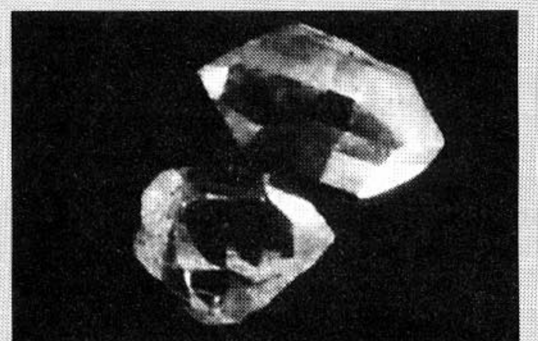
Box 3.1 What's Wrong With This Picture?

In the recent movie *Congo*, an exploration team goes to Africa to seek large, flawless diamonds. When the diamonds are shown, the movie immediately loses credibility with mineralogists because the crystals are hexagonal prisms (long crystals with a hexagonal cross section). Mineralogists know that diamond habit does not include hexagonal prisms (Figure 3.3).



►**FIGURE 3.3**
These quartz crystals with hexagonal prismatic habit are not diamonds because diamonds cannot form hexagonal crystals of this sort.

CRYSTAL SHAPE

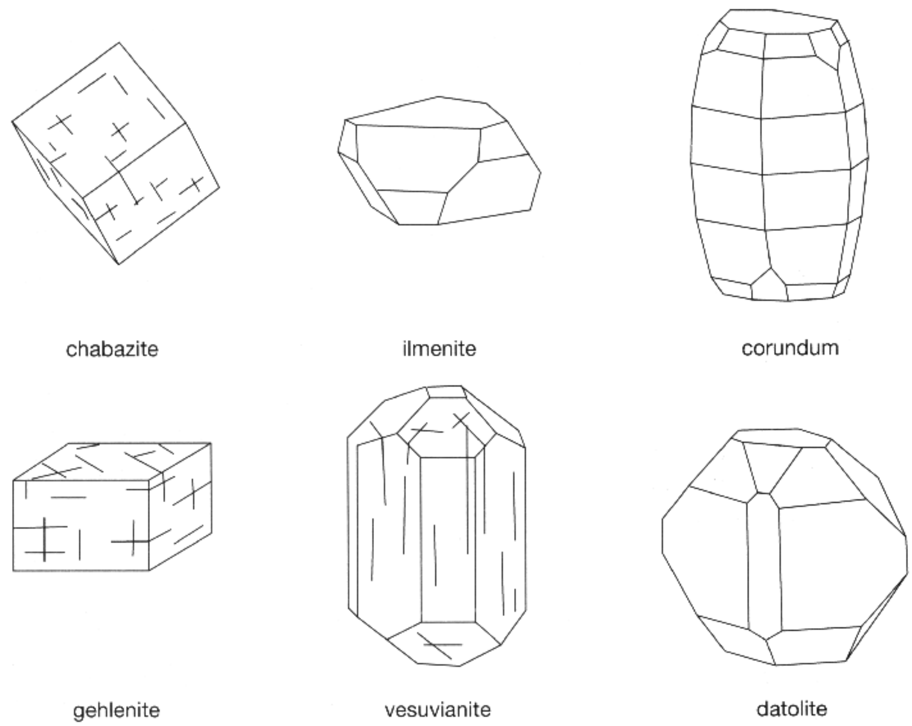
For well-developed crystals, crystal **form** and **habit** are excellent diagnostic properties. Habit refers to the overall shape of a crystal or aggregate of crystals. To mineralogists, the term *form* refers specifically to a group of crystal faces, related by the crystal's symmetry, that have identical chemical and physical properties. Although museum specimens and pictures of minerals in textbooks often show distinctive habits and forms, most mineral samples do not. Small irregular crystals without flat faces, or massive aggregates, are typical, often rendering habit and form of little use for hand specimen identification. Because form and habit reflect the internal arrangement of atoms in a crystal, when visible they are important diagnostic properties (Box 3.1).

