Minerals: Building Blocks of Rocks

MINERALS

- A *mineral* can be defined as a natural inorganic substance having a particular chemical composition or range of composition, and a regular atomic structure to which its crystalline form is related.
- Some minerals are very strong and produce strong rocks; while some minerals are softer and produce weak rocks.
- More than 2000 minerals are present on earth’s crust.

Definition

- Geologists define mineral as *any naturally occurring inorganic solid that possesses an orderly crystalline structure and can be represented by a chemical formula.*

Characteristics of Minerals

Earth materials that are classified as minerals exhibit the following characteristics:

1. **Naturally occurring.** Minerals form by natural, geologic processes. Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.

2. Solid substance. Only solid crystalline substances are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapor do not.

Characteristics of Minerals

3. Orderly crystalline structure. Minerals are crystalline substances, which means their atoms are arranged in an orderly, repetitive manner (FIGURE 2.2). This orderly packing of atoms is reflected in the regularly shaped objects called crystals. Some naturally occurring solids, such as volcanic glass (obsidian), lack a repetitive atomic structure and are not considered minerals.

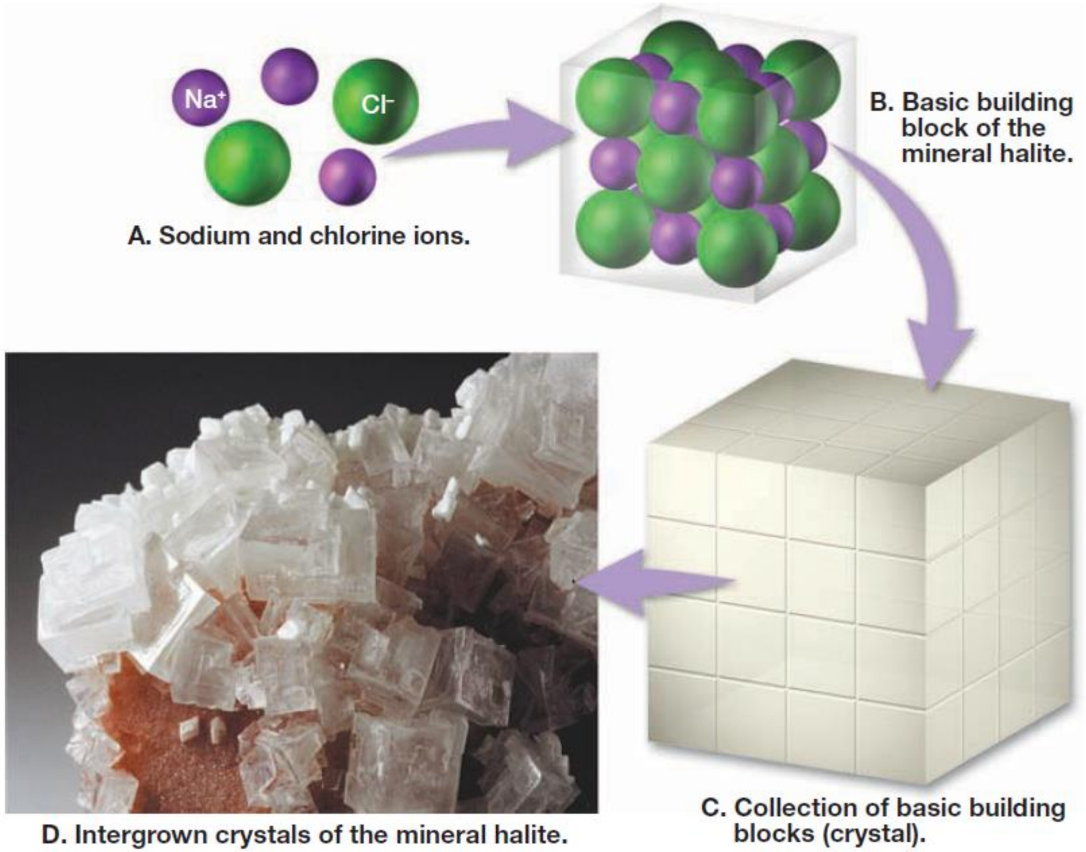


FIGURE 2.2 This diagram illustrates the orderly arrangement of sodium and chloride ions in the mineral halite. The arrangement of atoms into basic building blocks having a cubic shape results in regularly shaped cubic crystals. *(Photo by Dennis Tasa)*

Characteristics of Minerals

4. Generally inorganic. Inorganic crystalline solids, such as ordinary table salt (halite), that are found naturally in the ground are considered minerals. (Organic compounds, on the other hand, are generally not. Sugar, a crystalline solid like salt but which comes from sugarcane or sugar beets, is a common example of such an organic compound.) Many marine animals secrete inorganic compounds, such as calcium carbonate (calcite), in the form of shells and coral reefs. If these materials are buried and become part of the rock record, they are considered minerals by geologists.

Characteristics of Minerals

5. Can be represented by a chemical formula. Most minerals are chemical compounds having compositions that can be expressed by a chemical formula. For example, the common mineral quartz has the formula $SiO2$, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two.

Minerals

Five Characteristics of Minerals

1. Naturally occurring,
2. Inorganic,
3. Solid,
4. Definite chemical composition, and
5. Orderly internal crystal structure.

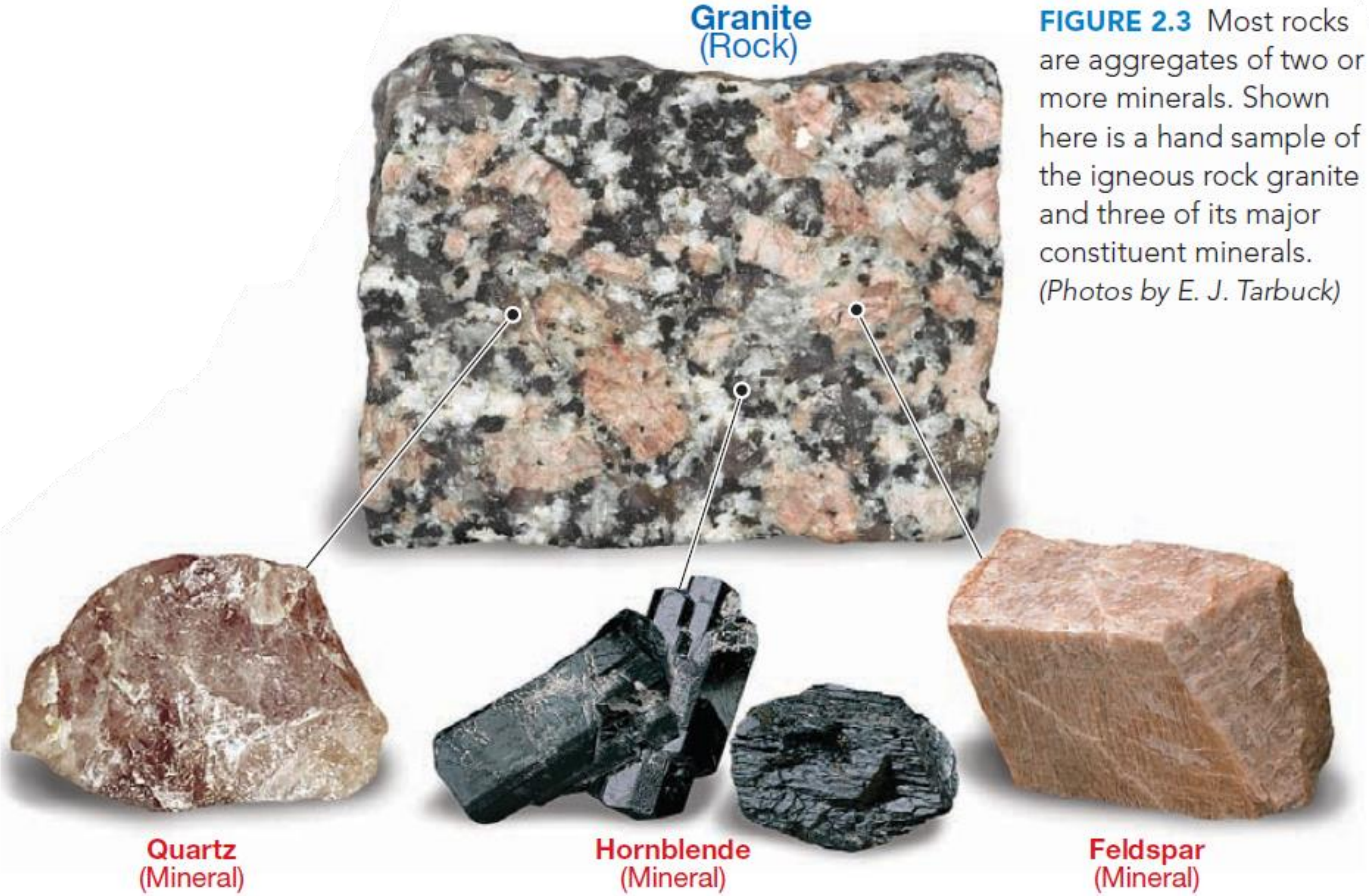


FIGURE 2.3 Most rocks are aggregates of two or more minerals. Shown here is a hand sample of the igneous rock granite and three of its major constituent minerals. *(Photos by E. J. Tarbuck)*

Optical properties of minerals

- Birefringent or doubly refractive
- Minerals which have the property of dividing a ray of light into two is said to be birefringent or doubly refractive.

