CHAPTER 1

PROPERTIES OF MINERALS

Materials Needed

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

To understand most geologic processes, we first must understand minerals. These are the basic chemical entities that make up the Earth. Minerals differ from each other in chemical composition and atomic arrangement, and these factors produce distinctive physical properties that enable minerals to be identified. The most useful physical properties for identifying minerals are examined in this chapter. In Chapter 2, these properties are used to identify minerals.

What is a Mineral?

A **mineral** is a naturally occurring compound or chemical element made of atoms arranged in an orderly, repetitive pattern. Its chemical composition is expressed with a chemical formula (symbols for important elements are given on the back endsheet). Both chemical composition *and* atomic arrangement characterize a mineral and determine its physical properties. Most minerals form by inorganic processes, but some, identical in all respects to inorganically formed minerals, are produced by organic processes (for example, the calcium carbonate in clam shells). A few naturally occurring substances called **mineraloids** have characteristic chemical compositions, but are amorphous; that is, atoms are *not* arranged in regular patterns. Opal is an example.

The precise chemical composition and internal atomic architecture that defines each mineral also directly determines its outward appearance and physical properties. Thus, in most cases, general appearance and a few easily determined physical properties are sufficient to identify the mineral.

Physical Properties

Color, luster, streak, hardness, cleavage, fracture, and crystal form are the most useful physical properties for identifying most minerals. Other properties—such as reaction with acid, magnetism, specific gravity, tenacity, taste, odor, feel, and presence of striations—are helpful in identifying certain minerals.

Color

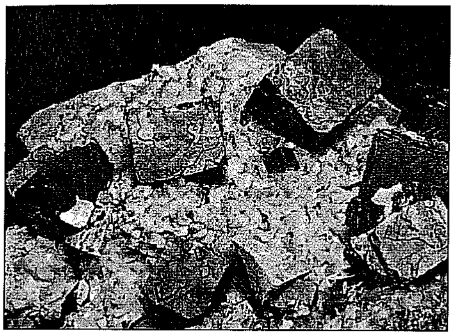
Color is the most readily apparent property of a mineral, but BE CAREFUL. Slight impurities or defects within the crystal structure determine the color of many minerals. For example, quartz can be colorless, white, pink, purple, green, gray, or black (Fig. 1.1). Color generally is diagnostic for minerals with a metallic luster (defined on next page) but may vary quite a bit in minerals with a nonmetallic luster. **Check the other properties before making an identification.**

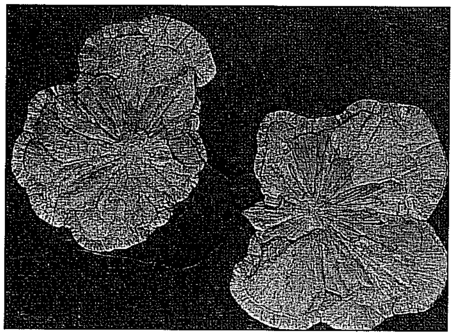
FIGURE 1.1
Varieties of quartz with different colors: amethyst (purple); rock crystal (clear); smoky (black).

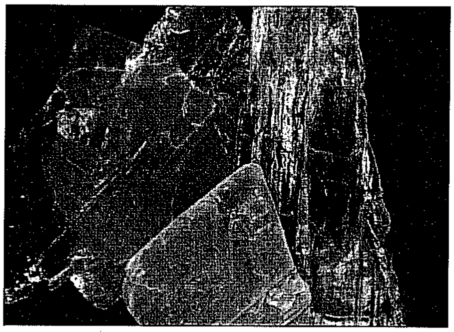
Luster

Luster describes the appearance of a mineral when light is reflected from its surface. Is it shiny or dull; does it look like a

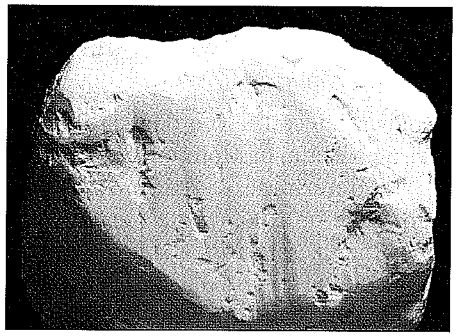
FIGURE 1.2
Types of luster: Metallic (A. galena [dark mineral] and B. pyrite); Nonmetallic, vitreous (C. muscovite and D. biotite); E. Nonmetallic, dull (kaolinite); F. Nonmetallic, pearly (talc); G. Nonmetallic, waxy (jasper); H. Nonmetallic, resinous (sphalerite).

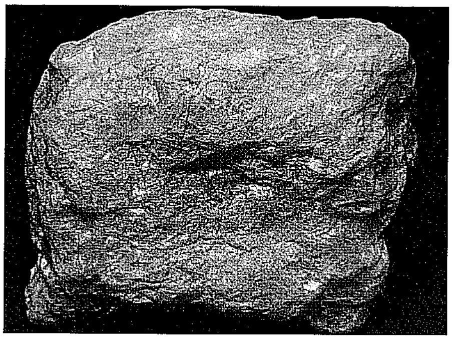

A. Metallic (galena)

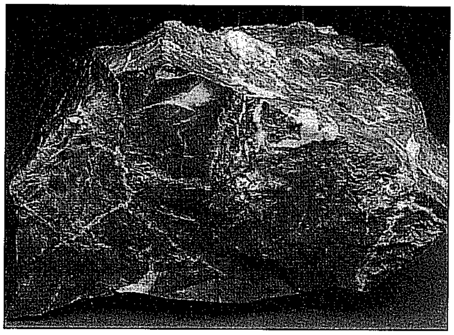

B. Metallic (pyrite)

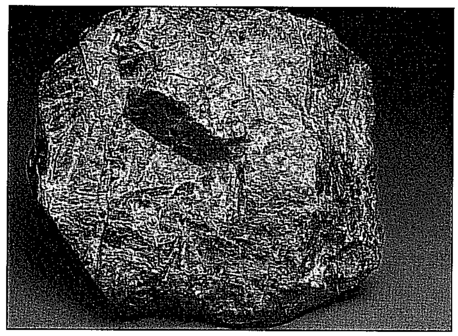

C. Nonmetallic, vitreous (muscovite)


D. Nonmetallic, vitreous (biotite)


E. Nonmetallic, dull (kaolinite)


F. Nonmetallic, pearly (talc)


G. Nonmetallic, waxy (jasper)


H. Nonmetallic, resinous (sphalerite)

metal or like glass? Most minerals have either a **metallic** or **nonmetallic** luster. As you will see, the first thing you must determine before a mineral can be identified using the tables in Chapter 2 is whether its luster is metallic or nonmetallic.

Minerals with a metallic luster look like a metal, such as steel or copper (Fig. 1.2A, B). They are opaque, even when looking at a thin edge. Many metallic minerals become dull looking when they are exposed to air for a long time (like silver, they tarnish). To determine whether or not a mineral has a metallic luster, therefore, you must look at a recently broken part of the mineral.