Faces of a single crystal form have identical properties because they contain identical atoms in identical arrangements. Some minerals, such as chabazite, halite, and garnet, normally contain only one form; others contain more (Figure 3.4). Chabazite crystals grow as rhombohedrons, cubes "squashed" along one main diagonal. Halite crystals are typically cubic, having six square faces. Garnet crystals commonly have 12 diamond-shaped faces. Other minerals, such as ilmenite, corundum, gehlenite, vesuvianite, and datolite (Figure 3.4), may contain multiple forms and have more complicated shapes. Some minerals—for example, calcite—have many common forms. But, as we shall see later, they all have a common property called *symmetry*.

A single crystal's habit is controlled by the forms that are present, the way the forms combine, the relative sizes of crystal faces, and other features relating to crystal growth. The most useful terms describing habit are self-explanatory (Table 3.2). Common ones used to describe habit of single crystals include **equant** (equidimensional), **acicular** (needlelike), **tabular,** and **bladed** (Figure 3.5). For a group of crystals, habit includes the shape of the crystals and the way they are intergrown. The terms **massive, granular, radiating,** and **fibrous** are typical of the terms used to describe crystal aggregates (Figure 3.5).

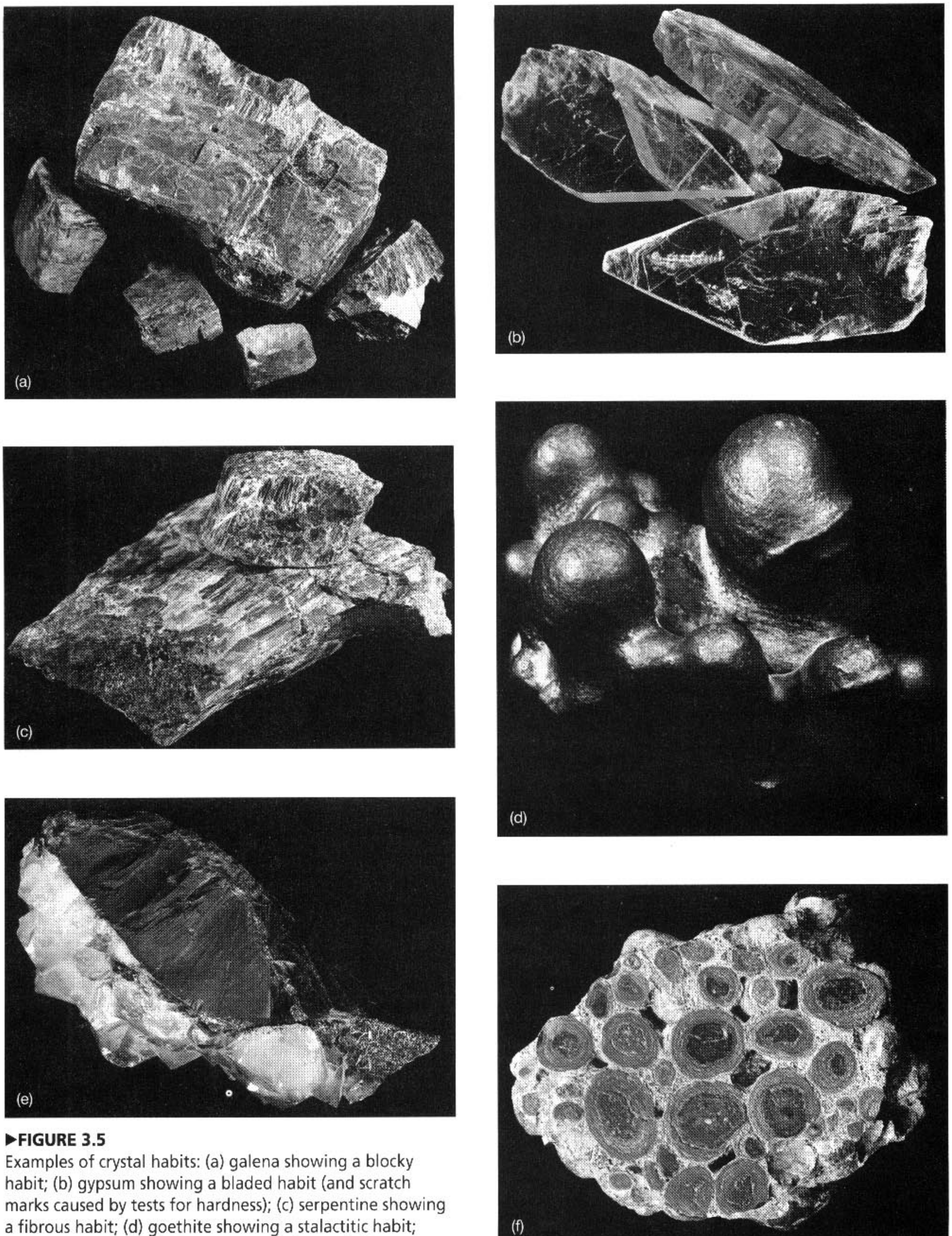
The color plates in this book show a wide range of crystal habits. The orthoclase crystals in Plate 1.5 are **blocky;** the celestite in Plate 1.6 is **tabular;** the okenite needles in Plate 1.7 and the selenite needles in Plate 3.5 are **acicular;** the smithsonite in Plate 1.8 and pectolite in Plate 3.1 are **botryoidal.** Most of the quartz crystals in Plate 2 are **prismatic,** as are the beryl and tourmaline in Plate 3.3. The actinolite in