Physical properties of minerals

- Optical Properties
  - Lustre
  - The ability to transmit light
  - Colour
  - Streak

- Crystal Shape or Habit or Form
- Mineral Strength
  - *tenacity*,
  - *hardness*,
  - *cleavage*, and
  - *Fracture*
- Density and Specific Gravity

Optical Properties

Of the many optical properties of minerals, their luster, their ability to transmit light, their color, and their streak are most frequently used for mineral identification.

Lustre

Lustre is the appearance of a mineral surface in reflected light. It may be described as *metallic,* as in pyrite or galena;

glassy or *vitreous,* as in quartz;

resinous or greasy, as in *opal;*

pearly, as in talc; or *silky,* as in fibrous minerals such as asbestos and satin-spar (fibrous gypsum).

Minerals with no lustre are described as *dull.*

FIGURE 2.9 The freshly broken sample of galena (right) displays a metallic luster, while the sample on the left is tarnished and has a submetallic luster. *(Photo courtesy of E. J. Tarbuck)*

- Several other terms are used to describe the luster of nonmetallic specimens, including the following:
- **Vitreous**—resembles the luster or sheen of glass
- **Resinous**—resembles a resin like amber or dried tree sap
- **Silky**—a silk-like reflection of light from thin parallel mineral fibers
- **Pearly**—resembling the luster of a pearl
- **Earthy**(dull)—lacking reflection, like dry soil
- **Waxy**—resembles wax
- **Satin**—resembles satin cloth
- **Greasy**—looks like it is covered in a thin film of oil or grease

THE ABILITY TO TRANSMIT LIGHT.

Another optical property used in the identification of minerals is the ability to transmit light. When no light is transmitted, the mineral is described as *opaque;* when light, but not an image, is transmitted through a mineral it is said to be *translucent.* When both light and an image are visible through the sample, the mineral is described as *transparent.*

Colour

Some minerals have a distinctive colour, for example the green colour of chlorite, but most naturally occurring minerals contain traces of substances which modify their colour. Thus quartz, which is colourless when pure, may be white, grey, pink or yellow, when certain chemical impurities or included particles are present.

FIGURE 2.10 Quartz. Some minerals, such as quartz, occur in a variety of colors. These samples include crystal quartz (colorless), amethyst (purple quartz), citrine (yellow quartz), and smoky quartz (gray to black). *(Photo courtesy of E. J. Tarbuck)*

Streak

The colour of a mineral in the powdered condition is known as the *streak.* This may be produced by rubbing the mineral on a piece of unglazed porcelain, called a streak-plate, or other rough surface.

Streak is useful, for example, in distinguishing the various oxides of iron;

haematite (Fe_2O_3) gives a red streak,

limonite (hydrated Fe_2O_3) a brown, and

magnetite(Fe_3O_4) a grey streak.

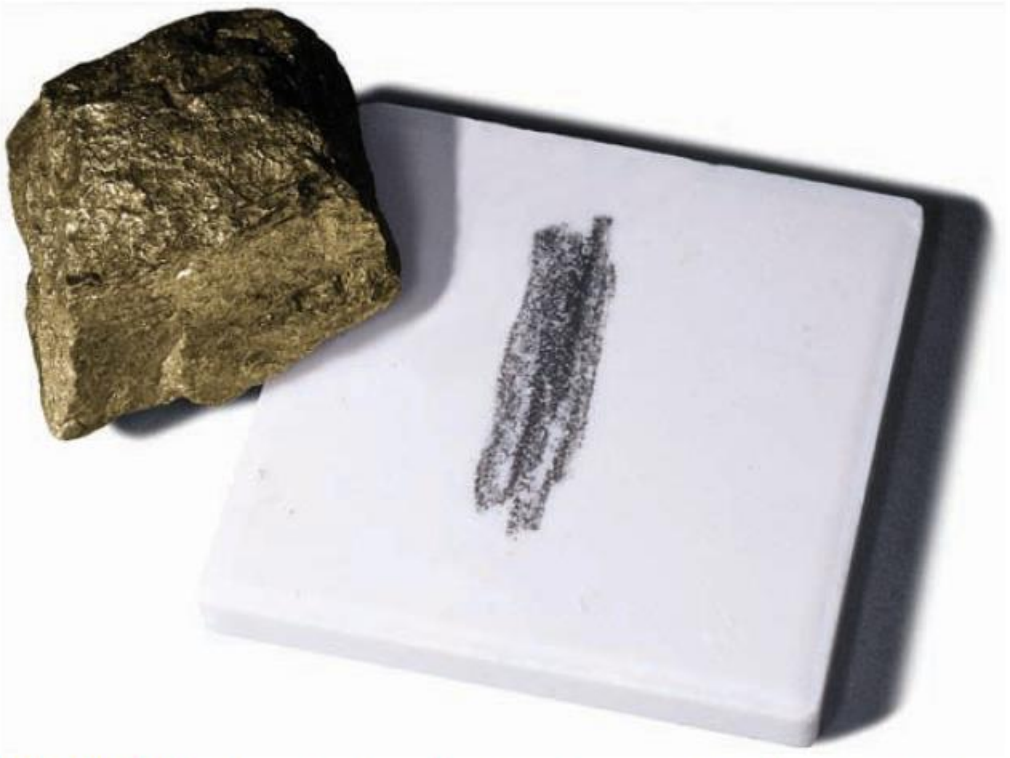


FIGURE 2.11 Although the color of a mineral is not always helpful in identification, the streak, which is the color of the powdered mineral, can be very useful. *(Photo by Dennis Tasa)*

Crystal Shape or Habit or Form

Mineralogists use the term crystal shape or habit to refer to the common or characteristic shape of a crystal or aggregate of crystals.

Form

Under this heading come a number of terms which are commonly used to describe various shapes assumed by minerals *in groups or cluster.*

Acicular

Botryoidal

Nodular

Dendritic

Reniform

Tabular

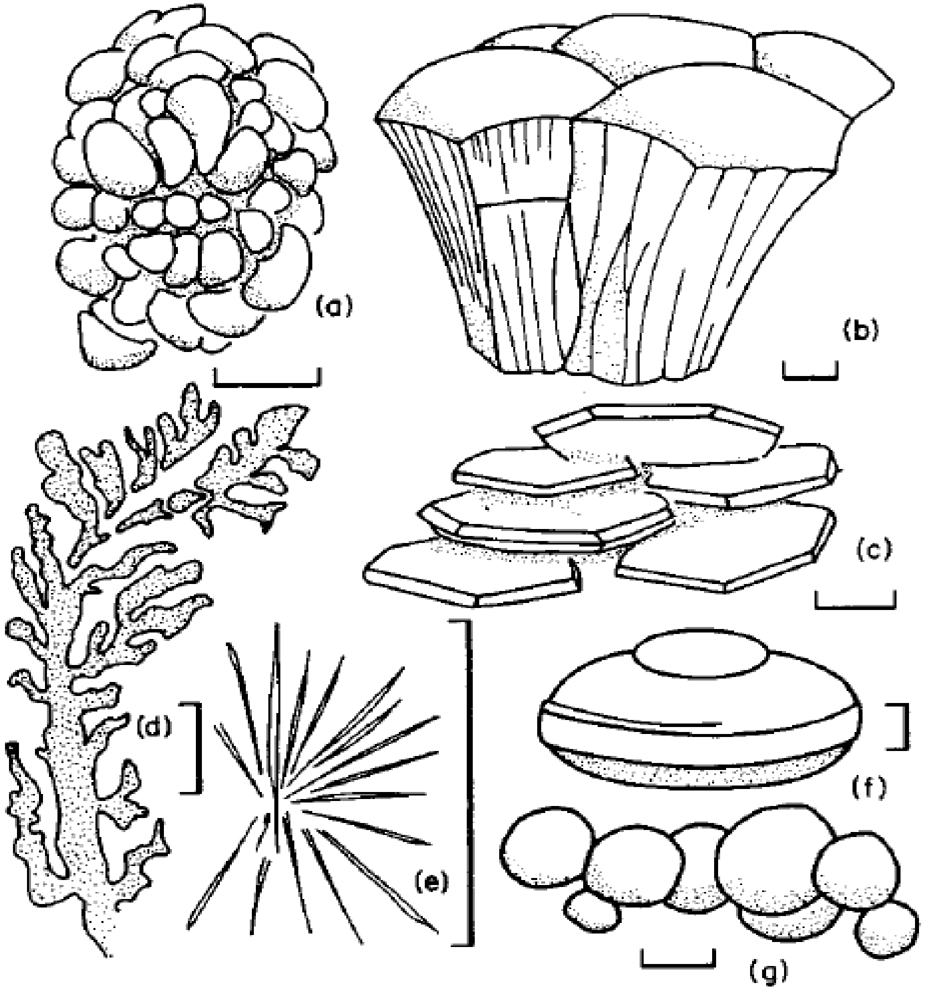
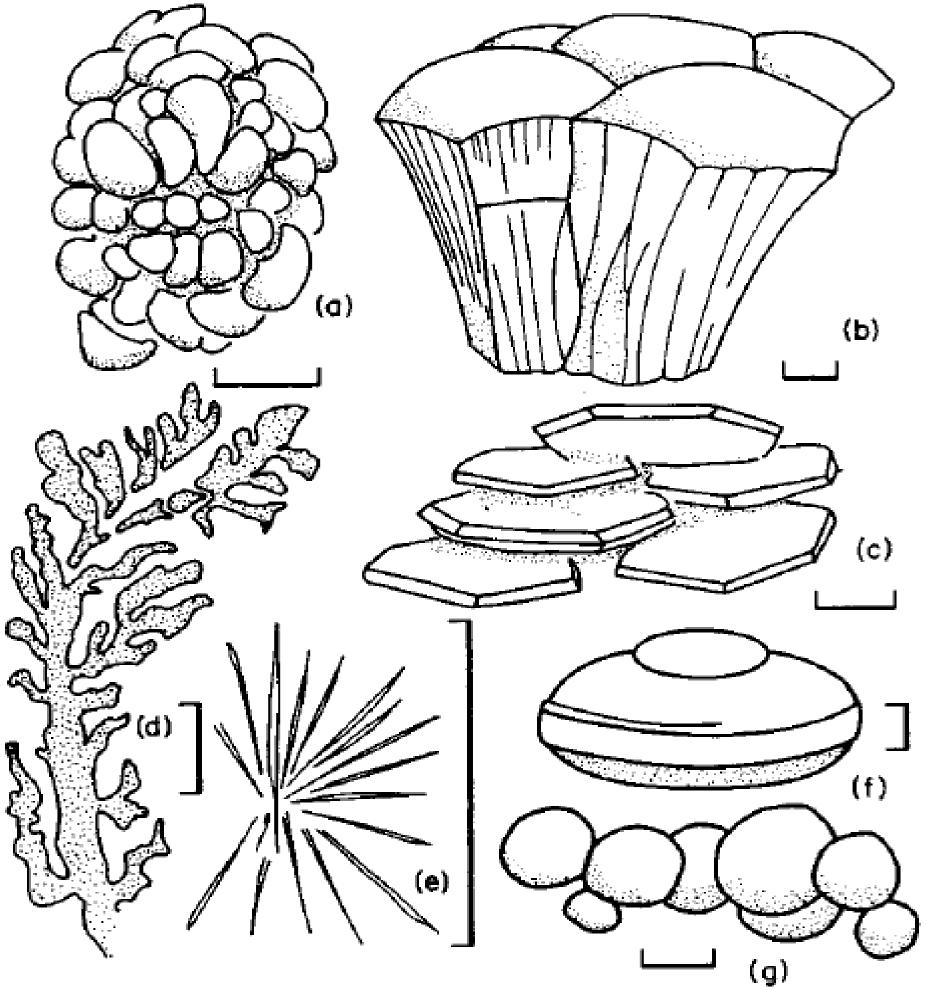