Minerals with nonmetallic luster can be any color. At first, you may have difficulty determining whether some black minerals have metallic or nonmetallic luster. However, thin pieces or edges of minerals with nonmetallic luster generally are translucent or transparent to light, and even thick pieces give you the sense that the reflected light has entered the mineral a bit before being reflected back. There are several types of nonmetallic lusters. *Vitreous luster* is like that of glass (Fig. 1.2C, D). Remember that glass can be almost any color, including black, so don't be fooled by the color. A *dull luster* has an earthy appearance caused by weak or diffuse reflection of light (Fig. 1.2E). Other nonmetallic lusters include: *pearly luster,* like a pearl or the inside of a fresh clam shell (Fig. 1.2F); *greasy luster,* as though covered by a coat of oil; *waxy luster,* like paraffin (Fig. 1.2G); and *resinous luster,* like resin or tree sap (Fig. 1.2H).

HARDNESS

Hardness is the resistance of a smooth surface to abrasion or scratching. A harder mineral scratches a softer mineral, but a softer one does not scratch a harder one. To determine the hardness of a mineral, something with a known hardness is used to scratch, or be scratched by, the unknown. The minerals in the Mohs Hardness Scale (Table 1.1) are used as standards for comparison. The Mohs hardnesses are also given for some common items, which you can use to determine the hardness of an

TABLE 1.1
SCALE OF HARDNESS

Mohs Hardness Scale

10	Diamond
9	Corundum
8	Topaz or Beryl
7	Quartz
6	Orthoclase feldspar
5	Apatite
4	Fluorite
3	Calcite
2	Gypsum
1	Talc

Mohs Hardness of Common Items

These usefully constrain hardnesses of many common minerals.

Streak plate	6.5 to 7
Steel knife	5 to 6
Glass	5 to 5.5
Copper coin	3.5
Fingernail	2 to 2.5

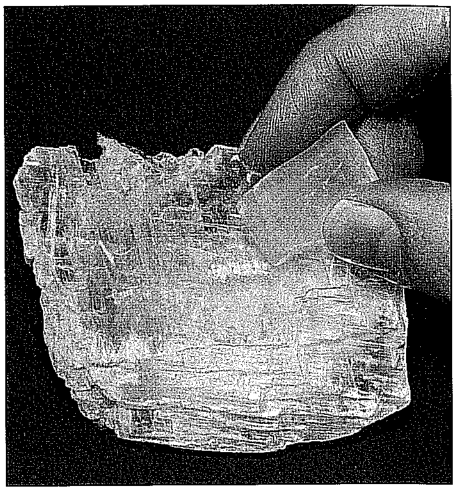


FIGURE 1.3
The harder white mineral (calcite) scratches the softer one (gypsum).

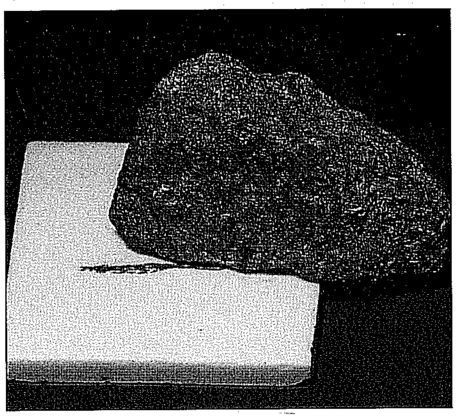


FIGURE 1.4
The streak of this dark gray mineral (hematite), obtained by rubbing it on the white streak plate, is reddish brown.

unknown mineral if you don't happen to have a pocketful of Mohs minerals.

To determine its hardness, run a sharp edge or a point of a mineral with known hardness across a smooth face of the mineral to be tested (Fig. 1.3). Do not scratch back and forth like an eraser, but press hard and slowly scratch a line, like you are trying to etch a groove in glass. Make sure that the contact points of both minerals are the minerals you intend to test, and not impurities. Also, make sure that the mineral has actually been scratched. Sometimes powder of the softer mineral is left on the harder mineral and gives the appearance of a scratch on the harder one. Brush the tested surface with your finger to see if a groove or scratch remains. You may need to use a hand lens or magnifying glass to see whether a scratch was made. If two minerals have the same hardness, they may be able to scratch each other.

A piece of window glass is commonly used in geology labs as a standard for determining hardness. There are several reasons for this: 1) it's easy to see a scratch on glass; 2) the hardness of glass (5 to 5½) is midway on the Mohs scale; and 3) glass is inexpensive and easily replaced. In fact, you will discover that the hardness of a mineral when compared to glass is one of the principal bases in identifying a mineral using the determinative tables in Chapter 2. Put the piece of glass on a stable, flat surface such as a tabletop. Then rub the mineral on the glass, and check to see if the glass was scratched. DO NOT TRY TO SCRATCH THE MINERAL WITH THE GLASS, because glass chips easily.

More sophisticated methods than the scratch test have been developed to determine hardness; Figure 1.5 illustrates how some of the minerals of the Mohs scale compare with their hardnesses, as determined by another method. As you can see, Friedrich Mohs, who devised the scale in 1822, did a pretty good job of selecting minerals so that the intervals between adjacent minerals on his scale were consistent.

STREAK

Streak is the color of the mineral when finely powdered; it may or may not be the same color as the mineral. Streak is more helpful for identifying minerals with metallic lusters, because those with nonmetallic lusters generally have a colorless or light-colored streak that is not very diagnostic. Streak is obtained by scratching the mineral on an unpolished piece of white porcelain called a streak plate (Fig. 1.4). Because the streak plate is harder than most minerals, rubbing the mineral across the plate produces a powder of that mineral. When the excess powder is blown away, what remains is the color of the streak. Because the streak of a mineral is usually the same, no matter what the color of the mineral, streak is commonly more reliable than color for identification.

CLEAVAGE AND FRACTURE

The way in which a mineral breaks is determined by the arrangement of its atoms and the strength of the chemical bonds holding them together. Because these properties are unique to the mineral, careful observation of broken surfaces may aid in mineral identification. A mineral that exhibits **cleavage** consistently breaks, or *cleaves,* along parallel flat surfaces called **cleavage planes.** A mineral **fractures** if it breaks along random, irregular surfaces. Some minerals break only by fracturing, while others both cleave and fracture.

