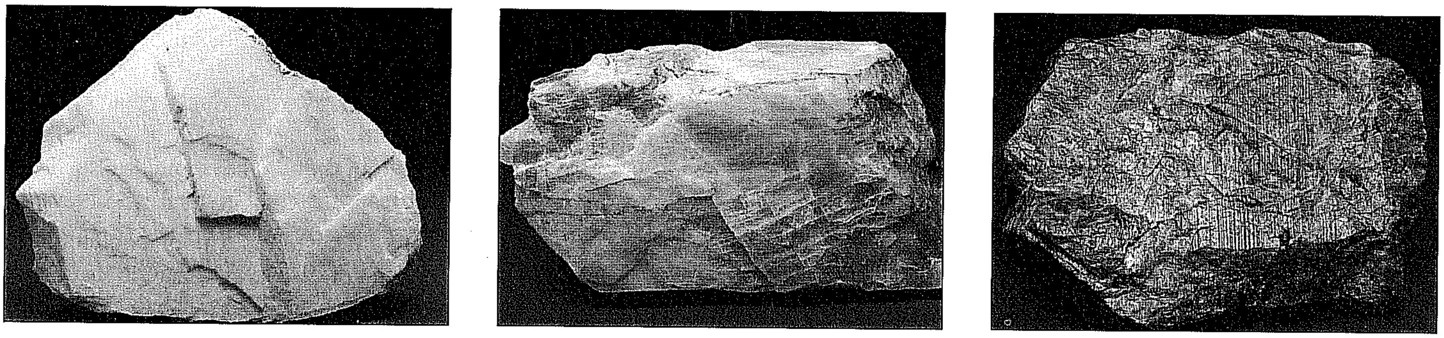


FIGURE 2.1
Various colors of plagioclase. Light-color varieties are usually richer in sodium. Darker varieties are richer in calcium.

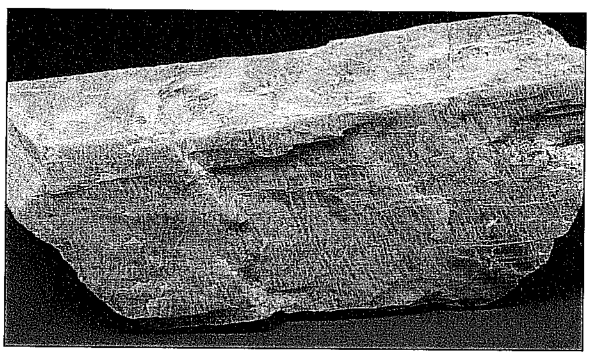


FIGURE 2.2
Microcline, a variety of potassium feldspar.

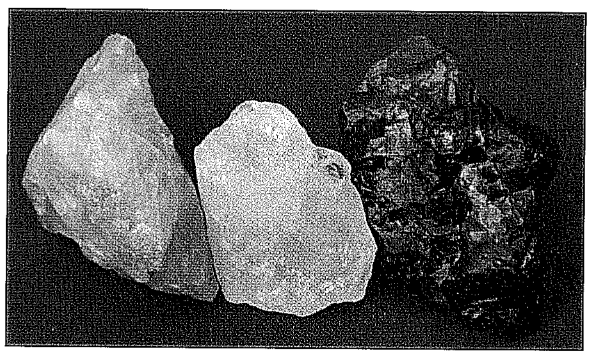


FIGURE 2.3
Rose quartz, common milky quartz, and smoky quartz.

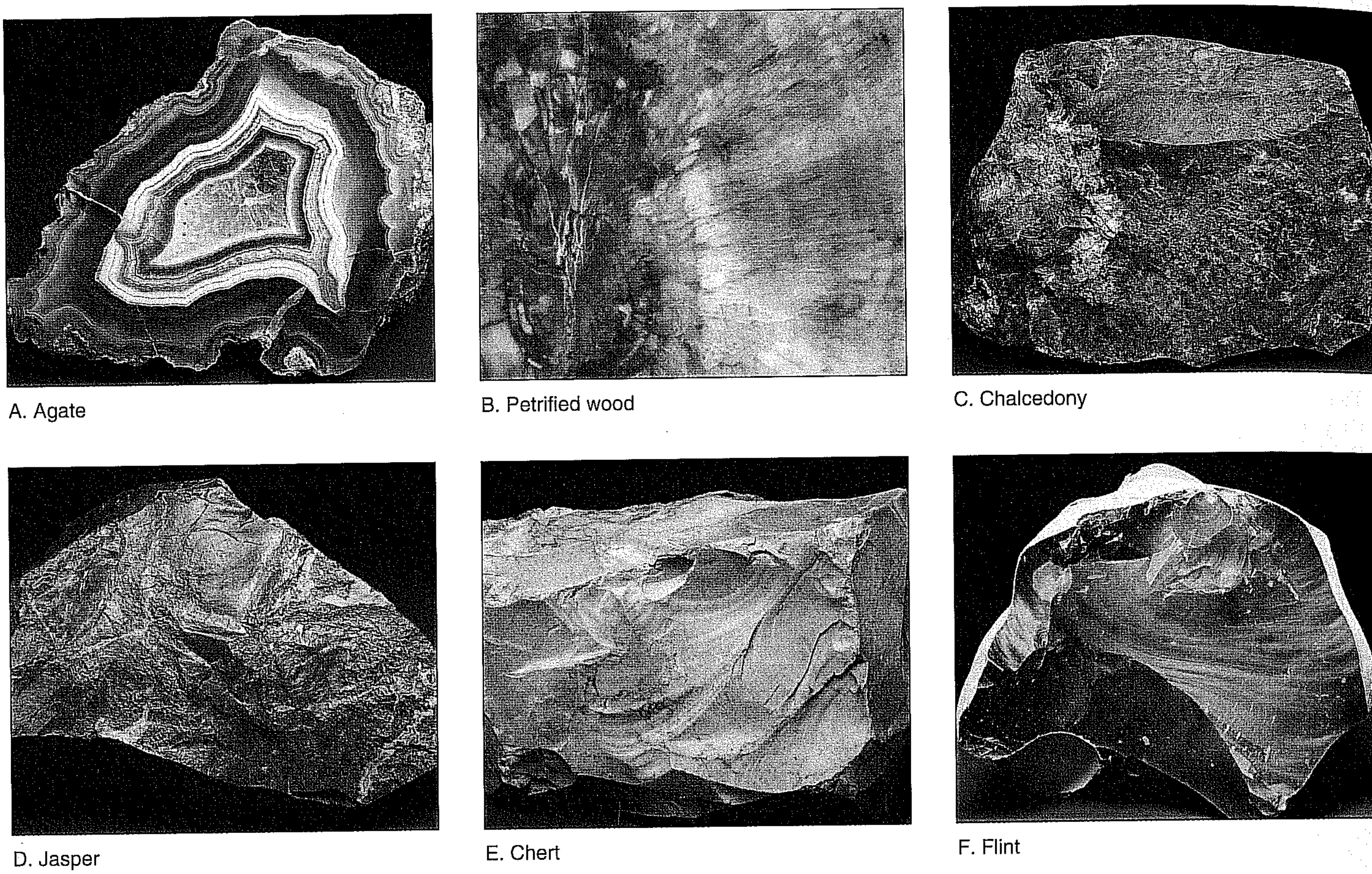


FIGURE 2.4
Microcrystalline varieties of SiO_2: A. agate; B. petrified wood; C. chalcedony; D. jasper; E. chert; F. flint.

banded varieties such as *agate* and *onyx* and more homogeneous varieties including *chalcedony* (brown or gray, and translucent), *jasper* (red), *chert* (gray, white, or pink), and *flint* (dark gray to black) (Fig. 2.4). *Petrified wood* typically is composed of microcrystalline quartz (Fig. 2.4).