Fig. 4.1 Common shapes of mineral clusters: scale bar=1 cm. (**a**) Botryoidal. (**b**) Reniform. (**c**) Tabular. (**d**) Dendritic. (**e**) Acicular. (**f** and **g**) Concretionary.

Form

Acicular - in fine needle-like crystals (also described as *filiform),* e.g. schorl, natrolite.



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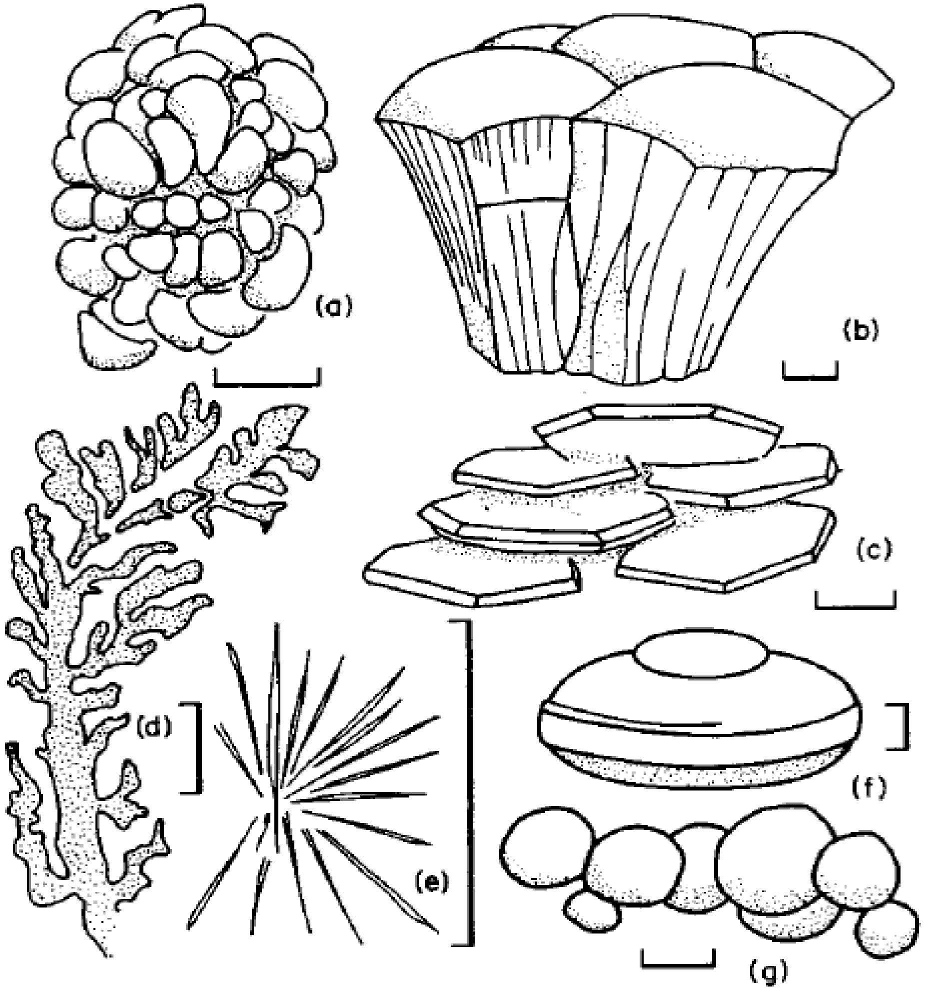
Form

Botryoidal - consisting of spheroidal aggregations, somewhat resembling a bunch of grapes; e.g. chalcedony. The curved surfaces are boundaries of the ends of many crystal fibres arranged in radiating clusters.



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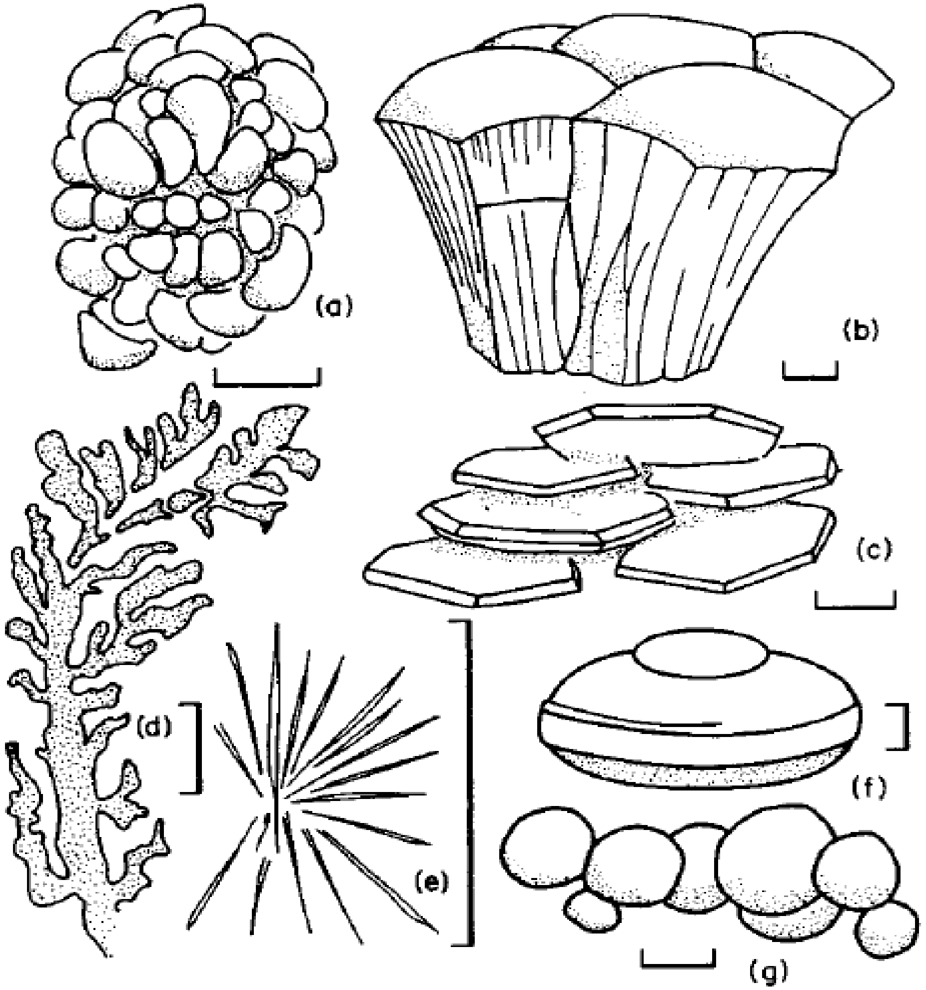
Form

Concretionary or nodular - terms applied to minerals found in detached masses of spherical, ellipsoidal, or irregular shape; e.g. the flint nodules of the chalk.