The mineral halite (sodium chloride [NaCl], or salt) illustrates how atomic arrangement determines the way a mineral breaks. Figure 1.6 shows the arrangement of sodium and chlorine atoms in

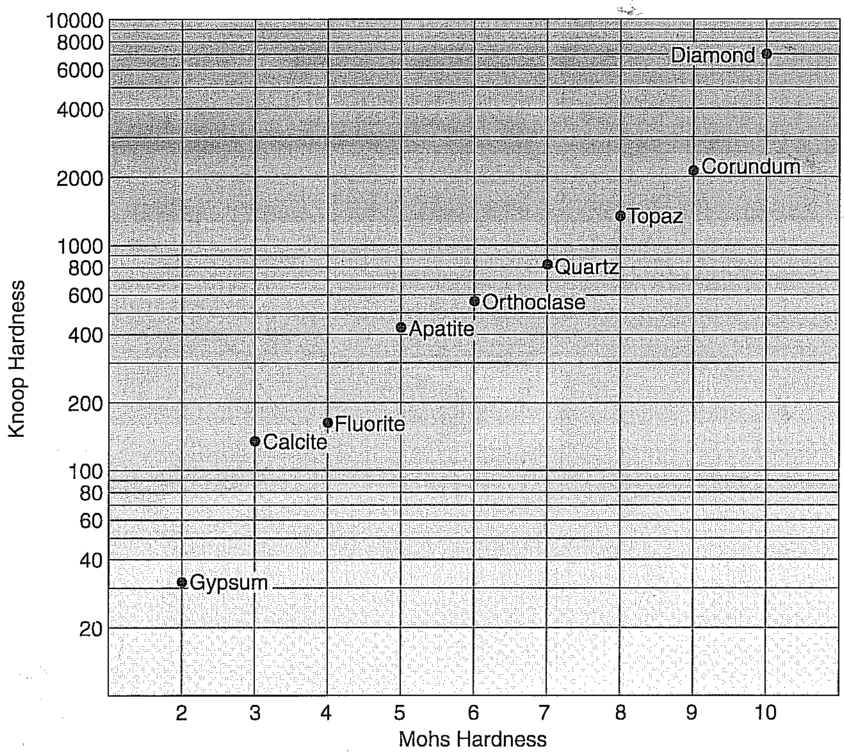
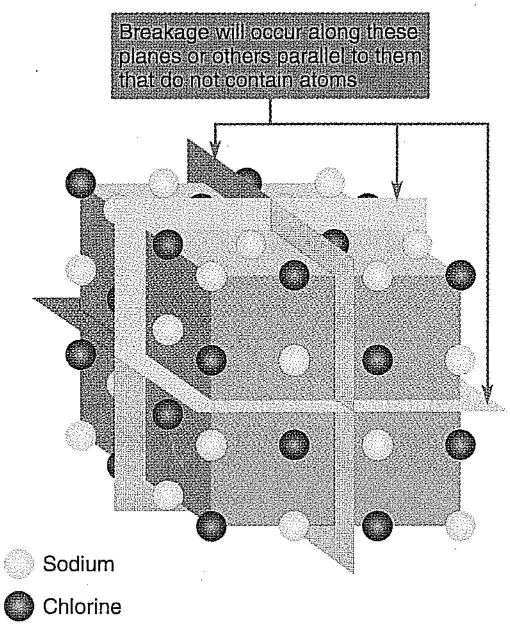


FIGURE 1.5
Comparison between Mohs-scale hardness and "actual" hardness (Knoop hardness). Note that "actual" hardness is shown with a logarithmic scale.

halite. Notice that there are planes with atoms and planes without atoms. When halite breaks, it breaks parallel to the planes with atoms but along the planes without atoms. Because there are three *directions* in which atom density is equal, halite has three **directions of cleavage,** each at 90° to each other. The *number of cleavage directions* and the angles between them are important in mineral identification because they reflect the underlying atomic architecture that defines each mineral.

Cleavage planes, as flat surfaces, are easily spotted by turning a sample in your hand until you see a single flash of reflected light from across the mineral surface. Individual cleavage surfaces may extend across the whole mineral specimen (Fig. 1.7) or, more commonly, they may be offset from each other by small amounts, as illustrated in Figure 1.8. Even though they are offset, they work as tiny mirrors that create the single flash seen in Figure 1.9. Figures 1.10 and 1.11A also show offset cleavage surfaces. Cleavage quality is described as *perfect, good,* and *poor.* Minerals with a *perfect* or excellent cleavage break easily along flat surfaces and are easy to spot. Minerals with *good* cleavages do not



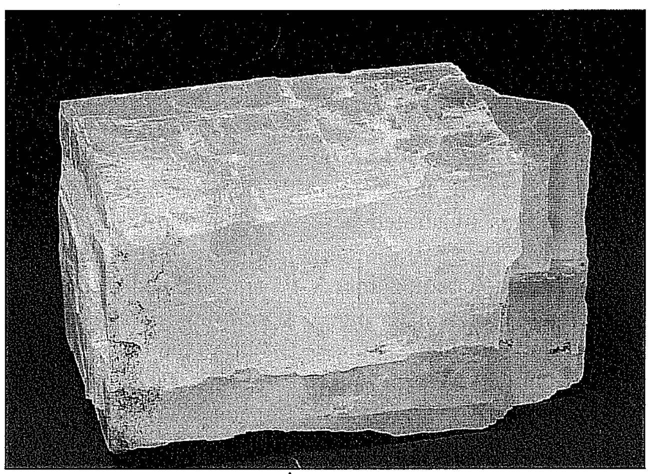


FIGURE 1.6
The illustration shows that atoms of sodium and chlorine in the mineral halite are parallel to three planes that intersect at 90°. Halite breaks, or *cleaves,* most easily between the three planes of atoms, so it has three *directions* of cleavage that intersect at 90°. The photograph of halite illustrates the three directions of cleavage.

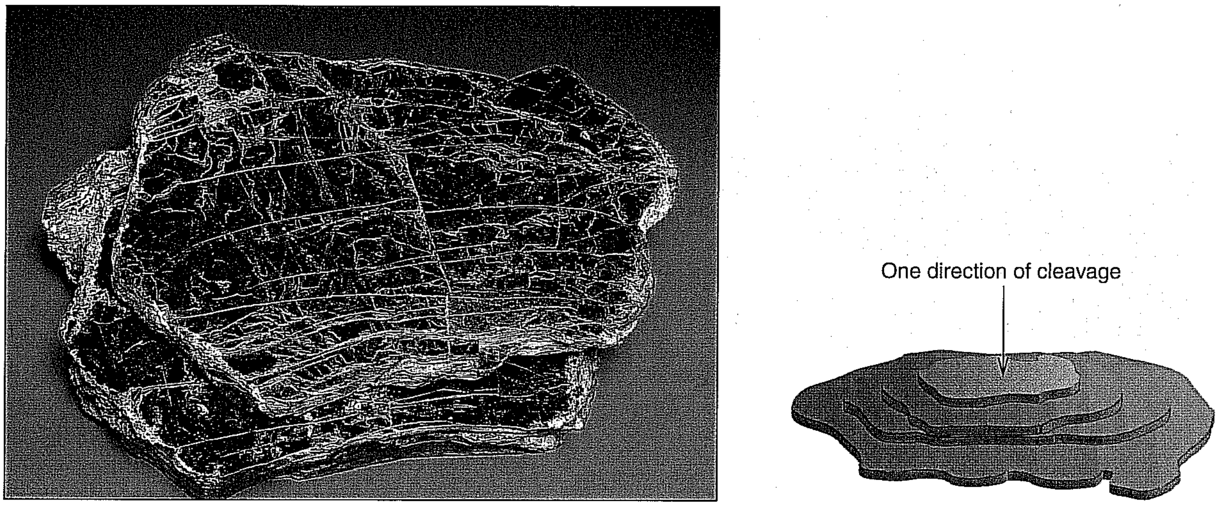


FIGURE 1.7
Biotite mica has one direction of cleavage (basal cleavage).