▶FIGURE 3.4
Forms and combinations of forms of six minerals. Different samples of the same mineral may crystallize with different forms, but those shown here are typical. The lines on the crystal faces show orientations of prominent cleavages.



▶TABLE 3.2
Terms Used to Describe Crystal Habit

Terms Generally Used to Describe Individual Crystals (with Example Minerals)	
equant	having approximately the same dimensions in all directions (garnet, spinel)
blocky	equant crystals with approximately square cross sections (halite, galena)
acicular	needlelike (actinolite, sillimanite)
tabular or platy	appearing to be plates or thick sheets stacked together (gypsum, graphite)
capillary or filiform	hairlike or threadlike (serpentine, millerite)
bladed	elongated crystals that are flattened in one direction (kyanite, wollastonite)
prismatic or columnar	elongated crystals with identical faces parallel to a common direction (apatite, beryl)
foliated or micaceous	easily split into sheets (muscovite, biotite)
Terms Generally Used to Describe Crystal Aggregates	
massive	solid mass with no distinguishing features
granular	composed of many individual grains
radiating or divergent	crystals emanating from a common point
fibrous	appearing to be composed of fibers
stalactitic	stalactite shaped
lamellar or tabular	flat plates or slabs growing together
stellated	aggregate of crystals giving a starlike appearance
plumose	having a feathery appearance
arborescent or dendritic	having a branching treelike or plantlike appearance
reticulated or latticelike	slender crystals forming a lattice pattern
colloform or globular	spherical or hemispherical shapes made of radiating crystals
botryoidal	having an appearance similar to a bunch of grapes
reniform	having a kidney-shaped appearance
mammillary	breastlike
drusy	having surfaces covered with fine crystals
elliptic or pisolitic	very small or small spheres



▶FIGURE 3.5
Examples of crystal habits: (a) galena showing a blocky habit; (b) gypsum showing a bladed habit (and scratch marks caused by tests for hardness); (c) serpentine showing a fibrous habit; (d) goethite showing a stalactitic habit; (e) hematite (on quartz) showing a radiating habit; and (f) limonite showing a pisolitic habit.

Box 3.2 Asbestiform Minerals and Health Risks

We use the term **asbestiform** to describe a mineral habit characterized by small, strong, and flexible fibers, equivalent to hairs or whiskers (e.g., serpentine, as shown in Figure 3.5c and Plate 3.7; and anthophyllite, as shown in Plate 3.4). **Asbestos** is a commercial name for any marketable asbestiform mineral. Mineralogists have described many asbestiform mineral varieties, but most are rare and only a few are produced for sale. "White asbestos," composed of the mineral chrysotile, accounts for about 95% of the commercial market. Chrysotile, a member of the serpentine group, is a widespread but minor mineral in many altered ultramafic rocks. In North America, production occurs in a few large deposits in Quebec and California. Other commercial asbestos is composed of crocidolite ("blue asbestos") and amosite ("brown asbestos"), varieties of the amphiboles riebeckite and grunerite, respectively. Other minerals with asbestiform varieties include other amphiboles (anthophyllite, tremolite, actinolite), clays (sepiolite, palygorskite), and members of the zeolite group, including roggianite, mazzite, erionite, mordenite, and okenite.