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Form

Dendritic - moss-like or tree-like forms, generally produced by the deposition of a mineral in thin veneers on joint planes or in crevices; e.g. dendritic deposits of manganese oxide.

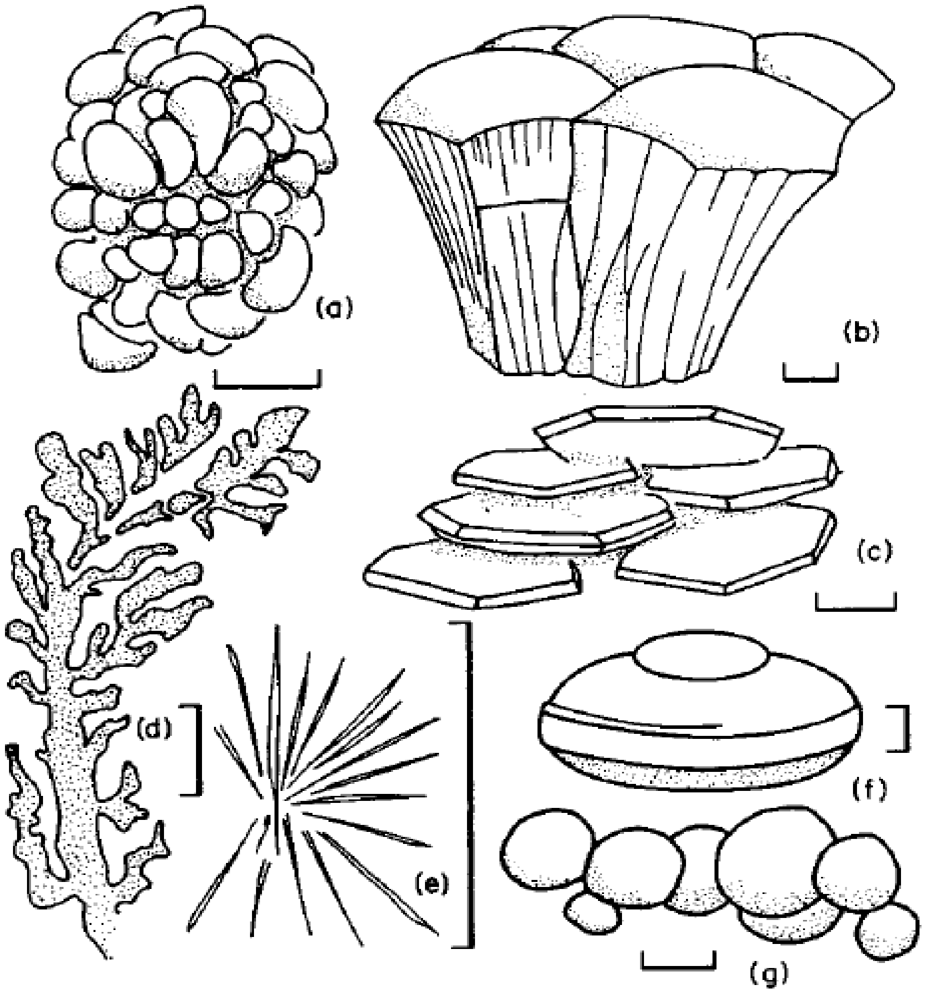
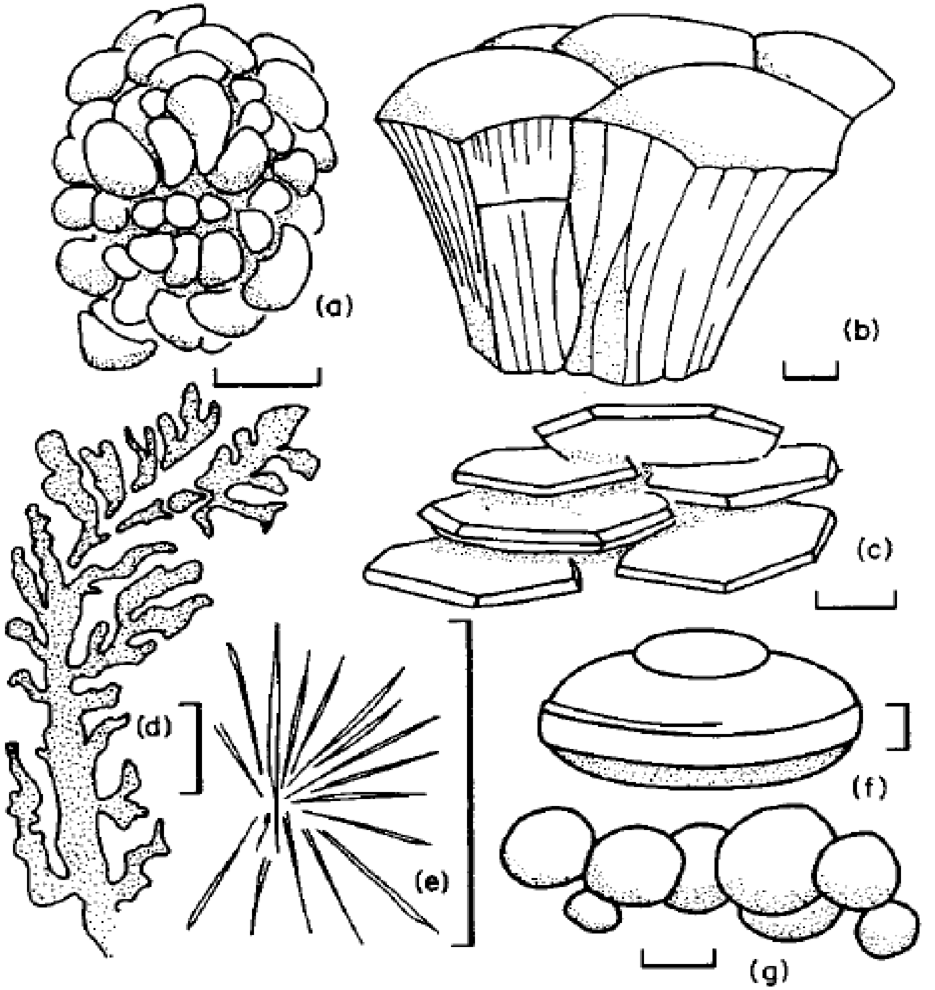


Fig. 4.1 Common shapes of mineral clusters: scale bar=1 cm. (**a**) Botryoidal. (**b**) Reniform. (**c**) Tabular. (**d**) Dendritic. (**e**) Acicular. (**f and g**) Concretionary.

Form

Reniform - kidney-shaped, the rounded surfaces of the mineral resembling those of kidneys; e.g. kidney iron ore, a variety of haematite.



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Form

Tabular - showing broad flat surfaces; e.g. the 6-sided crystals of mica.

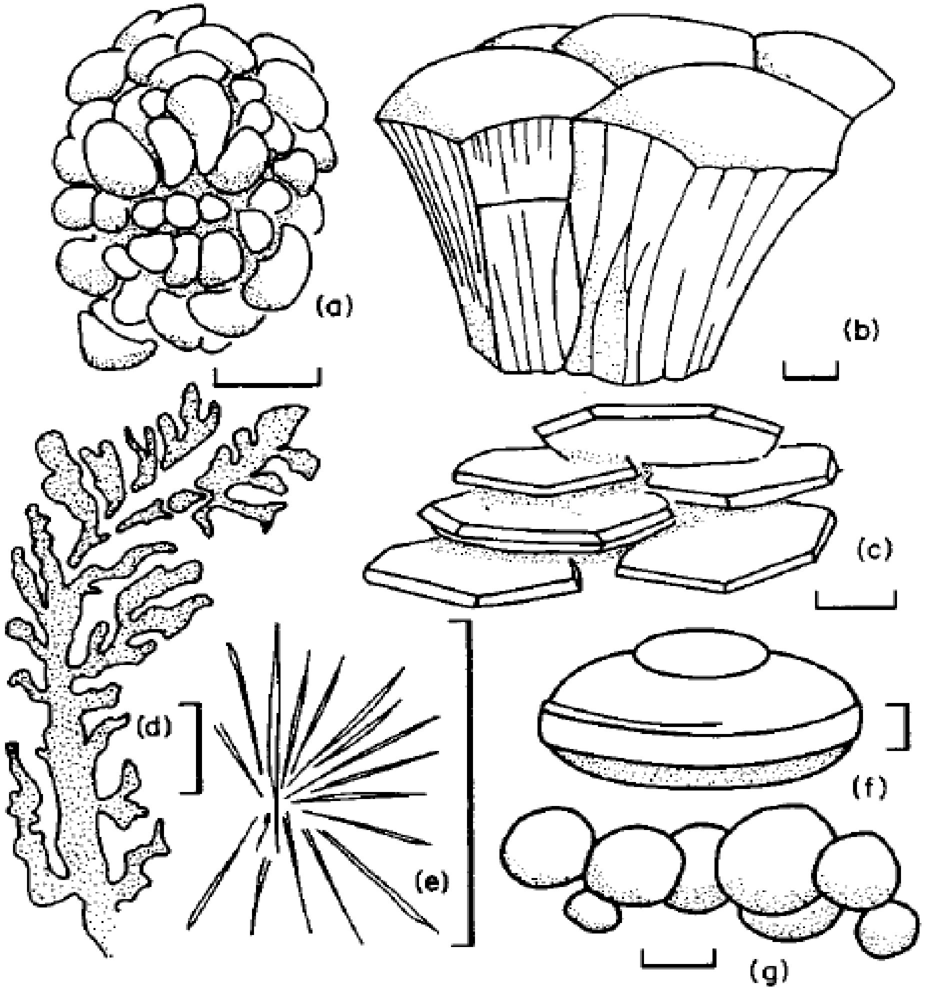


Fig. 4.1 Common shapes of mineral clusters: scale bar=1 cm. (**a**) Botryoidal. (**b**) Reniform. (**c**) Tabular. (**d**) Dendritic. (**e**) Acicular. (**f and g**) Concretionary.