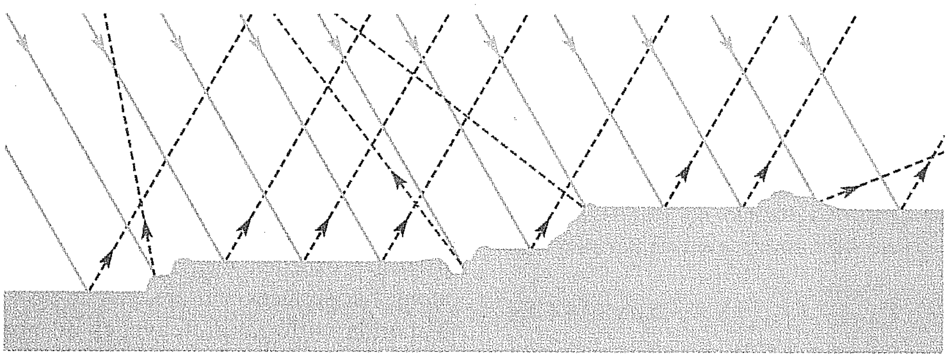


FIGURE 1.8
When incoming light rays (yellow lines) strike parallel cleavage surfaces, the rays are all reflected in the same direction (pink lines), even though the surfaces are at different elevations. When viewed from that direction, the mineral shines. Rays striking irregular fracture surfaces reflect in many different directions (green lines), causing fracture surfaces to appear duller.

FIGURE 1.9
The parallel cleavage planes in hornblende shine because the light is reflected in the same direction.

have such well-defined cleavage planes and reflect less light. *Poor* cleavages are the toughest to recognize, but can be spotted by small flashes of light in certain positions. All cleavages illustrated here are perfect or good.

Minerals have characteristic numbers of cleavages. This number is determined by counting the number of cleavage surfaces that are *not* parallel to each other. For example, the mineral in Figure 1.7 has two cleavage surfaces that are visible plus the one lying on the table. However, each of these cleavage surfaces is parallel to the other, so this mineral is said to have only one **one cleavage direction.** Minerals with one cleavage are often said to have a *basal cleavage.*

Two cleavage directions are illustrated in Figure 1.10. The drawing in Figure 1.10A shows several horizontal cleavage surfaces that are parallel to each other, and two vertical cleavage surfaces. Figure 1.10B shows several horizontal and inclined cleavage surfaces. Counting only nonparallel surfaces, each example shows only two cleavage directions. Intersecting cleavages may define an elongate geometric object called a prism, in which case they are said to have a *prismatic cleavage.* When there are two cleavages, you should note the angle between them. Most commonly, cleavage angles are close to 90°, 60°, or 120° (Fig. 1.10).

With **three cleavage directions,** a mineral can be broken in the shape of a cube if the three cleavages intersect at 90° (called a *cubic cleavage;* Fig. 1.11A) or a rhombohedron if the angles are not 90° (called a *rhombohedral cleavage;* Fig. 1.11B).

Minerals with **four** or **six cleavage directions** are not common. Four cleavage planes can intersect to form an eight-sided figure known as an octahedron (Fig. 1.12). Fluorite is the most common mineral with an *octahedral cleavage.* Six cleavage directions intersect to form a *dodecahedron,* a twelve-sided form with diamond-shaped faces. A common mineral with *dodecahedal cleavage* is sphalerite (Fig. 1.13).

When counting cleavage directions it is essential that you count surfaces on

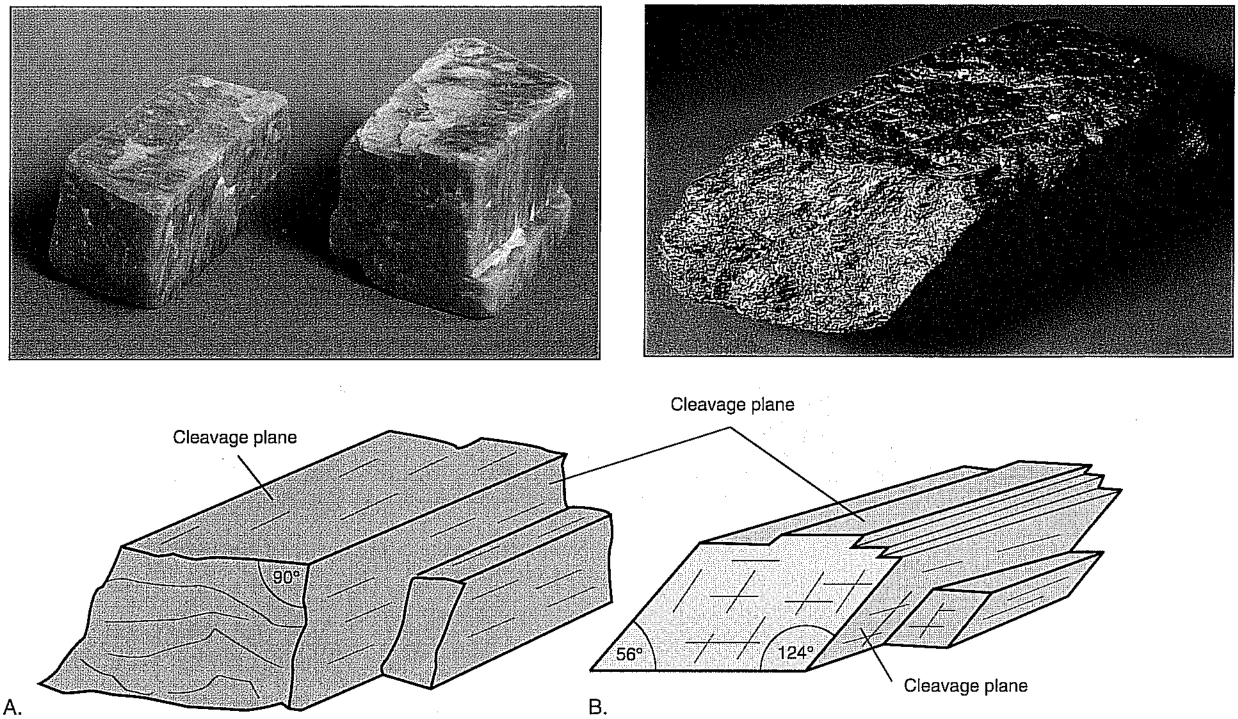


FIGURE 1.10
Two directions of cleavage: A. Cleavages in potassium feldspar intersect at 90°; B. Prismatic cleavages in hornblende intersect at 56° and 124°.