Quartz has many uses. It is a major constituent in glass, including the world's best microscope and telescope lenses. Some varieties are used in jewelry (rock crystal, amethyst, tiger's eye, citrine), and both chert and flint were used to make arrowheads, spear points, and other sharp tools. Quartz watches keep good time because a quartz crystal, when hooked to a battery, vibrates at a constant rate. As sand grains or parts of rocks, quartz is also used in concrete, mortar, and building stone. Although some assign spiritual properties to quartz crystals, these have not been scientifically verified and, indeed, individual believers do not agree as to exactly which spiritual properties quartz possesses.

Amphiboles (Complex Hydrous Na, Ca, Mg, and Fe Al-Silicates)

Hornblende is the most common amphibole. As you can see in Figures 1.7 and 1.10B, Chapter 1, hornblende is a black mineral with two directions of good cleavage that are at roughly 60° or 120°; the cleavage gives it a splintery look, which helps to identify it. Hornblende occurs most commonly as small crystals in combination with other minerals in igneous and metamorphic rocks, but even there, it is distinctive when viewed with a hand lens.

The principal use of amphibole is for a small subset of the group with a fibrous habit that, as with some varieties of serpentine, makes it useful as asbestos. While airborne asbestos fibers can become imbedded in various parts of the lung or abdomen and cause asbestosis, only one variety (the amphibole crocidolite) is known to be especially carcinogenic. Asbestos is a poor conductor of heat and electricity and can be made into a variety of fabrics. These properties make it useful in many industrial applications, including cements, flooring, friction material, roofing, coatings, packings, gaskets, and protective clothing.

Pyroxenes (Ca, Mg, and Fe Silicates)

Like the amphiboles, most pyroxenes occur as small, crystalline components of rocks, especially certain igneous rocks. The most common pyroxene is *augite*, a greenish-black to black mineral that is easily confused with hornblende. Figure 2.5 shows that augite has two cleavages that intersect at about 90°, and it is not splintery looking like some hornblende. The cleavages may be difficult to see and are not nearly as good as those on hornblende. Another pyroxene, *diopside*, is commonly light green. A few varieties of pyroxene, such as *jadeite*, are prized for their ornamental value.

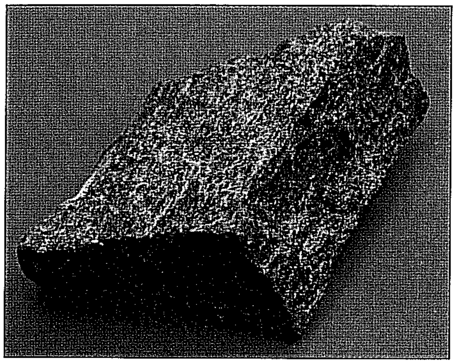


FIGURE 2.5
Augite, a variety of pyroxene. Pyroxenes have two poor cleavages at 90°, but they can be tough to spot.

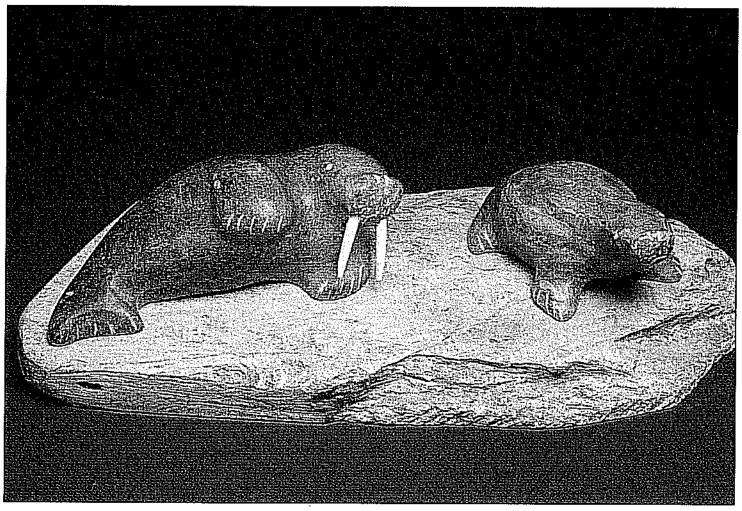


FIGURE 2.6
Inuit carving of walrus mother and baby in soapstone, a rock composed mostly of talc.

Micas (Hydrous K, Mg, and Fe Al-Silicates)

The two most frequently encountered micas, *biotite* and *muscovite,* are both common constituents of igneous and metamorphic rocks. Biotite is black, and muscovite commonly is colorless to pale gray, as you can see in Figures 1.2 and 1.7, Chapter 1. Both have one excellent cleavage and a vitreous luster, so they are usually easy to identify. Muscovite is an excellent insulator for both heat and electricity and is used widely in the electrical industry. Big sheets were used as windows on old wood stoves and in early automobiles (isinglass).

Chlorite (Hydrous Mg and Fe Al-Silicate)

This dark green mineral exhibits one perfect cleavage, but unlike the micas, thin pieces don't spring back to their original position after being bent; pieces are flexible, but not elastic. Most chlorite occurs as small grains in metamorphic rocks, and you may have to use a hand lens to see that it looks like a dark green mica.

Talc (Hydrous Mg Al-Silicate)

As number one on the Mohs hardness scale, talc is suitable for use even on a baby's soft bottom. Talcum powder is talc. Talc crystals, if large enough, show one perfect cleavage, but in most cases they are too small to see. Instead, the pearly luster (Fig. 1.2F), greasy feel, and softness are distinctive. Talc forms by the alteration (e.g., metamorphism) of preexisting minerals such as olivine, and is the major ingredient in the rock soapstone. You may be familiar with the soapstone carvings of the American Indians (especially peace pipes), Kenyans (decorative plates, bowls, and candle holders), and the Inuits of the Canadian Arctic (Fig. 2.6).

Clays (Hydrous Al-Silicates)

Clay minerals are a significant component of soils, sediment, and sedimentary rocks. But they are not the sort of thing that you would want to put in a display case; in fact, when you dust the display case, you commonly are getting rid of clays! The word *clay* is used in two different ways: it refers to a specific group of minerals and to particles that are extremely small (<0.004 mm [<0.0002 in] diameter). Clay minerals are usually clay-sized particles. Clays are used for all kinds of things, from the manufacture of china and bricks, to stopping leaks in dams, to fillers in paper, paint, medicine (the clay mineral kaolinite is used in Kaopectate™), and chocolate (doesn't that make your mouth water?).

Clays are recognized by their extremely small crystal size, dull luster, softness, and earthy odor. Their colors vary, but the variety most commonly encountered in physical geology labs is the white clay *kaolinite* (Fig. 2.7).