Mineral Strength

How easily minerals break or deform under stress is determined by the type and strength of the chemical bonds that hold the crystals together. Mineralogists use terms including *tenacity*, *hardness*, *cleavage*, and *fracture* to describe mineral strength and how minerals break when stress is applied.

Tenacity

- The term tenacity describes a mineral's toughness, or its resistance to breaking or deforming.
- The response of a mineral to a hammer blow, to cutting with a knife and to bending is described by its tenacity.
- Minerals that can be beaten into new shapes are *malleable;* e.g. the native metals of gold, silver and copper.
- Most minerals are *brittle* and fracture when struck with a hammer. A few brittle minerals can be cut with a knife and are described as *sectile*.
- Flakes of mica can be bent and yet return to their flat tabular shape when free to do so: they are both *flexible* and *elastic:* cleavage flakes of gypsum are flexible but *inelastic.*

Descriptive terms for the tenacity of minerals

- Brittle-shatters easily.
- Flexible- can be bent, but will not return to original position af ter pressure is released.
- Elastic- can be bent, and returns to original position after pressure is released.
- Malleable-can be hammered into thin sheets.
- Sectile- can be cut by a knife.
- Ductile- can be drawn into thin wires.

Hardness

Hardness, or resistance to abrasion, is measured relative to a standard scale often minerals, known as Mohs' Scale of Hardness.

These minerals are chosen so that their hardness increases in the order 1 to 10. Hardness is tested by attempting to scratch the minerals of the scale with the specimen under examination.

A mineral which scratches calcite, for example, but not fluorspar, is said to have a hardness between 3 and 4, or H = 3-4.

Table 2.6 Mohs scale of hardness

Hardness (H)	*Mineral*	*Character*
1	Talc	Soapy to greasy feel
2	Gypsum	Can be scratched by finger nails
3	Calcite	Can be scratched by a copper coin
4	Fluorspar	Can be scratched by a penknife
5	Apatite	Can be scratched by window glass
6	Orthoclase	Can be scratched by a steel file
7	Quartz	Equivalent hard object porcelain
8	Topaz	Can be scratched by corundum but not by quartz
9	Corundum	Cannot be scratched by any mineral except diamond
10	Diamond	Cannot be scratched by corundum

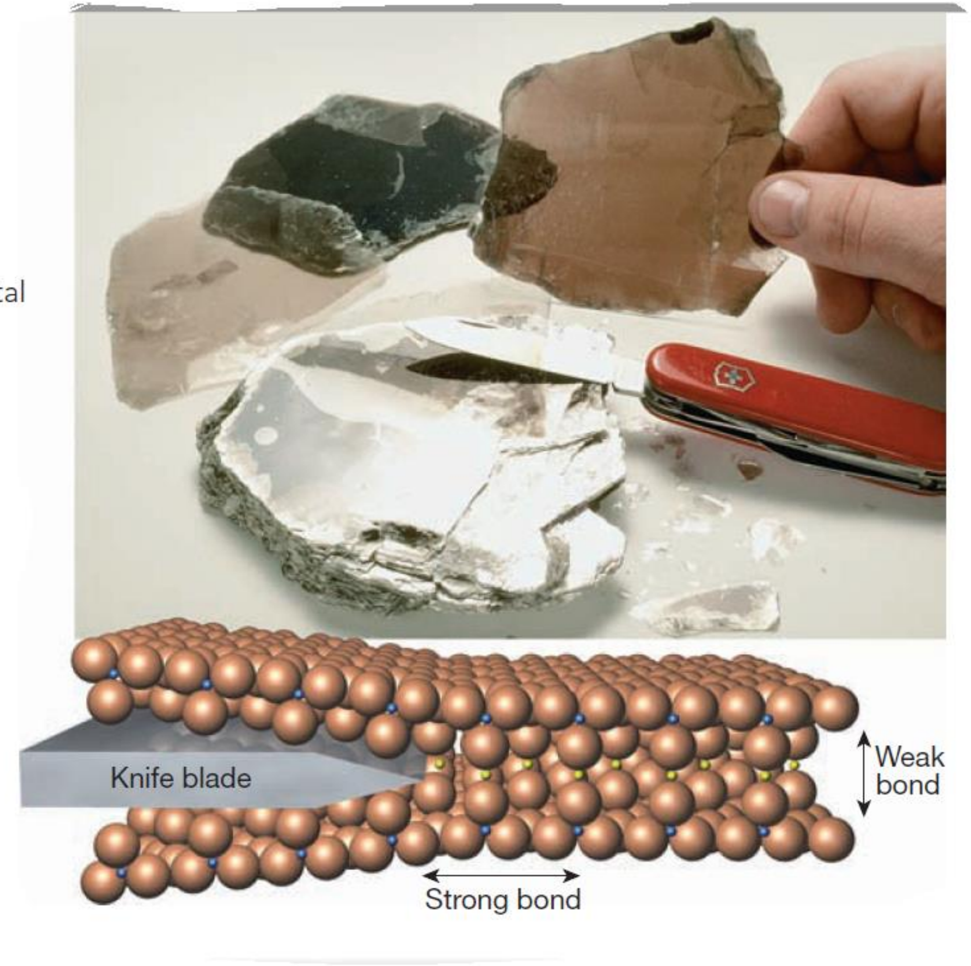
CLEAVAGE

In the crystal structure of many minerals, some atomic bonds are weaker than others. It is along these weak bonds that minerals tend to break when they are stressed. Cleavage(*Kleiben* = carve) is the tendency of a mineral to break (cleave) along planes of weak bonding. Not all minerals have cleavage, but those that do can be identified by the relatively

The simplest type of cleavage is exhibited by the micas (FIGURE 2.15).

Because these minerals have very weak bonds in one direction, they cleave to form thin, flat sheets. Some minerals have excellent cleavage in one, two, three, or more directions, whereas others exhibit fair or poor cleavage, and still others have no cleavage at all. When minerals break evenly in more than one direction, cleavage is described by *the number of cleavage directions and the angle(s) at which they meet*

FIGURE 2.15 The thin sheets shown here were produced by splitting a mica (muscovite) crystal parallel to its perfect cleavage. *(Photo by Chip Clark)*