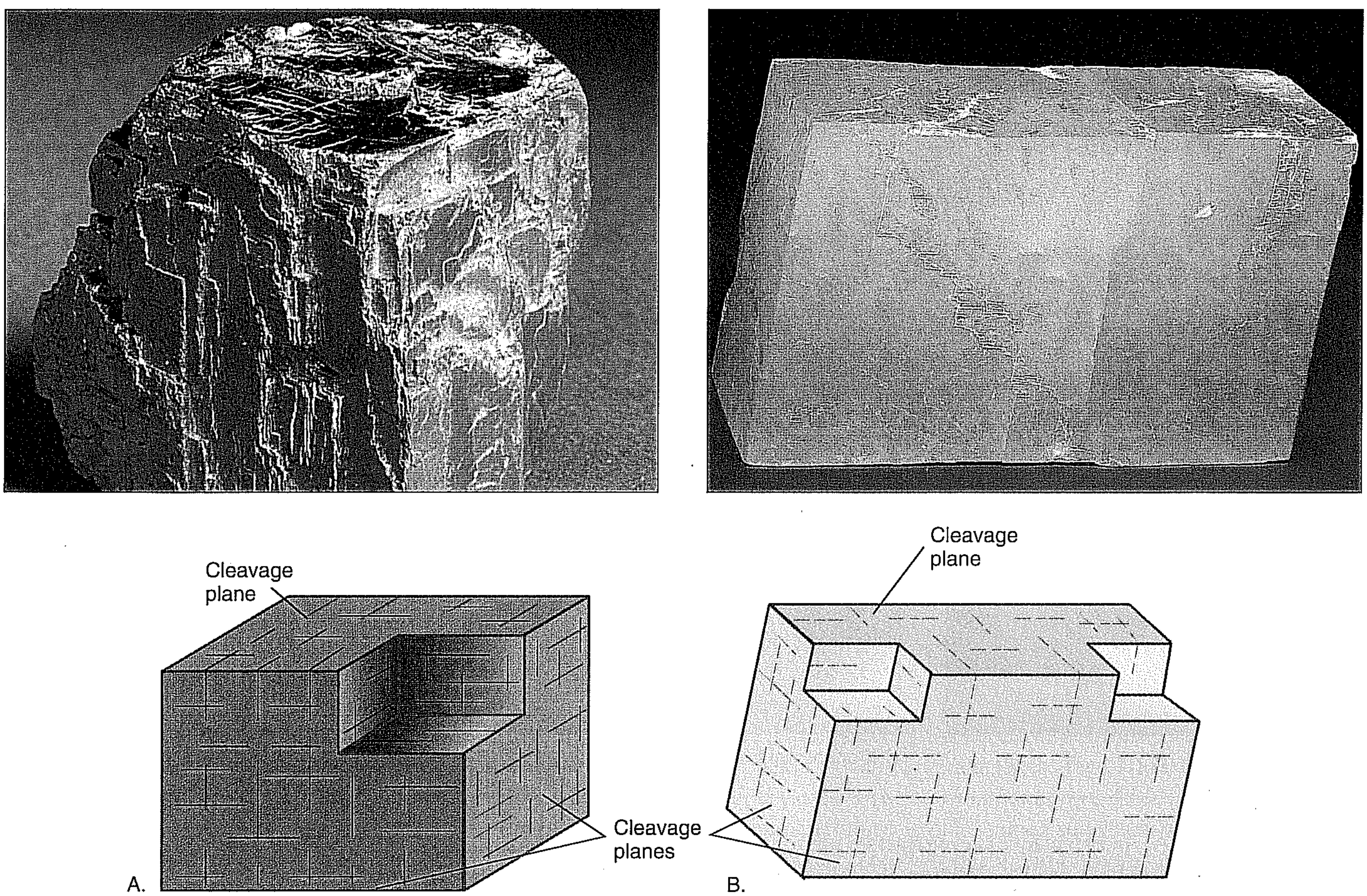


FIGURE 1.11
Three directions of cleavage: A. Cleavages in galena intersect at 90° (cubic cleavage). Note the metallic luster! B. Cleavages do not intersect at 90° in calcite (rhombohedral cleavage).

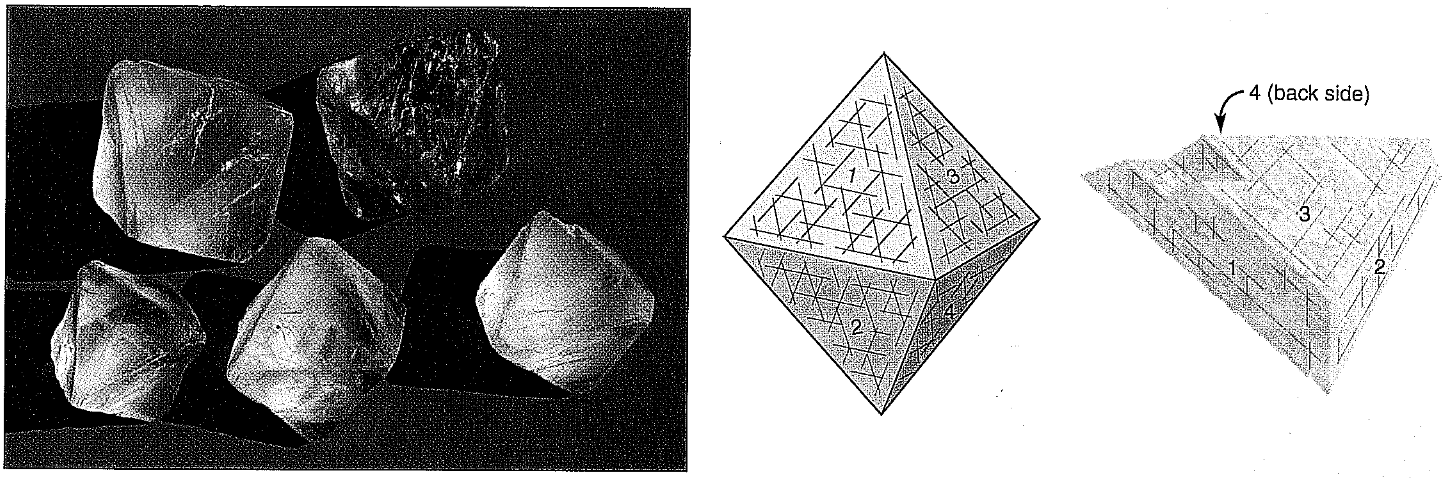


FIGURE 1.12
Four directions of cleavage (octahedral cleavage) in these samples of fluorite. Numbers indicate different cleavage directions.