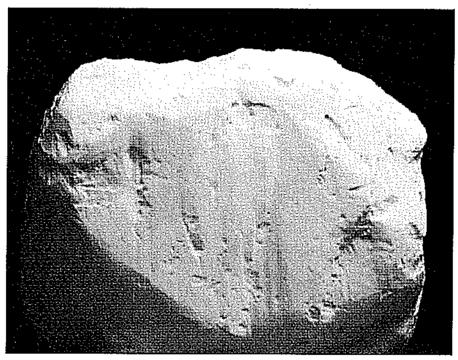


FIGURE 2.7
Kaolinite, a type of clay mineral. The homogeneous appearance of this sample makes it a good example of a **massive** texture: There is no obvious visible structure or color variation apart from the surface scratchings.

Olivine (Mg, Fe Silicate)

Figure 2.8 illustrates a typical sample of olivine. It is yellowish green to green and is granular, being made of a multitude of small grains (crystals). You have to look at individual crystals to see that it has a conchoidal fracture but no obvious cleavage. And if you check the hardness, make sure that little pieces aren't breaking off, because it is hard (H = 6.5 to 7). Most olivine occurs in dark-colored igneous rocks. There is a gem variety of olivine (*peridot*), and some is used for refractory bricks.

Calcite ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$)

These two carbonates are the major minerals in the common sedimentary rocks limestone and dolostone, and their metamorphosed equivalent, marble. Calcite is also one of the most common minerals to form in veins and open cavities in rocks. When formed in such places, large cleavable pieces and beautiful crystals may develop, such as those shown in Figure 1.18, Chapter 1.

If you have a piece of calcite that shows cleavage (chances are you will), the three directions of cleavage not at 90° to each other are a giveaway. Add to that the Mohs hardness of 3, and calcite is easy to identify. The easiest way to distinguish calcite from dolomite is to put a drop of dilute hydrochloric acid (HCl) on them to see if they bubble; calcite bubbles strongly, dolomite not so much, or not at all unless powdered.

FIGURE 2.8
Olivine.

Gypsum ($CaSO_4 \cdot 2H_2O$)

Gypsum ranges from a massive, white to gray, carvable variety known as *alabaster* to a white variety with a silky or satiny luster and distinctive fibrous fracture known as *satin spar* to clear crystals or cleavage fragments known as *selenite* (Fig. 2.9). Its hardness—softer than your fingernail—gives it away. The clusters of crystals can be quite beautiful, but they are so fragile that you have to display them in a safe place. Gypsum is used extensively as the basis for plaster and plaster board. If you have a clay-rich soil in your garden, you may have used it as a soil conditioner. Gypsum is a common evaporite mineral found as thick layers in sedimentary rocks.

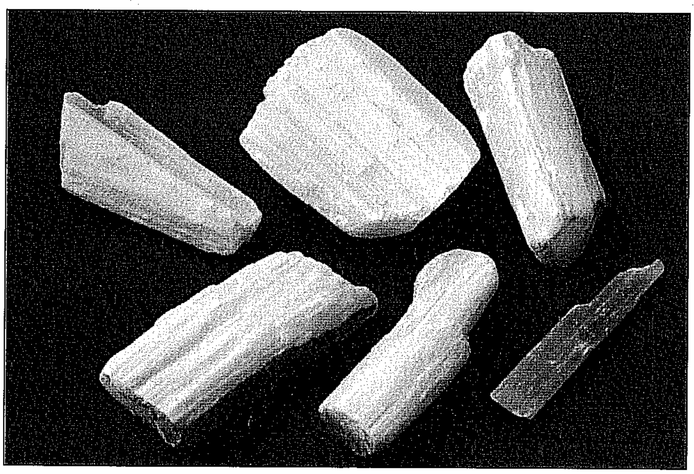
Halite (NaCl)

This is an easy mineral to identify. Just taste it—it's salt. If you don't like the idea of licking where others have licked before, however, check the other properties. It is generally colorless or white, although impurities may add color. It commonly displays perfect cubic cleavage (see Fig. 1.6, Chapter 1) and is soft (H = 2.5). Halite occurs in sedimentary rocks that formed from the evaporation of seawater and commonly is associated with other *evaporite* minerals, such as gypsum. Its principal use is not for a flavoring or for melting ice, but as a source of sodium and chlorine for the chemical industry.

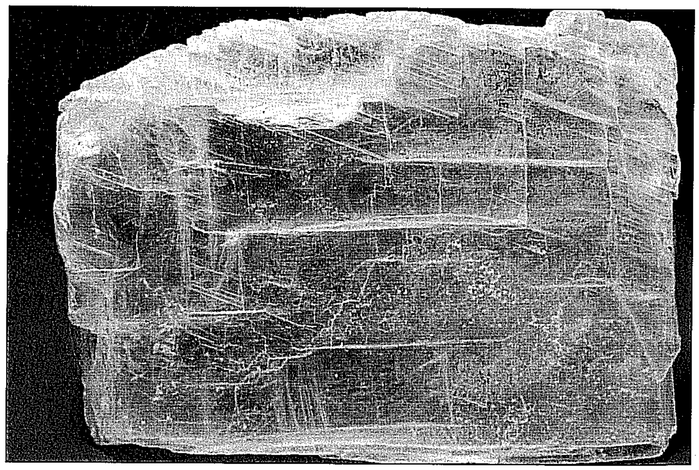
Accessory and Minor Minerals

Fluorite (CaF_2)

Fluorite is a pretty mineral that ranges in color from colorless to pale yellow, light green, or purple, and frequently occurs as either large cubic crystals or octahedral cleavage fragments (Fig. 1.12, Chapter 1). It would make a great gemstone except for its softness (Mohs hardness = 4) and ready ability to cleave. It is used as a flux in making steel and for the manufacture of hydrofluoric acid. Hydrofluoric acid is one of the few substances that dissolves silicate minerals.



A.



B.

FIGURE 2.9
Gypsum. A. Satin spar variety. B. Selenite variety showing one perfect and two poor cleavages.

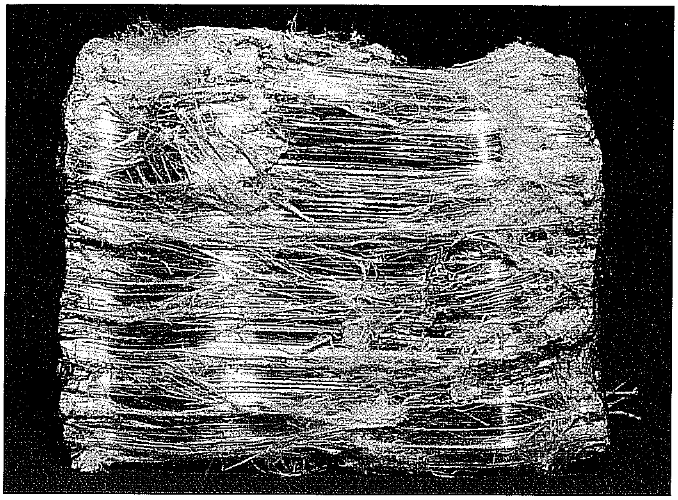


FIGURE 2.10
Serpentine asbestos. Note the fibers.