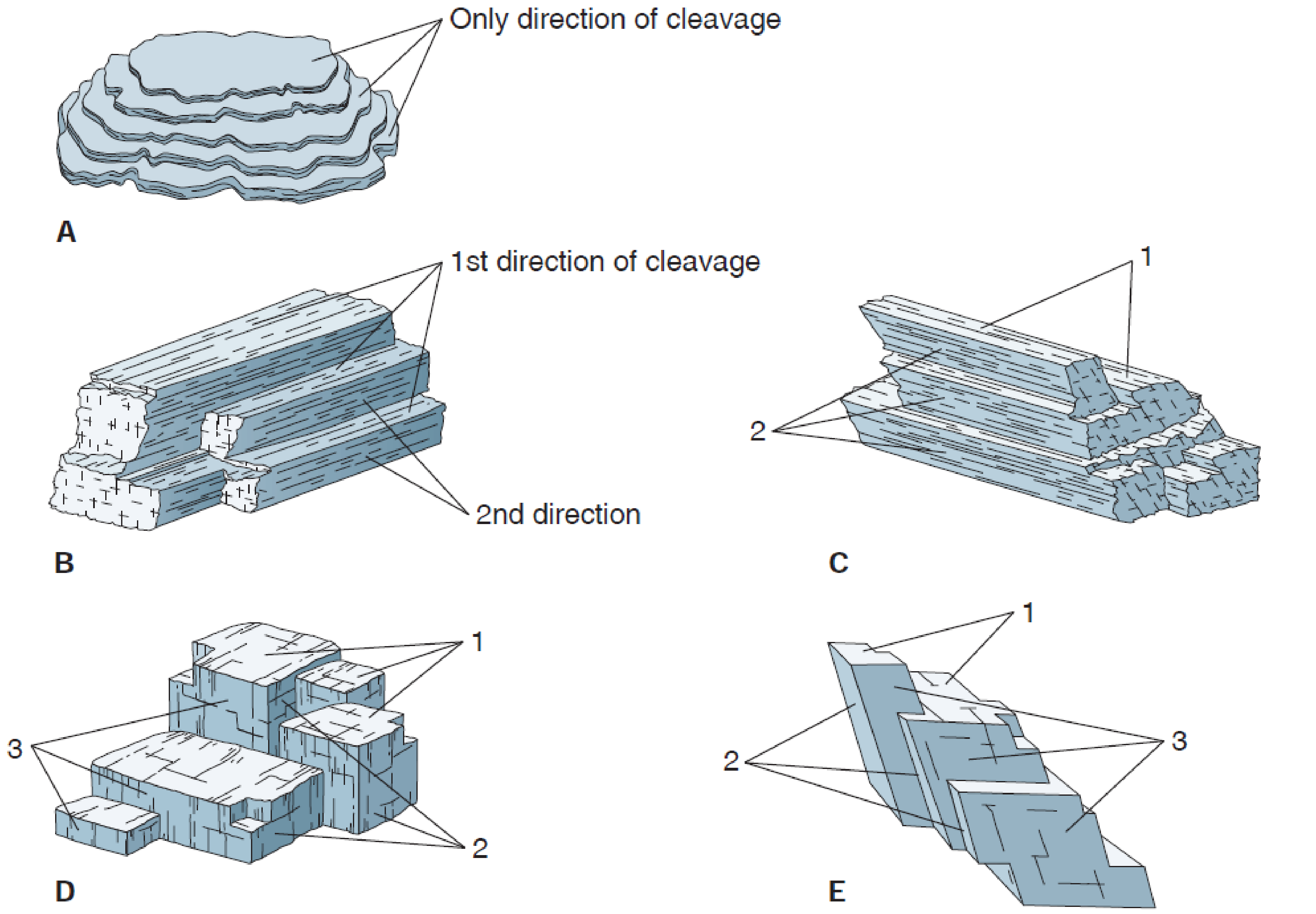


FIGURE 9.23

Most common types of mineral cleavage. Straight lines and flat planes represent cleavage. (*A*) One direction of cleavage. Mica is an example. (*B*) Two directions of cleavage that intersect at 90° angles. Feldspar is an example. (*C*) Two directions of cleavage that do not intersect at 90° angles. Amphibole is an example. (*D*) Three directions of cleavage that intersect at 90° angles. Halite is an example. (*E*) Three directions of cleavage that do not intersect at 90° angles. Calcite is an example. Not shown are the two other possible types of cleavage—four directions (such as in diamond) and six directions (as in sphalerite).

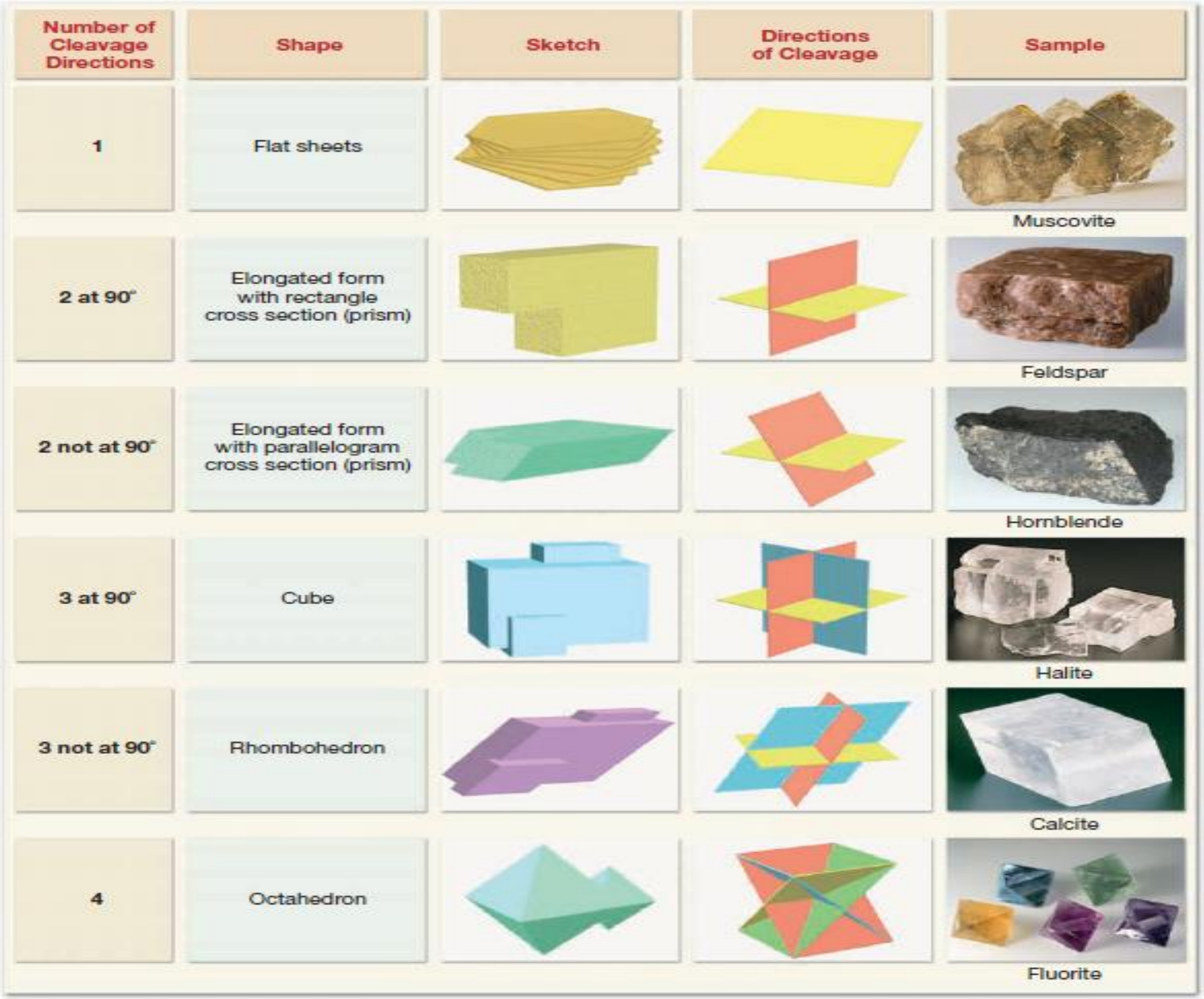
Cleavage

Many minerals possess a tendency to split easily in certain regular directions, and yield smooth plane surfaces called *cleavage planes* when thus broken. These directions depend on the arrangement of the atoms in a mineral , and are parallel to definite crystal faces. *Perfect, good, distinct,* and *imperfect* are terms used to describe the quality of mineral cleavage.

Mica, for example, has a perfect cleavage by means of which it can be split into very thin flakes;

feldspars have two sets of good cleavage planes;

Calcite has three directions of cleavage.



Number of Cleavage Directions	Shape	Sketch	Directions of Cleavage	Sample
1	Flat sheets			Muscovite
2 at 90°	Elongated form with rectangle cross section (prism)			Feldspar
2 not at 90°	Elongated form with parallelogram cross section (prism)			Hornblende
3 at 90°	Cube			Halite
3 not at 90°	Rhombohedron			Calcite
4	Octahedron			Fluorite

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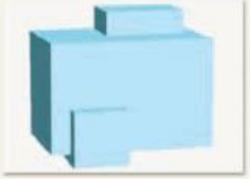
3 at 90°	Cube			 Halite
3 not at 90°	Rhombohedron			 Calcite
4	Octahedron			 Fluorite

Fracture

Fracture is the way a substance breaks where not controlled by cleavage. Minerals that have no cleavage commonly have an *irregular fracture.*

The nature of a broken surface of a mineral is known as *fracture,* the break being irregular and independent of cleavage. It is sometimes characteristic of a mineral and, also, a fresh fracture shows the true colour of a mineral.

Fracture is described as *conchoidal,* when the mineral breaks with a curved surface, e.g. in quartz and flint;

Even, when it is nearly flat;

Uneven, when it is rough;

Hackly when the surface carries small sharp irregularities. Most minerals show uneven fracture.

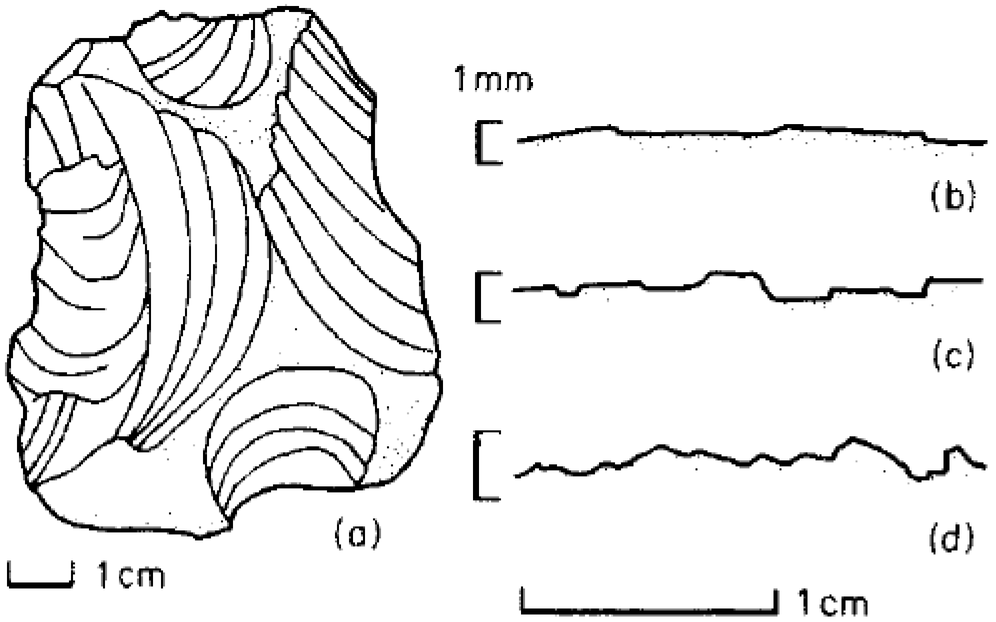


Fig. 4.3 Mineral fracture. (**a**) Conchoidal, which can occur on a smaller scale than shown. (**b**) Even. (**c**) Uneven. (**d**) Hackly.