Historically, asbestos has had many uses. Since around 1878, it has been mined in large quantities because it is tough, flexible, and fire and chemical resistant. Between 1900 and 1986, builders sprayed asbestos on walls, ceilings, and pipes in many buildings in the United States. Industries have used asbestos in brake linings, roof shingles, and other applications. Unfortunately, asbestos easily crumbles to make a fine dust that people can inhale. So, fibers can become embedded in lung tissue and cause asbestosis (a chronic breathing disorder that may be fatal), lung cancer, or mesothelioma (another form of cancer). For the most part, epidemiologists have documented these diseases in workers exposed to high levels of asbestos over long times.

In 1907 health workers reported the first asbestos-related diseases, but it was not until around 1960 that the threat posed by asbestos was accepted as serious. In 1974 the Environmental Protection Agency (EPA) banned asbestos for most commercial use in the United States, and soon afterwards launched a vigorous program to remove asbestos from commercial structures. However, American companies still ship many products containing asbestos to developing countries.

Despite the ban and efforts to eliminate asbestos from our environment, it is still common in many buildings and as a component in urban dust. Fortunately, current studies suggest that exposure to low levels of chrysotile, the most common form of asbestos, may not pose as serious a health threat as once thought. Furthermore, the EPA has found that removing asbestos that is not crumbling or releasing fibers can increase asbestos concentrations in the air and cost a great deal of money without significantly decreasing health threats. For these reasons, Congress modified asbestos laws in 1986.

Plate 3.2 and the kyanite in Plate 3.6 are **bladed,** while the anthophyllite (Plate 3.4) and chrysotile (Plate 3.7) are **fibrous** aggregates. In Plate 3.8, **drusy** pyrite has grown on top of calcite.

STRENGTH AND BREAKING OF MINERALS

The color and shape of minerals are obvious to anyone, but there are other, more subtle, properties that a mineralogist will notice. Several relate to the strengths of bonds that hold crystals together. These properties are especially reliable for mineral identification because they are not strongly affected by chemical impurities or defects in crystal structure.

Tenacity

The term *tenacity* refers to a mineral's toughness and its resistance to breaking or deformation. Those that break, bend, or deform easily have little tenacity. In contrast, strong unbreakable minerals have great tenacity. Jade, composed of either the pyroxene jadeite or the amphibole actinolite, is one of the most tenacious natural materials known. It does not easily break or deform, even when under extreme stress. Table 3.3 contains some of the terms typically used to describe tenacity.

▶TABLE 3.3
Terms Used to Describe Tenacity

flexible	bendable
elastic	a bendable mineral that returns to its original shape after release
malleable	capable of being hammered into different shapes
ductile	capable of being drawn into a wirelike shape
brittle	easily broken or powdered
sectile	capable of being cut into shavings with a knife

The tenacity of a mineral is controlled by the nature of its chemical bonds. Ionic bonding often leads to rigid, brittle minerals. Halite is an excellent example of a **brittle** mineral. It shatters into many small pieces when struck. Quartz, too, is brittle, although the bonding in quartz is only about 50% ionic. Many metallically bonded minerals, such as native copper, are **malleable.** Other minerals, such as gypsum, are **sectile.** Some minerals, including talc and chlorite, are **flexible** due to weak van der Waals and hydrogen bonds holding well-bonded layers of atoms together. When force is applied, slippage between layers allows bending. When pressure is released, they do not return to their original shape. Still other minerals, notably the micas, are **elastic.** They may be bent but resume their original shape after pressure is released if they were not too badly deformed. In micas and other elastic minerals, the bonds holding layers together are stronger than those in chlorite or clays.

Cleavage, Parting, and Fracture

Because atomic structure is not the same in all directions and chemical bonds are not all the same strength, most crystals break along preferred directions. The orientation and manner of breaking are important clues to crystal structure. If the fractures are planar and smooth, the mineral is said to have good **cleavage.** Cleavage refers to minerals breaking parallel to atomic planes. There are a few exceptions, such as quartz, that break along curved surfaces to form **conchoidal fractures** (see Plate 2.1), but the majority of minerals cleave to form flat surfaces. For minerals that do not have good cleavage, terms used to describe fracture include **conchoidal, splintery,** and **hackly** (Table 3.4).