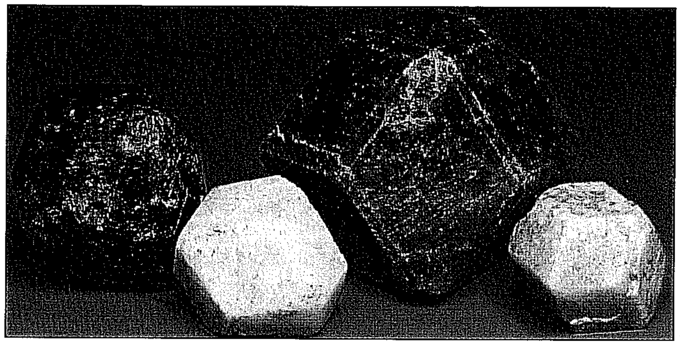


FIGURE 2.11
Twelve-sided crystals (dodecahedrons) of different varieties of garnet.

Serpentine (Hydrous Mg Silicate)

The most familiar type of serpentine is serpentine asbestos (Fig. 2.10), but massive, green serpentine is most common. The greasy to waxy luster (and feel) of massive serpentine is distinctive; its Mohs hardness (H = 3–5) serves to distinguish it from massive talc (H = 1). Massive-veined serpentine is commonly used as a decorative building stone. More than 95 percent of the asbestos produced in the world is serpentine. Studies have shown that health risks from serpentine asbestos are considerably less than from certain types of amphibole asbestos, although the distinction is rarely recognized by the public.

Garnet (Ca, Mg, Fe, and Al Silicate)

Garnet is a metamorphic mineral that almost always occurs as a perfect crystal (Fig. 2.11). However, some crystals are so large that the sample you see in the lab may be just a piece of a crystal. Mohs hardness (H = 6.5–7.5), vitreous to resinous luster, and crystal form help to identify garnet, but be careful of color. A common color is brownish red, but garnet can be black, brown, yellow, green, or other colors. Garnet is used for abrasives (such as in garnet sandpaper) and gemstones.

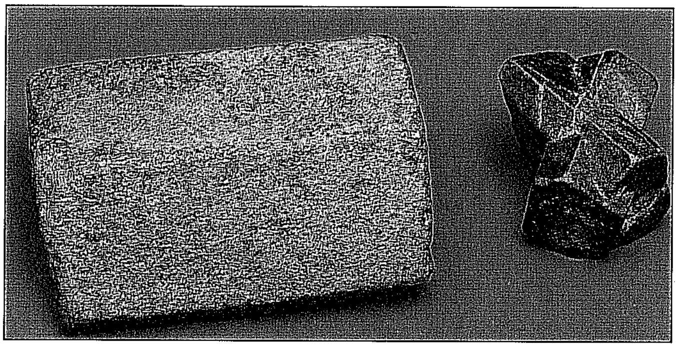


FIGURE 2.12
Crystals of staurolite. Intergrown crystals on right are *twinned.*

Staurolite (Hydrous Fe Al-Silicate)

Like garnet, staurolite almost always occurs as "well-formed" crystals in metamorphic rocks. Dark brownish crystals (Fig. 2.12) are characteristic of this mineral. Intergrown crystals called *twins* are common and are sometimes sold as "fairy crosses."

Kyanite (Al_2SiO_5)

This metamorphic mineral is light blue and forms blade-shaped crystals (Fig. 2.13). It is used in the manufacture of spark plugs, among other things.

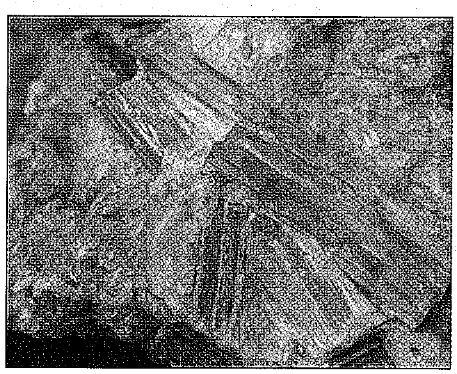


FIGURE 2.13
Kyanite varies from sky blue to blue grey, but frequently shows its *bladed* crystal habit. The mineral surrounding the kyanite is quartz.

Ore Minerals

Hematite (Fe_2O_3)

The red to red-brown streak is the key to identifying hematite, because, as shown in Figure 2.14, it occurs as several strikingly different forms. One form is a reddish brown, soft, earthy material. Another is dull black and hard. A third type, known as *specular hematite,* has a metallic luster and occurs as a mass of small, mica-like scales. However, scratch any hematite, or rub it across a streak plate, and you will see the same red powder. Most hematite occurs in sedimentary rocks (or their metamorphic equivalents) called *iron formations.* It is the most important ore of iron, which is the principal ingredient in steel.

Magnetite (Fe_3O_4)

The only magnetic mineral you are likely to see in this lab is magnetite (Fig. 2.15). But just in case you don't have a magnet, other properties (such as black color and streak, metallic luster on fresh breaks, and moderately high specific gravity) should identify it. Magnetite is a common accessory mineral in igneous and metamorphic rocks. It is an important ore of iron in iron formation and where concentrated by igneous processes.

Limonite (Various Fe Oxides)

Limonite is a general name for a mixture of poorly crystalline, hydrated and nonhydrated iron oxides. Although really a rock, it was once considered to be a distinct mineral. The name applies to yellow, yellow-brown, red or black, dull to metallic, soft to hard material. An example is shown in Figure 2.16. It usually forms by oxidation of iron-bearing minerals, so in essence, it is a rust. It has a yellow-brown streak, which serves to distinguish it from hematite, and is a minor ore of iron.

Galena (PbS)

Figures 1.2A and 1.11A, Chapter 1, show that galena has an obvious metallic luster and three perfect cleavages that intersect at 90°. It also has a very high specific gravity (SG = 7.5). Galena is almost the only ore of lead, which is used in batteries and metal products, and occurs most commonly in veinlike deposits.

Sphalerite (ZnS)

This may be the only mineral you will ever see with six directions of cleavage, although you probably will have a difficult time seeing them all (see Fig. 1.13, Chapter 1). If the cleavage is hard to see, look for the resinous luster (like tree sap); the yellow, brown, or black color; and the yellow-brown streak with its faint, rotten-egg-like odor of hydrogen sulfide. Sphalerite is the most important ore of zinc and commonly is found with galena. Zinc

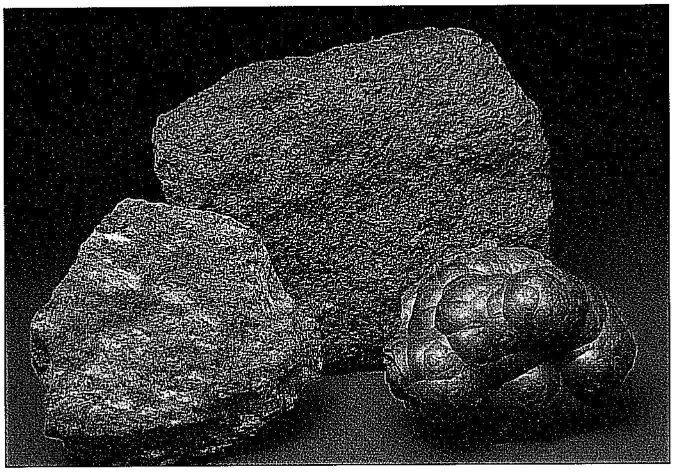


FIGURE 2.14
Three varieties of hematite: specular hematite (left), pisolitic hematite, and botryoidal hematite (right).