FIGURE 2.17 Conchoidal fracture. The smooth curved surfaces result when minerals break in a glasslike manner. *(Photo by E. J. Tarbuck)*

Density and Specific Gravity

Density, an important property of matter, is defined as mass per unit volume. Mineralogists often use a related measure called specific gravity to describe the density of minerals. Specific gravity is a number representing the ratio of a mineral's weight to the weight of an equal volume of water.

Most common rock-forming minerals have a specific gravity of between 2 and 3. For example, quartz has a specific gravity of 2.65. By contrast, some metallic minerals such as pyrite, native copper, and magnetite are more than twice as dense and thus have more than twice the specific gravity as quartz. Galena, an ore of lead, has a specific gravity of roughly 7.5, whereas the specific gravity of 24-karat gold is approximately 20.

Mineral Groups

Over 4000 minerals have been named, and several new ones are identified each year.

Collectively, these few make up most of the rocks of Earth's crust and, as such, are often referred to as *the rock-forming minerals*.

- Although less abundant, many other minerals are used extensively in the manufacture of products and are called *economic minerals.*

Mineral Groups

It is worth noting that *only eight elements* make up the vast majority of the rock-forming minerals and represent more than 98 percent (by weight) of the continental crust (FIGURE 2.20).

These elements, in order of abundance, are oxygen (O),

- silicon (Si),
- aluminum (Al),
- iron (Fe),
- calcium (Ca),
- sodium (Na),
- potassium (K), and
- magnesium (Mg).

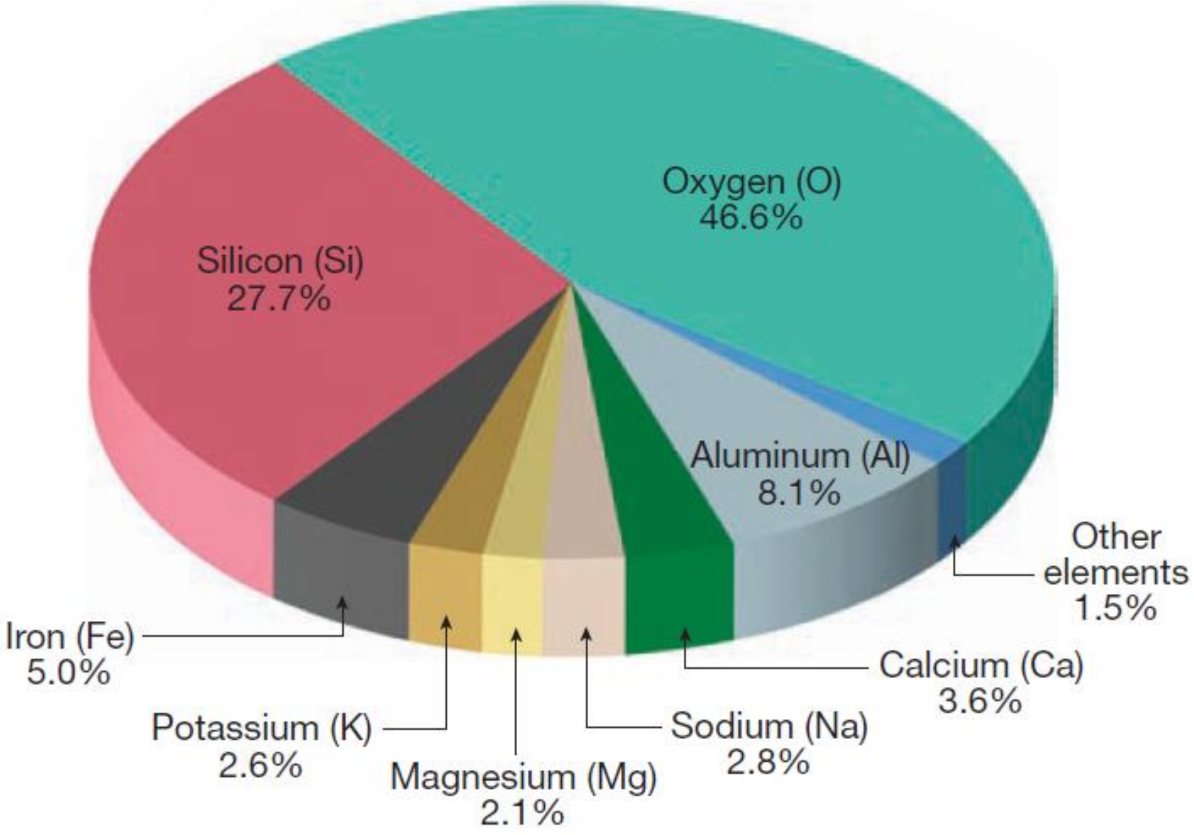


FIGURE 2.20 Relative abundance of the eight most abundant elements in the continental crust.

Mineral Groups

- As shown in Figure 2.20, silicon and oxygen are by far the most common elements in Earth's crust. Furthermore, these two elements readily combine to form the basic "building block" for the most common mineral group, the silicates.
- More than 800 silicate minerals are known, and they account for more than 90 percent of Earth's crust.
- Because other mineral groups are far less abundant in Earth's crust than the silicates, they are often grouped together under the heading nonsilicates.

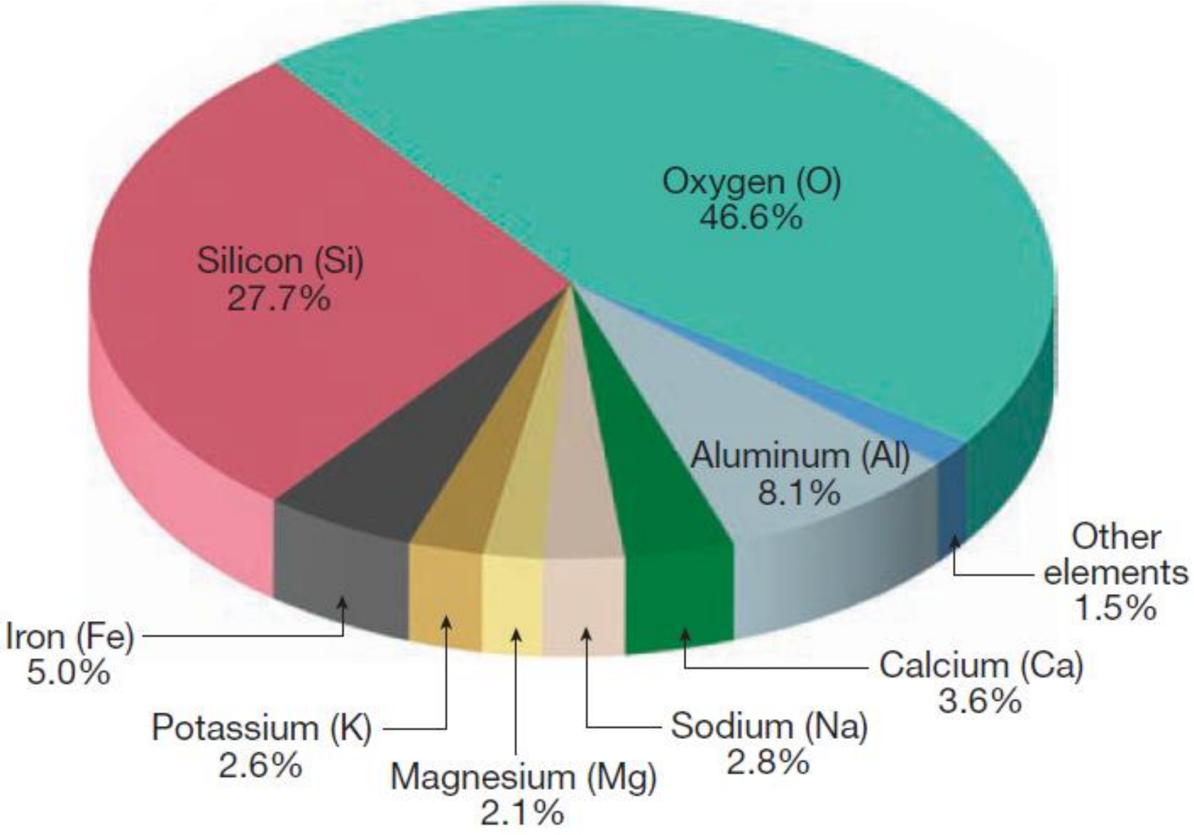


FIGURE 2.20 Relative abundance of the eight most abundant elements in the continental crust.