If a mineral cleaves along one particular plane, a nearly infinite number of parallel planes are equally prone to cleavage. This is due to the repetitive arrangement of atoms in atomic structures. The spacing between planes is the repeat distance of the atomic structure, on the order of Ångstroms ($1 Å = 10^{-10}$ m). The whole set of planes, collectively referred to as a cleavage, represents planes of weak bonding in the crystal structure. Biotite (Plate 6.6) is an excellent example of a mineral with one excellent cleavage. Minerals that have more than one direction of weakness will have more than one cleavage direction (Figure

▶TABLE 3.4
Terms Used to Describe Fracture Surfaces and Cleavages (and Examples)

Fracture Terms	
even	breaking to produce smooth planar surfaces (halite)
uneven or irregular	breaking to produce rough and irregular surfaces (rhodonite)
hackly	jagged fractures with sharp edges (copper)
splintery	forming sharp splinters (kyanite, pectolite)
fibrous	forming fibrous material (chrysotile, crocidolite)
conchoidal	breaking with curved surfaces as in the manner of glass (quartz)
Cleavage Terms	
basal	also sometimes called *platy;* refers to cleavage in minerals such as micas that have one well-developed planar cleavage
cubic	geometric term used to describe three cleavages at 90° to each other (galena)
octahedral	geometric term used to describe four cleavages that produce octahedral cleavage fragments (fluorite)
prismatic	multiple directions of good cleavage all parallel to one direction in the crystal

3.6). The direction and angular relationships between cleavages, therefore, give valuable hints about atomic structure.

Minerals that are equally strong in all directions, such as quartz, fracture to form irregular surfaces (Plate 2.1). Minerals with only one direction of weakness, such as gypsum and micas, have one direction of cleavage and usually break to form thick slabs or sheets. Kyanite (Plate 3.6) and anthophyllite, which have two good cleavages, easily break into splintery shapes. Other minerals may have 3 (halite), 4 (fluorite), or even 6 cleavages (Figure 3.6). The ease with which a mineral cleaves is not the same for all minerals or for all the cleavages in a particular mineral. Mineralogists describe the quality of a particular cleavage with qualitative terms: *perfect, good, distinct, indistinct,* and *poor.* Quartz has poor cleavage in all directions, while micas have one perfect cleavage.

Crystal faces and cleavage surfaces may be difficult to tell apart. A set of parallel fractures indicates a cleavage, but if only one flat surface is visible, there can be ambiguity. However, crystal faces often display subtle effects of crystal growth. **Twinning** (oriented intergrowths of multiple crystals) and other **striations** (parallel lines on a face), growth rings or layers, pitting, and other imperfections make a face less smooth than a cleavage plane and give it lower reflectivity and a drabber luster. In some minerals, principal cleavage directions are parallel to crystal faces, but in most they are not. Plates 1.3 and 2.7 show pyrite with well-developed striations on its crystal faces.

Cleavage is an excellent property for mineral identification. Often the quality and number of cleavages may be seen in hand specimen. Sometimes a hand lens is used to identify the set of fine parallel cracks, more irregular than twinning and striations, which indicate a cleavage that is too poorly developed to be seen with the naked eye. Angles between cleavages may be estimated or, if accurate angular measurements are needed, techniques involving a **petrographic microscope** or a device called a **goniometer** may be used to measure them.

Some mineral specimens exhibit **parting,** a phenomenon that looks like cleavage. Parting is not due to atomic structure weaknesses, but to crystallographic imperfections such as **twin planes** (planes that separate domains with different atomic-structure orientations), stress, or chemical alteration. In contrast with cleavage, parting is restricted to one or a few distinct planes rather than an infinite set. Unlike cleavage, parting will not be present in all specimens of a particular mineral, and parting surfaces are usually less smooth than cleavage planes.

HARDNESS: MOH'S Hardness Scale (NOT absolute):

Talc	1	The
Gypsum	2	Girls/Guys
Calcite	3	Can
Fluorite	4	Flirt
Apatite	5	And
Orthoclase	6	Other
Quartz	7	Queer
Topaz	8	Things
Corundum	9	Can
Diamond	10	Do

MOH'S Hardness of Common Items:

Fingernail……………………**2 to 2.5**

Copper coin………………**3.5**

Steel knife…………………**5 to 6**

Glass…………………………**5 to 5.5**

Streak plate………………**6.5 to 7**