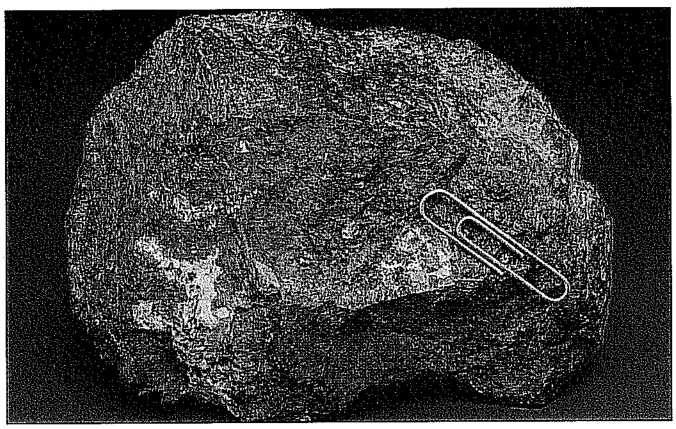


FIGURE 2.15
The lodestone variety of magnetite is a natural magnet strong enough to hold the paper clip.

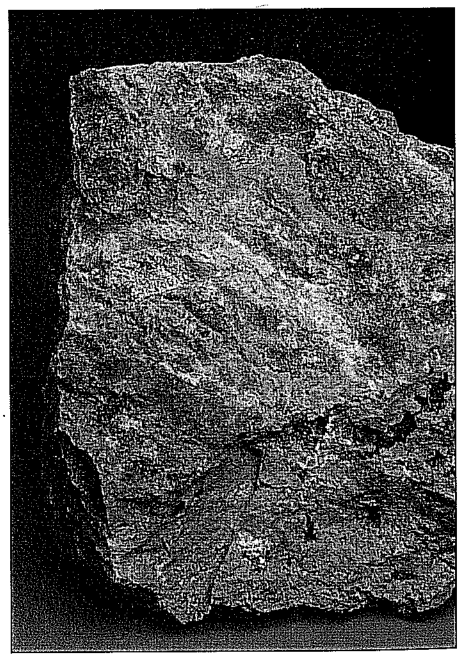


FIGURE 2.16
Limonite.

is used in galvanizing iron or as a metal by itself; it is also used in batteries, paints, dyes, alloys, and dandruff shampoo.

Pyrite (FeS_2)

Pyrite is pale brass-yellow, has a metallic luster, and is called *Fool's gold* by those in the know (who, presumably, are not themselves fools). Crystals in the form of cubes and pyritohedrons (see Fig. 1.17, Chapter 1) are common, but so are irregular masses that show the characteristic color and uneven fracture. Given these properties, a Mohs hardness of 6 to 6.5 will enable you to distinguish it from other yellow sulfide minerals such as chalcopyrite or, should the chance arise, gold. It is a common accessory mineral in igneous, sedimentary, and metamorphic rocks and is concentrated in veins or irregular masses in many places. Pyrite is mined along with the more valuable sulfide minerals with which it occurs, and some of it is used in the production of sulfuric acid.

Chalcopyrite ($CuFeS_2$)

This brass-yellow mineral is distinguished from massive pyrite by its slightly more yellow color and its Mohs hardness of 3.5 to 4. It is one of the most important ores of copper. Copper is used for electrical conductors (such as wire), brass (an alloy with zinc), bronze (an alloy with tin), fittings, sheathings, and other manufactured items. Chalcopyrite occurs in veins and various types of more massive deposits.

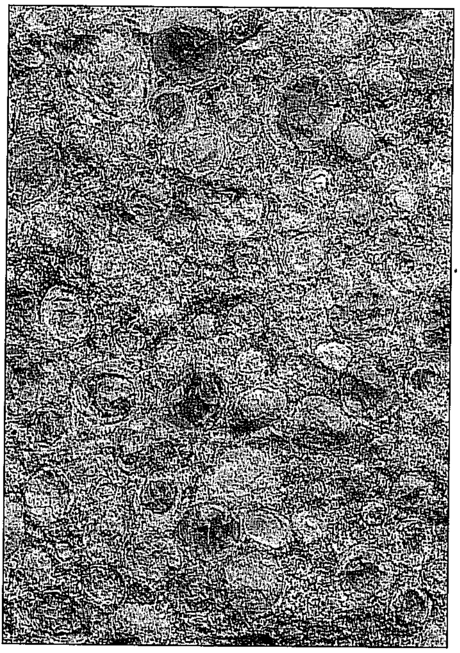


FIGURE 2.17
Bauxite with pea-shaped structures.

Graphite (C)

Graphite is dark gray, silver gray, or black, and is greasy, soft, and soils your fingers or whatever it touches. Mixed with clay, it forms the "lead" in pencils, and mixed with oil, it is a good lubricant. It has other uses as well, including generator brushes, batteries, and electrodes. It is usually found in metamorphic rocks.

Bauxite (Various Al oxides)

Bauxite is really a rock made of several hydrous Al oxide minerals, but it once was regarded as a mineral. It is characterized by pea-shaped structures (Fig. 2.17); it may be white, gray, or red, and usually is soft, dull, and earthy. It forms by extensive weathering in tropical to subtropical climates. It is important because it is the only ore of aluminum, which is used wherever a light, strong metal is needed.

How to Identify Minerals

Warning: The samples you see in lab may, at first glance, look quite different from the photos in the manual. Nature is expert at providing infinite variation in color and shape, and these are the features most easily captured by camera. In addition, certain photos show museum-quality specimens (for example, pyrite in Fig. 1.17), which are too rare and expensive to use in labs. Thus, you will have to identify your mineral specimens using the physical properties that you learned in Chapter 1 and the tables that follow (Tables 2.2A through F). These tables are designed to allow you to use basic observations to quickly narrow the possibilities to just a few choices. In terms of the scientific method, you will first make some observations and form one or several hypotheses regarding the identity of the mineral. Then you will closely examine the descriptions in the tables to guide you toward making additional observations that eliminate certain possibilities and help you settle on the best mineral identification. Finally, check to see that the mineral description correctly matches your sample in all important regards.

In practical terms, the use of the table is illustrated with the following example.

Suppose you have identified the following properties in a mineral:

Luster	**Hardness**	**Streak**
nonmetallic, vitreous	3.5 to 5	white
Cleavage	**Color**	**Other**
four perfect	clear	purplish tinge

The first separation is on the basis of luster. Table 2.2A contains minerals with metallic luster; Tables 2.2B through 2.2F contain minerals with nonmetallic luster (Fig. 2.18). Because the example has nonmetallic luster, the mineral is not in Table 2.2A, and this table can be eliminated.

The second separation is on the basis of hardness. Tables 2.2B through 2.2D contain minerals with hardnesses less than 5.5 (that is, softer than glass or most knives), so our unknown, with hardness between 3.5 and 5, must be in one of them.