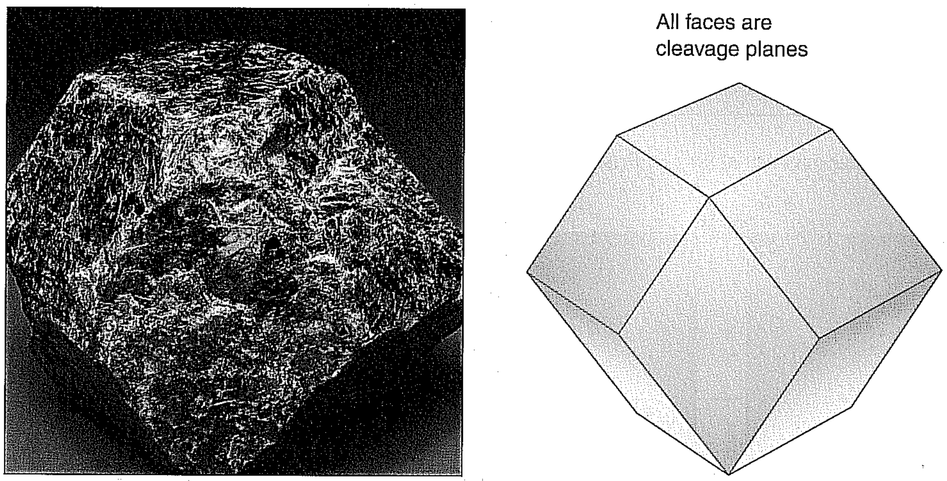
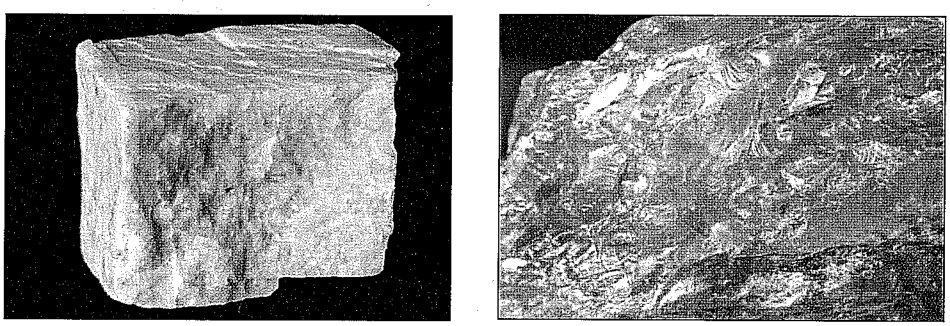


FIGURE 1.13
Six directions of cleavage (dodecahedral cleavage) in a sample of sphalerite.



A. Irregular fracture

B. Conchoidal fractures

FIGURE 1.14
Two types of fracture: A. An irregular or uneven fracture surface on the end of a potassium feldspar cleavage fragment (note the two cleavages at 90° to each other). B. Numerous conchoidal fractures mark the broken surface of this large quartz crystal. Figure 3.3 shows a much larger conchoidal fracture in obsidian.

just one mineral crystal. The photographs shown here used single large, broken crystals to illustrate cleavage. In nature you often find that a single hand-sized sample contains a large number of crystals grown together (see following discussion under "Crystal Form"). If you count up cleavage surfaces from more than one crystal, a wrong number is likely.

Finally, **fracture surfaces** can cut a mineral grain in any direction. Fractures are generally rough or irregular, rather than flat, and thus appear duller than cleavage surfaces (Fig. 1.14A). Some minerals fracture in a way that helps to identify them. For example, quartz has no cleavage but, like glass, it breaks along numerous small, smooth, curved surfaces called *conchoidal fractures* (Fig. 1.14B). Other kinds of fracture have descriptive names such as fibrous, splintery, or irregular.

In the field you will often have to break samples into pieces to observe cleavages and fractures on fresh surfaces. While it is instructional to hammer some mineral samples yourself, do not break the lab samples without your instructor's approval! Samples cost money and in most cases have already been broken to show characteristic features.

Crystal Form

A **crystal** is a solid, homogeneous, orderly array of atoms and may be nearly any size. Some crystals have smooth, plane faces and regular, geometric shapes (Fig. 1.15); these are what most people

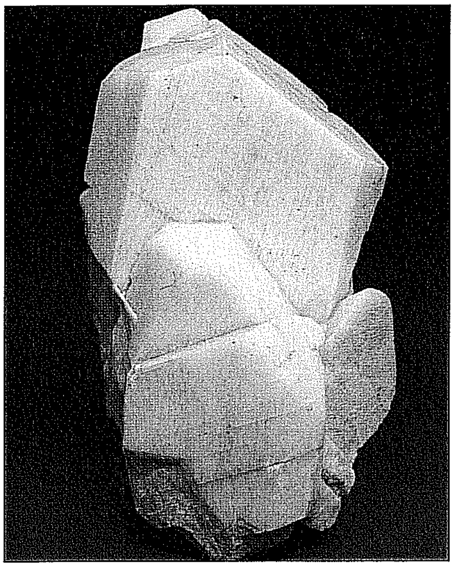


FIGURE 1.15
These crystals of potassium feldspar have smooth, flat faces and regular, geometric shapes.