The next thing to look at is streak. The white streak eliminates Table 2.2B, which contains minerals with colored streaks. Tables 2.2C and 2.2D are all that remain.

The last major distinction is on the basis of cleavage. Table 2.2C is for minerals with no cleavage, and 2.2D is for minerals with one or more cleavages. Because the example has four good cleavages, it must be in Table 2.2D; there is only one choice, fluorite.

NOTE: The most useful properties for identifying a given mineral are underlined in the tables. "*H*" in the descriptions refers to *hardness,* and "*S.G.*" to *specific gravity.* Some minerals appear in more than one table, because they may or may not show a particular property in the sample you examine. For example, hematite appears in Table 2.2A, because one variety has a metallic luster, and in Table 2.2B, because another variety does not. Hornblende, augite, and bauxite are listed in two places, because their hardness may be greater or less than 5.5.

- Check luster.
  - → Metallic? Go to Table 2.2A
  - → Non-metallic?
    - ↓ Check hardness.
      - → Hardness < 5.5? Check streak.
        - → Colored streak: Table 2.2B
        - → White to faintly colored streak? Check cleavage.
          - → No cleavage: Table 2.2C
          - → One or more cleavages: Table 2.2D
      - → Hardness > 5.5: White/whitish streak. Check cleavage.
        - → No cleavage: Table 2.2E
        - → One or more cleavages: Table 2.2F

FIGURE 2.18
A flow-chart guide to the mineral identification tables.

Figure 2.18 is a flow chart that can be used to lead you quickly to the correct table. Table 2.3 gives the chemical groupings and formulae of the minerals in Tables 2.2 A–F.

Insecure About Mineral Identification?

As you work through this lab and the next few that require rock identification, you may feel some insecurity in your mineral identifications. How can you be *sure* that you are correct? Well, all geologists feel this unease at first. With experience, however, confidence and skill grow. This is why every geologist tries to see as many different samples as possible. If you continue in geology, you will also encounter more sophisticated tools used to make more definitive identifications. Geology majors use expensive petrographic microscopes to identify unknown minerals. Graduate students and other researchers use advanced technology to help identify pesky but potentially important unknown minerals. For example, electron microprobes zap samples with electron beams to work out their chemical composition. If more information is needed, an X-ray diffractometer uses X-rays to map out the atomic structure of unknown minerals. Such techniques either provide a definitive mineral name or, with luck, uncover a mineral that is new to science!

TABLE 2.2 A

METALLIC LUSTER OR TARNISHED (DULLED) METALLIC LUSTER*

Hardness	*Streak*	*Cleavage*	*Other*	*Mineral*
Less than 5.5	Black, greenish black brownish black, or gray	One (but not always visible)	Gray to black; H = 1; S.G. = 2.5; may have dull luster; greasy feel, soils paper and fingers. **See p. 23.** Also in Table 2.2B.	**Graphite** C
		Three (excellent cubic cleavage)	Silvery gray; H = 2.5; S.G. = 7.5; cubic crystals common. **See p. 22.**	**Galena** PbS
		None	Black to brownish black; H = 5.5; S.G. = 4.6; luster may be submetallic; brownish-black streak; weakly magnetic.	**Chromite** $FeCr_2O_4$
		None	Golden yellow or greenish yellow; H = 3.5 to 4; S.G. = 4.2; massive. **See p. 23.**	**Chalcopyrite** $CuFeS_2$
	Yellow-brown	None	Dark brown to black; H = 5 to 5.5; S.G. = 4; massive or rounded forms with radiating, fiberlike layers.	**Goethite** FeO(OH)
	Copper-red	None	Copper to brown, may have green coating; H = 2.5 to 3; S.G. = 8.9; malleable, sectile.	**Native Copper** Cu
Greater than 5.5	Greenish black to black	None	Brass-yellow; H = 6 to 6.5; S.G. = 5.0; massive or as crystals (cube, pyritohedron). **See p. 23.**	**Pyrite** FeS_2
	Black	None	Dark gray to black; H = 6; S.G. = 5.2; may have dull luster if surface not fresh; attracted to magnet. **See p. 22.**	**Magnetite** Fe_3O_4
	Red-brown	None	Steel gray to dull red; H = 6; S.G. = 5.0; may be micaceous (tiny flakes) or massive. **See p. 22.** Also listed in Table 2.2B.	**Hematite** Fe_2O_3

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

*Like metals, many minerals with a metallic luster oxidize or tarnish as they react with moisture and various compounds in air. This transforms metallic lusters into dull lusters. Geologists in the field break open rocks to expose fresh surfaces (that's why we carry rock hammers!). In this lab you are probably not allowed to smash the samples, so if you have a sample with a dull luster that looks like it could almost be metallic, take a streak and check out the distinctive properties listed in this table.

TABLE 2.2B

NONMETALLIC LUSTER • HARDNESS LESS THAN 5.5 • STREAK—COLORED

Streak	*Cleavage*	*Other*	*Mineral*
Gray-black	One (not always visible)	Gray to black; H = 1; S.G. = 2.5; may have metallic luster; greasy feel; soils paper and fingers. **See p. 23.** Also listed in Table 2.2A.	**Graphite** C
Red-brown	None	Red to reddish brown; H = 1.5 to 5.5; S.G. = 5.0; dull luster; earthy or oolitic (containing spherical structures having diameters of 0.25 to 2 mm) masses. **See p. 22.** Also listed in Table 2.2A.	**Hematite** Fe_2O_3
Yellow-brown	None	Yellow-brown, orange-brown to dark brown; H = 1.5 to 5.5; S.G. = 3.6 to 4.0; dull luster, earthy, may be a rustlike coating. Not a true mineral. Limonite is a general name for several rustlike, hydrous iron oxides. **See p. 22.**	**Limonite** Various hydrous iron oxides
Yellow	None	Yellow; H = 1.5 to 2.5; S.G. = 2.1; resinous or vitreous luster.	**Sulfur** S
	Six-may be difficult to count	Light yellow, yellowish brown, black; H = 3.5 to 4; S.G. = 4.0; resinous or vitreous luster; faint odor of hydrogen sulfide (rotten eggs). **See p. 22.**	**Sphalerite** ZnS
Blue	None	Azure blue; H = 3.5 to 4; S.G. = 3.8; occurs as coatings, masses, or tiny crystals, commonly with malachite, and commonly as an accessory mineral.	**Azurite** $Cu_3(CO_3)_2(OH)_2$
Green	None	Bright green; H = 3.5 to 4; S.G. = 4.0; occurs as coatings, masses, or tiny crystals, commonly with azurite, and commonly as an accessory mineral.	**Malachite** $Cu_2CO_3(OH)_2$

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

TABLE 2.2C

NONMETALLIC LUSTER • HARDNESS LESS THAN 5.5 • STREAK—WHITE, WHITISH, OR FAINTLY COLORED • NO APPARENT CLEAVAGE

Cleavage	*Other*	*Mineral*
None or Indistinct	White; H = 1 to 2.5; S.G. = 2.6; dull luster; greasy feel, earthy odor, powdery. **See p. 19.**	**Kaolinite** $Al_2Si_2O_5(OH)_4$
	White, gray, or apple green; pearly luster; H = 1 (or 2 in some impure varieties); S.G. = 2.7 to 2.8; greasy feel; may have light gray streak. **See p. 19.** Also listed in Table 2.2D.	**Talc** $Mg_3Si_4O_{10}(OH)_2$
	White; H = 2; S.G. = 2.3; Satiny or silky luster and fibrous fracture indicates satin spar variety of gypsum. An opaque, white to gray, massive variety is alabaster. **See p. 20.** Also in Table 2.2D.	**Gypsum** $CaSO_4 \cdot 2H_2O$
	Reddish brown to brown color; H = 1 to 6; S.G. = 2.0 to 2.5; dull to earthy luster; massive or with pea-shaped structures; may scratch glass with difficulty. Not a true mineral, but a rock consisting of several similar minerals. May have faint, red-brown streak. **See p. 23.** Also listed in Table 2.2E.	**Bauxite** Mixture of hydrous aluminum oxides
	Multicolored green, gray, black; H = 3 to 5; S.G. = 2.5 to 2.6; dull to greasy luster; slight greasy feel; massive to fibrous (asbestos). **See p. 21.**	**Serpentine** $Mg_3Si_2O_5(OH)_4$
	Light green to medium green, brown, yellow; vitreous luster; H = 5; S.G. = 3.2; six-sided crystals common; may show one poor cleavage.	**Apatite** $Ca_5(PO_4)_3(F,Cl,OH)$
	Buff, gray, white, pinkish; H = 3.5 to 4; S.G. = 2.8 to 2.9; small, rhombohedral crystals or massive; three cleavages, not at 90°, may be indistinct in massive varieties; reacts slowly or not at all with dilute hydrochloric acid unless powdered. **See p. 20.** Also listed in Table 2.2D.	**Dolomite** $CaMg(CO_3)_2$

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

TABLE 2.2D

NONMETALLIC LUSTER • HARDNESS LESS THAN 5.5 • STREAK—WHITE, WHITISH, OR FAINTLY COLORED • ONE OR MORE CLEAVAGES

Cleavage	*Other*	*Mineral*
One	Light apple green, gray, white; pearly luster; H = 1; S.G. = 2.7 to 2.8; cleavage not evident in finely crystalline, massive varieties; may have light gray streak; greasy feel. **See p. 19.** Also listed in Table 2.2C.	**Talc** $Mg_3Si_4O_{10}(OH)_2$
	Green to blackish green; dull to vitreous or pearly luster; H = 2 to 2.5; S.G. = 2.6 to 3.3; may have faint green-yellow streak; cleavage flakes are flexible but not elastic; finely crystalline aggregates common. **See p. 19.**	**Chlorite** Hydrous Mg-Fe-Al silicate
	Black to brownish black; vitreous luster; H = 2.5 to 3.0; S.G. = 2.8 to 3.2; may have faint brown-gray streak; individual crystals commonly are small and cleavage surfaces are wavy; perfect cleavage; transparent, flexible and elastic in thin sheets. **See p. 19.**	**Biotite** Hydrous K-Mg-Fe-Al silicate
	Colorless, silvery white, brownish silvery white; vitreous luster; H = 2.0 to 2.5; S.G. = 2.8 to 2.9; perfect cleavage; transparent, flexible, and elastic in thin sheets. **See p. 19.**	**Muscovite** Hydrous K-Al silicate
	Clear, white, light gray; H = 2; S.G. = 2.3; vitreous to pearly luster; brittle sheets; one perfect cleavage, two poor cleavages indicate the selenite variety of gypsum; alabaster is massive, satin spar is fibrous. **See p. 20.** Also listed in Table 2.2C.	**Gypsum** $CaSO_4 \cdot 2H_2O$
Two	Black; H = 5 to 6; S.G. = 3.0 to 3.4; vitreous luster; may have faint green-gray streak; two perfect cleavages meet at 124° and 56°; cleavage faces stepped rather than smooth; splintery appearance; may have greenish black to black streak. An amphibole. **See p. 18.** Also listed in Table 2.2F.	**Hornblende** Hydrous Na-Ca-Mg-Fe-Al silicate
	Black to dark green; H = 5 to 6; S.G. = 3.2 to 3.4; vitreous to dull luster; two imperfect cleavages meet at nearly 90°. A pyroxene. Another pyroxene, diopside, is similar but is light grayish green. **See p. 18.** Also listed in Table 2.2F.	**Augite** Ca-Mg-Fe silicate
Three	Clear to gray to red; H = 2.5; S.G. = 2.2; three perfect cleavages meet at 90° (cleavage surfaces may dull and partially dissolve with prolonged exposure); salty taste. **See p. 20.**	**Halite** NaCl
	Clear, white, light gray; H = 2; S.G. = 2.3; vitreous to pearly luster; brittle sheets; one perfect cleavage, two poor cleavages may be evident in clear pieces. **See p. 20.** Also in Table 2.2C.	**Gypsum** $CaSO_4 \cdot 2H_2O$
	Colorless or white; H = 3 to 3.5; S.G. = 4.5—heavy for a nonmetallic; tabular crystals, roselike array of crystals, or massive; three cleavages meet at 90°.	**Barite** $BaSO_4$
	Clear, white, less commonly other colors; vitreous luster; H = 3; S.G. = 2.7; three perfect cleavages form rhombic cleavage fragments; double image seen through clear pieces; reacts strongly with dilute hydrochloric acid. **See p. 20.**	**Calcite** $CaCO_3$
	Buff, gray, white, pinkish; H = 3.5 to 4; S.G. = 2.8 to 2.9; small, rhombohedral crystals or massive; three cleavages, not at 90°, may be indistinct; reacts slowly or not at all with dilute hydrochloric acid unless powdered. **See p. 20.** Also listed in Table 2.2C.	**Dolomite** $CaMg(CO_3)_2$
Four	Purple, green, blue, yellow, clear; H = 4; S.G. = 3.2; vitreous luster; perfect cleavage up to four directions may yield octahedral cleavage fragments; may occur as cubic crystals. **See p. 20.**	**Fluorite** CaF_2

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

TABLE 2.2E
NONMETALLIC LUSTER • HARDNESS GREATER THAN 5.5 • STREAK—WHITE OR WHITISH IF SOFTER THAN STREAK PLATE • NO CLEAVAGE