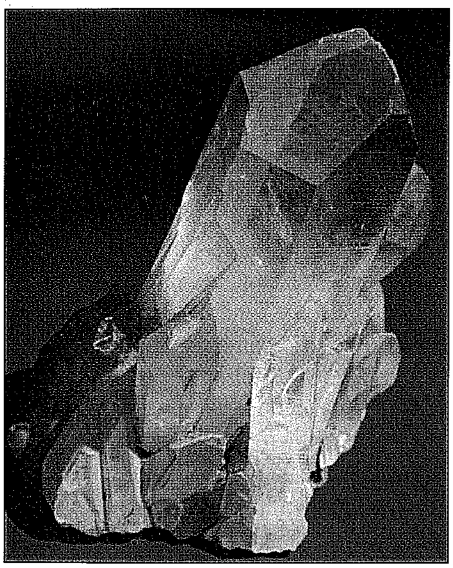
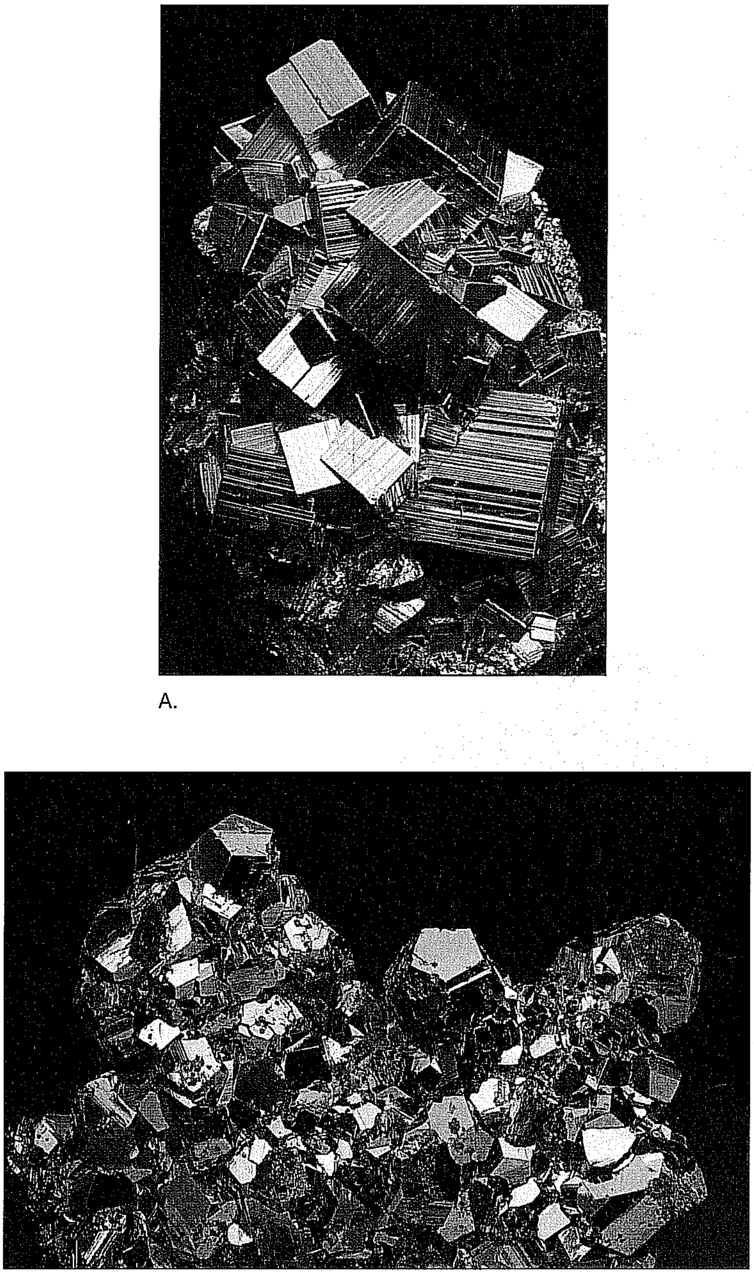


FIGURE 1.16
Crystal of quartz. Sides form a hexagonal prism that is capped with pyramid-like faces. Note the fine grooves on some crystal faces.



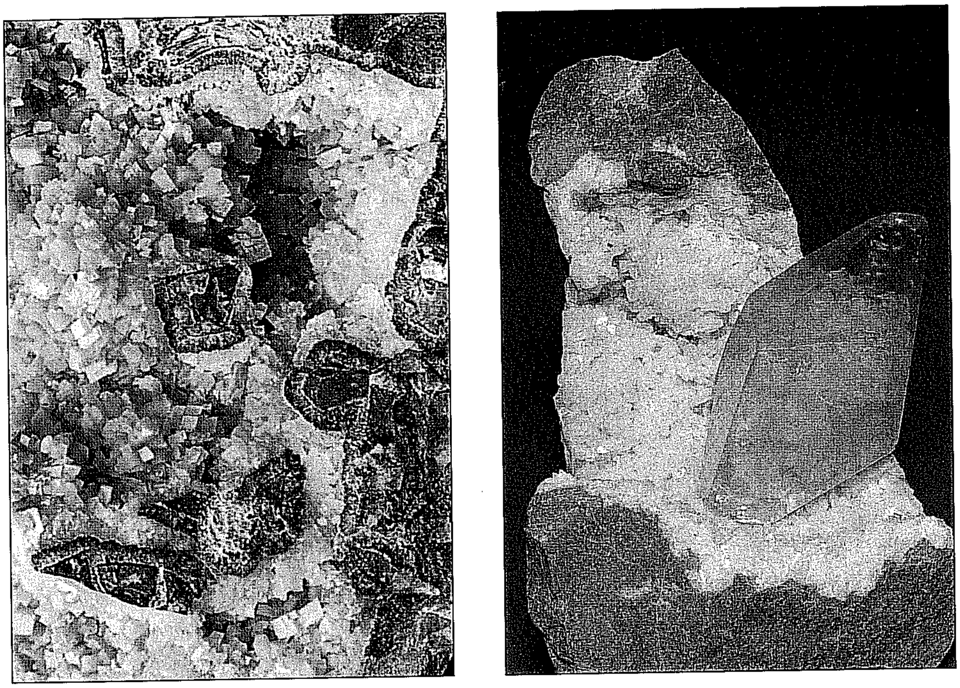
A.

B.

FIGURE 1.17
Crystals of pyrite in the form of (A) a cube and (B) pyritohedron. Note the fine grooves on the faces of the cubes.

think of as crystals. However, a small piece broken from one of these nicely shaped crystals is also a crystal, because the atoms within that small fragment have the same orderly arrangement throughout. When examining minerals, and especially when determining cleavage, you must determine whether you are looking at a single crystal with well-developed crystal faces, a fragment of such a crystal, or a group of small, irregularly shaped intergrown crystals.

The arrangement of atoms in a mineral determines the shape of its crystals. Some minerals commonly occur as well-developed crystals, and their crystal forms are diagnostic. A detailed nomenclature has evolved to describe crystal forms, and some of the common names may be familiar. For example, quartz commonly occurs as *hexagonal* (six-sided) *prisms* with pyramid-like shapes at the top (Fig. 1.16); pyrite occurs as *cubes* (Fig. 1.17A) or *pyritohedrons* (forms with twelve pentagonal faces, Fig. 1.17B); calcite occurs as *rhombohedrons* (six-sided forms that look like cubes squashed by pushing down on one of the corners; Fig. 1.18A) or more complex, twelve-faced forms called *scalenohedrons* (Fig. 1.18B).



A. B.

FIGURE 1.18
Crystals of calcite (yellow) in the form of (A) a rhombohedron and (B) a scalenohedron (yellow).

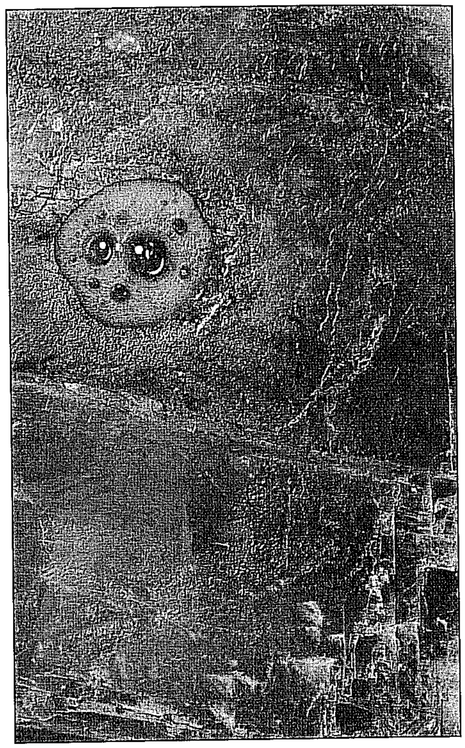


FIGURE 1.19
Calcite reacting to a drop of acid.