Cleavage	*Other*	*Mineral*
None	Brown, pink, blue, gray; H = 9; S.G. = 4.0; six-sided prismatic crystals; *ruby* (red) and *sapphire* (commonly blue) are gem varieties.	**Corundum** Al_2O_3
	Black, pink, blue, green, brown; vitreous luster; H = 7 to 7.5; S.G. = 3.0 to 3.3; slender crystals with triangular cross sections and striated sides.	**Tourmaline** Complex hydrous silicate
	Reddish brown, yellowish tan; vitreous to resinous luster; H = 6.5 to 7.5; S.G. = 3.6 to 4.3; twelve-sided crystals common. Broken surfaces may resemble cleavage in some samples. **See p. 21.**	**Garnet** Ca-Mg-Fe-Al silicate
	Red-brown to brownish black; vitreous, resinous, or dull luster; H = 7 to 7.5; S.G. = 3.7; prismatic and X- or cross-shaped crystals. **See p. 21.**	**Staurolite** Hydrous Fe-Al silicate
	Coarsely crystalline varieties: clear, milky, white, purple, smokey, pink; transparent to translucent; vitreous luster; H = 7; S.G. = 2.7; conchoidal fracture; usually massive; sometimes occurs as six-sided crystals; milky = *milky quartz,* purple = *amethyst,* smoky = *smoky quartz,* pink = *rose quartz.* Microcrystalline varieties: *chert* (gray, dull luster), *flint* (black, dull luster), *chalcedony* (brown to gray, translucent, waxy luster), *agate* and *onyx* (varicolored bands, vitreous luster). **See p. 17 and 18.**	**Quartz** SiO_2
	Olive green to yellow green; vitreous to dull luster; H = 6 1/2 to 7 but difficult to test because granular; S.G. = 3.3 to 4.4. **See p. 20.**	**Olivine** $(Mg,Fe)_2SiO_4$
	Colorless, white, or pale shades of yellow, green, red, or blue; may show play of colors; vitreous to resinous luster; H = 5 to 6; S.G. = 2.0 to 2.3; rounded forms common, but also massive; conchoidal fracture. A mineraloid.	**Opal** $SiO_2 \cdot nH_2O$
	Reddish brown to brown color; H = 1 to 6; S.G. = 2.0 to 2.5; dull to earthy luster; massive or with pea-shaped structures; may scratch glass with difficulty. Not a true mineral, but a rock consisting of several similar minerals. **See p. 23.** Also listed in Table 2.2C.	**Bauxite** Mixture of hydrous aluminum oxides

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

TABLE 2.2F
NONMETALLIC LUSTER • HARDNESS GREATER THAN 5.5 • STREAK—WHITE OR WHITISH IF SOFTER THAN STREAK PLATE • ONE OR TWO CLEAVAGES

Cleavage	*Other*	*Mineral*
One	Colorless, yellow, brown, pink, bluish; H = 8; S.G. = 3.4 to 3.6; vitreous luster; elongate crystal prisms with pointed ends and striated side faces.	**Topaz** $Al_2SiO_4(OH,F)_2$
	Bluish green, yellow, white, pink; H = 7.5 to 8; S.G. = 2.7 to 2.8; elongate, six-sided crystal prisms with flat ends common.	**Beryl** $Be_3Al_2(Si_6O_{18})$
	Light blue to greenish blue; vitreous luster; H = 5 parallel to long direction of crystal, seven across crystal; blade-shaped crystals; one cleavage. **See p. 21.**	**Kyanite** Al_2SiO_5
	White, pale green, brown; H = 6 to 7; S.G. = 3.2; long, slender crystals, commonly as groups of parallel crystals.	**Sillimanite** Al_2SiO_5
Two	Salmon-pink, white, gray, green; vitreous luster; H = 6; S.G. = 2.5 to 2.6; two cleavage directions meet at nearly right angles; no striations. **See p. 16.**	**Potassium feldspar** $KAlSi_3O_8$
	White to dark gray, sometimes buff; vitreous luster; H = 6; S.G. = 2.6 to 2.8; two cleavage directions meet at nearly right angles; some cleavage faces have perfectly straight, parallel striations, which show up in reflected light. **See p. 16.**	**Plagioclase feldspar** $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$
	Pistachio green, yellowish green; H = 6 to 7; S.G. = 3.3 to 3.5; elongate crystals or finely crystalline masses.	**Epidote** Hydrous Ca-Fe-Al silicate
	Black; H = 5 to 6; S.G. = 3.0 to 3.4; vitreous luster; may have faint green-gray streak; two perfect cleavages meet at 124° and 56°; cleavage faces stepped rather than smooth, giving splintery appearance; may have faint greenish-gray streak. An amphibole. **See p. 18.** Also listed in Table 2.2D.	**Hornblende** Hydrous Na-Ca-Mg-Fe-Al silicate
	Black to dark green; H = 5 to 6; S.G. = 3.2 to 3.4; vitreous to dull luster; two imperfect cleavages meet at nearly 90°. A pyroxene. Another pyroxene, *diopside,* is similar but is light gray to light grayish green. **See p. 18.** Also listed in Table 2.2D.	**Augite** Ca-Mg-Fe silicate

Underlined properties are most useful in mineral identification. H = hardness (Mohs). S.G. = specific gravity.

TABLE 2.3
CHEMICAL GROUPING AND FORMULAE OF THE MINERALS IN TABLES 2.2A–F

Chemical Group	*Mineral Name*	*Chemical Formula*
Elements	Copper	Cu
	Sulfur	S
	Graphite	C
Sulfides	Galena	PbS
	Sphalerite	ZnS
	Chalcopyrite	$CuFeS_2$
	Pyrite	FeS_2

Oxides and hydroxides	Corundum	Al_2O_3
	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
	Chromite	$FeCrO_4$
	Goethite	$FeO(OH)$
Halides	Halite	$NaCl$
	Fluorite	CaF_2
Carbonates	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
	Malachite	$Cu_2CO_3(OH)_2$
	Azurite	$Cu_3(CO_3)_2(OH)_2$
Sulfates	Barite	$BaSO_4$
	Gypsum	$CaSO_4 \cdot 2H_2O$
Phosphates	Apatite	$Ca_5(PO_4)_3(F,C,OH)$
Silicates[1]		
Isolated SiO_2 tetrahedra	Olivine	$(Mg,Fe)_2SiO_4$
	Garnet	$(Mg,Fe,Ca)_3(Al,Fe)_2(SiO_4)_3$
	Kyanite and sillimanite	Al_2SiO_5
	Topaz	$Al_2SiO_4(OH,F)_2$
	Staurolite	$Fe_2Al_9O_6(SiO_4)_4(O,OH)_2$
Double SiO_2 tetrahedra	Epidote	$Ca_2(Fe,Al)Al_2O(SiO_4)(Si_2O_7)(OH)$
Rings of SiO_2 tetrahedra	Tourmaline	$(Na,Ca)(Li,Mg,Al)(Al,Fe)(BO_3)_2(Si_6O_{18})(OH)_4$
	Beryl	$Be_3Al_2(Si_6O_{18})$
Single chains of SiO_2 tetrahedra (Pyroxene group)	Augite	$Ca(Mg,Fe)(SiO_3)_2$
Double chains of SiO_2 tetrahedra (Amphibole group)	Hornblende	$(Ca,Na)_{2-3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2$
Sheet of SiO_2 tetrahedra	Serpentine	$Mg_3Si_2O_5(OH)_4$
	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Talc	$Mg_3Si_4O_{10}(OH)_2$
	Muscovite	$KAl(AlSi_3O_{10})(OH)_2$
	Biotite	$K_2(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
	Chlorite	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)_6$
Framework of SiO_2 tetrahedra	Quartz	SiO_2
	Opal	$SiO_2 \cdot nH_2O$
	K-feldspar	$KAlSi_3O_8$
	Plagioclase feldspar	$NaAlSi_3O_8$-$CaAl_2Si_2O_8$

[1]The silicates are grouped according to the way in which the silica (SiO_2) tetrahedra are arranged in their crystal structures. Many of the silicates have variable chemical compositions, and the formulae given in the table may be representative only.