Cleavage surfaces may be confused with natural crystal faces; in fact, cleavage planes are parallel to possible (but not always developed) crystal faces. They can be distinguished as follows: (1) Crystal faces are normally smooth, whereas cleavage planes, though also smooth, commonly are broken in a step-like fashion (see Fig. 1.10B or 1.11A). (2) Some crystal faces have fine grooves or ridges on their surfaces (Figs. 1.16, 1.17), whereas cleavage planes do not. Similar-looking, very thin, parallel grooves, or *striations,* are seen on plagioclase cleavage surfaces, but these features persist throughout the mineral and are not surficial, as described below. (3) Finally, unless crystal faces happen to coincide with cleavage planes, the mineral will not break parallel to them.

Other Properties

Special properties help identify some minerals. These properties may not be distinctive enough in most minerals to help with their identification, or they may be present only in certain minerals.

Reaction with Acid

Some minerals, especially carbonate minerals, react visibly with acid. (Usually, a dilute hydrochloric acid [HCl] is used.) The acid test is especially useful for distinguishing the two carbonate minerals calcite and dolomite. When a drop of dilute hydrochloric acid is placed on calcite, it readily bubbles or effervesces, releasing carbon dioxide (Fig. 1.19). When a drop of acid is put on dolomite, the reaction is much slower unless the dolomite is powdered first; you may even have to look with a hand lens to see the bubbles, or, if the acid is weak, there may not be any. BE CAREFUL when using the acid—even dilute acid can burn your skin or put a hole in your clothing. Only a small drop of acid is needed to see whether or not the mineral bubbles. When you finish making the test, wash the acid off the mineral immediately. Should you get acid on yourself, wash it off right away, or if you get it on your clothing, rinse it out immediately.

Magnetism

Some minerals are attracted to a hand magnet. To test a mineral for magnetism, just put the magnet and mineral together and see if they are attracted. Magnetite is the only common mineral that is strongly magnetic.

Striations

Plagioclase feldspar can be positively identified and distinguished from potassium feldspar by the presence of *very thin, parallel grooves* called **striations** (Fig. 1.20). The grooves are present on only one of the two sets of cleavages and are best seen with a hand lens. They may not be visible on all parts of a cleavage surface. Before you decide there are no striations, look at all parts of all visible cleavage surfaces, moving the sample around as you look so that light is reflected from these surfaces at different angles.

Until you have seen striations for the first time, you may confuse them with the small, somewhat irregular, differently colored intergrowths or veinlets seen on cleavage faces of some specimens of potassium feldspar (Fig. 1.21). However, these have variable widths, are not strictly parallel, and are not grooves, so they are easily distinguished from striations.

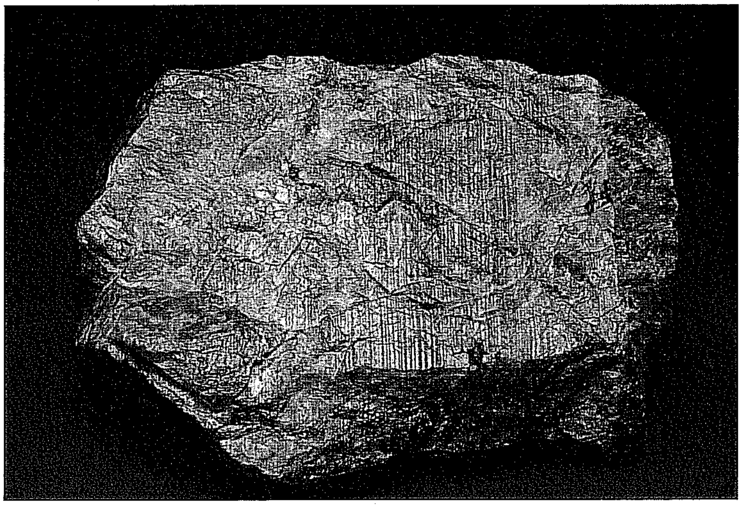


FIGURE 1.20
Striations are visible on the upper surface of this sample of plagioclase.

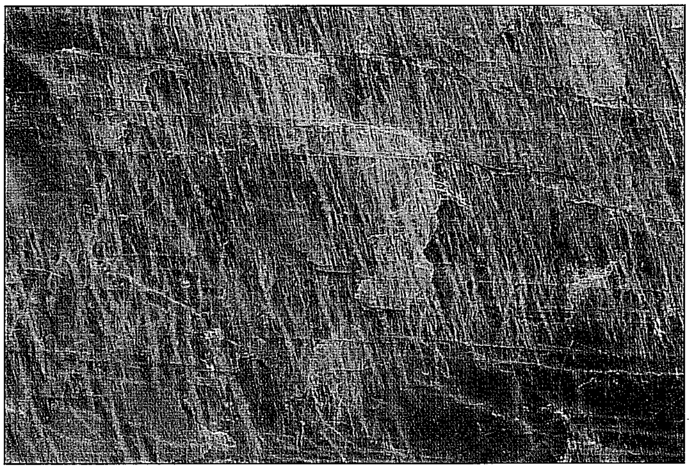


FIGURE 1.21
The thin veinlets seen in some potassium feldspars should not be confused with striations in plagioclase.

Specific Gravity

The **specific gravity** of a mineral is the weight of that mineral divided by the weight of an equal volume of water. The specific gravity of water equals 1.0, by definition. Most of the rock-forming minerals (see Chapter 2) have specific gravities of 2.6 to 3.4; the ore minerals (Chapter 2) are usually heavier, with specific gravities of 5 to 8. If you compare similar-sized samples of two different minerals, the one with the higher specific gravity will feel the heaviest; it has a greater **heft.** For most minerals, specific gravity is not a particularly noteworthy feature, but for some, high specific gravity is distinctive (examples are barite and galena).

Taste, Odor, Feel

Some minerals have a distinctive taste (halite is salt, and tastes like it), some a distinctive odor (the powder of some sulfide minerals, such as sphalerite, a zinc sulfide, smells like rotten eggs), and some a distinctive feel (talc feels slippery).

Tenacity

The **tenacity,** or toughness, of a mineral describes its resistance to being broken. *Brittle* minerals, such as quartz, shatter when broken; *flexible* minerals, like chlorite, can be bent without breaking, but will not resume their original shape when the pressure is released; *elastic* minerals, such as the micas, can be bent without breaking and will spring back to their original position when the pressure is released; *malleable* minerals can be hammered into thin sheets (examples are gold and copper); *sectile* minerals can be cut with a knife (for example, gypsum).