The rock-forming minerals

- Silicates, oxides, and carbonates are the main rock-forming minerals.
- Minerals that are the dominant constituents of rocks are called *essential* rock-forming minerals. Quartz, feldspars, amphiboles, pyroxenes, micas, chlorite, nepheline, olivine, serpentine, talc, calcite, dolomite, gypsum, magnetite, and hematite are essential rock-forming minerals.
- In addition to these minerals, there are others that occur in rocks in minor proportions. These are known as *accessory* rock-forming minerals, which include garnet, tourmaline, epidote, zircon, apatite, rutile, ilmenite, magnetite, hematite, pyrite, staurolite, kyanite, and sillimanite.

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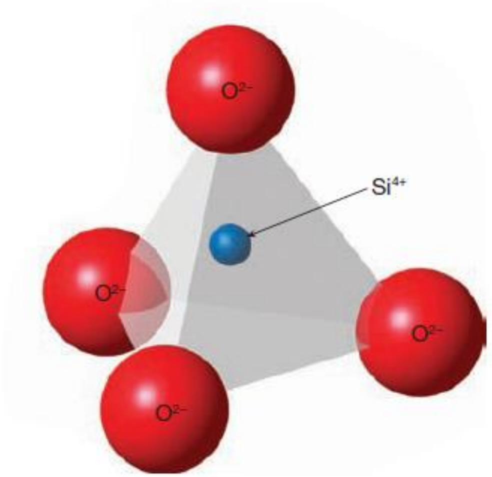
- ilmenite,
- magnetite,
- hematite,
- pyrite,
- staurolite,
- kyanite, and sillimanite.

The rock-forming minerals: Silicates

- The silicates make up about 95 percent of the Earth's crust and upper mantle, occurring as the major constituents of most igneous rocks and in appreciable quantities in sedimentary and metamorphic varieties as well. They also are important constituents of lunar samples, meteorites, and most asteroids. In addition, planetary probes have detected their occurrence on the surfaces of Mercury, Venus, and Mars.
- Of the approximately 600 known silicate minerals, only the feldspars, amphiboles, pyroxenes, micas, olivines, feldspathoids, and zeolites are significant in rock formation.
- Because other mineral groups are far less abundant in Earth's crust than the silicates, they are often grouped together under the heading non silicates.

Silicates

- The basic structural unit of all silicate minerals is the silicon tetrahedron in which one silicon atom is surrounded by and bonded to four oxygen atoms, each at the corner of a regular tetrahedron.



Common Silicate Minerals

The major groups of silicate minerals and common examples are given in FIGURE 2.24.

The feldspars are, by far, the most plentiful silicate group, comprising more than 50 percent of Earth's crust.

Quartz, the second most abundant mineral in the continental crust, is the only common mineral made completely of silicon and oxygen.

Most silicate minerals form when molten rock cools and crystallizes. Cooling can occur at or near Earth's surface (low temperature and pressure) or at great depths (high temperature and pressure). The environment during crystallization and the chemical composition of the molten rock determine, to a large degree, which minerals are produced. For example, the silicate mineral olivine crystallizes at high temperatures, whereas quartz crystallizes at much lower temperatures.

The Light Silicates

The light (or nonferromagnesian) silicates are generally light in color and have a specific gravity of about 2.7, which is considerably less than the dark (ferromagnesian) silicates. These differences are mainly attributable to the presence or absence of iron and magnesium.

- Feldspar,
- Quartz.
- Muscovite.
- Clay Minerals.

The Dark Silicates

The dark (or ferromagnesian) silicates are those minerals containing ions of iron and/or magnesium in their structure.

Because of their iron content, ferromagnesian silicates are dark in color and have a greater specific gravity, between3.2 and 3.6, than nonferromagnesian silicates.

The most common dark silicate minerals are:

- olivine,
- the pyroxenes,
- the amphiboles,
- dark mica (biotite), and
- garnet.

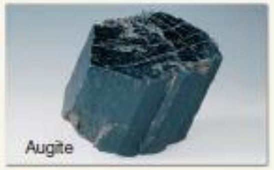
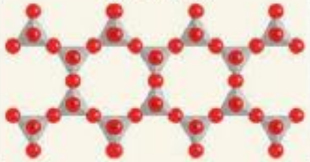
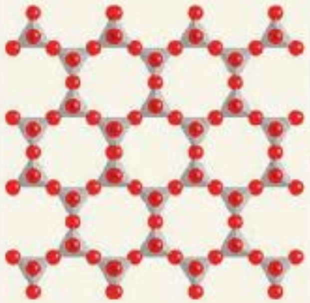
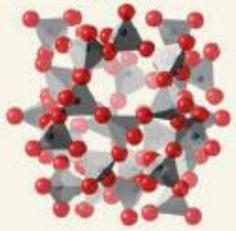
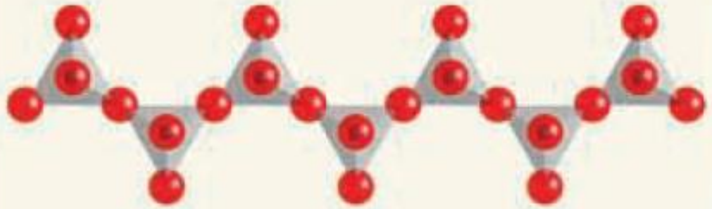
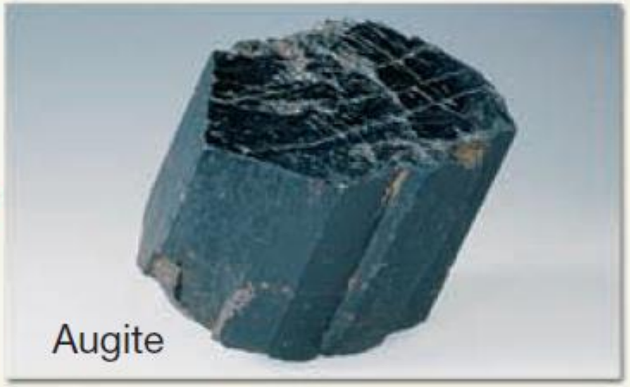
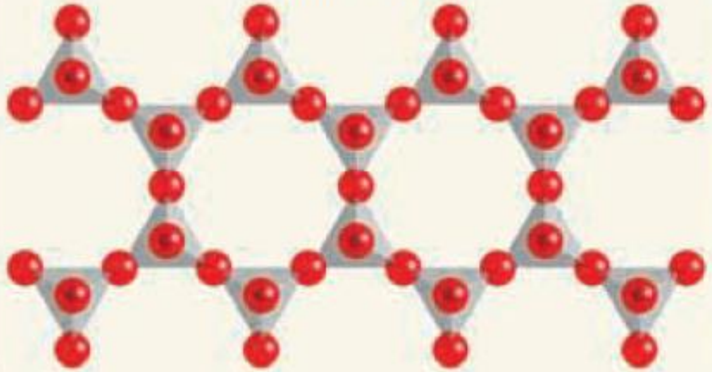
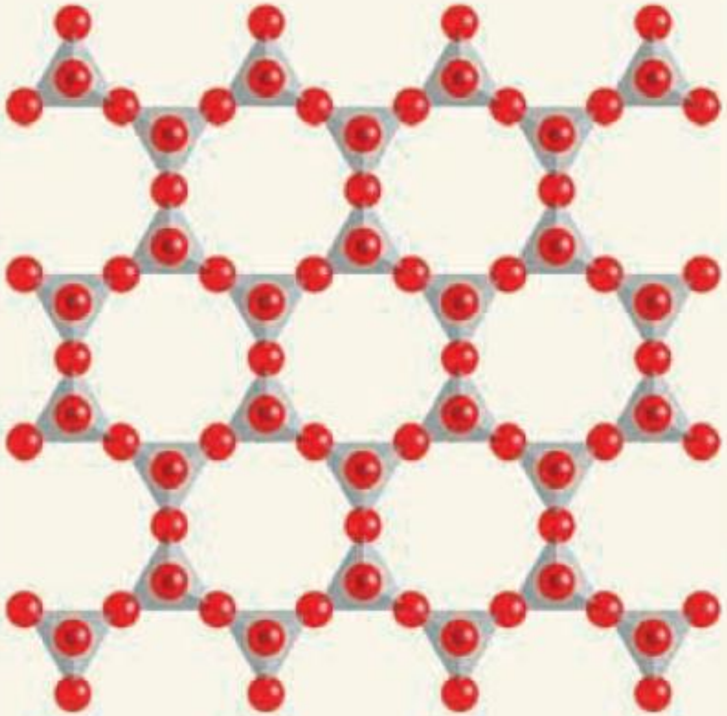
Mineral/Formula		Cleavage	Silicate Structure	Example
	Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedron 	
	Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains 	
	Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	
Micas	Biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 	
Micas	Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$	One plane	Sheets	
Feldspars	Potassium feldspar (Orthoclase) $KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks 	
Feldspars	Plagioclase $(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks	
	Quartz SiO_2	None	Three-dimensional networks	

FIGURE 2.24 Common silicate minerals. Note that the complexity of the silicate structure increases from top to bottom. *(Photos by Dennis Tasa and E. J. Tarbuck)*

Mineral/Formula	Cleavage	Silicate Structure	Example
Olivine group $(Mg, Fe)_2SiO_4$	None	Single tetrahedron 	
Pyroxene group (Augite) $(Mg,Fe)SiO_3$	Two planes at 90°	Single chains 	
Amphibole group (Hornblende) $Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains 	

Micas	**Biotite** $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets 	
	Muscovite $KAl_2(AlSi_3O_{10})(OH)_2$			

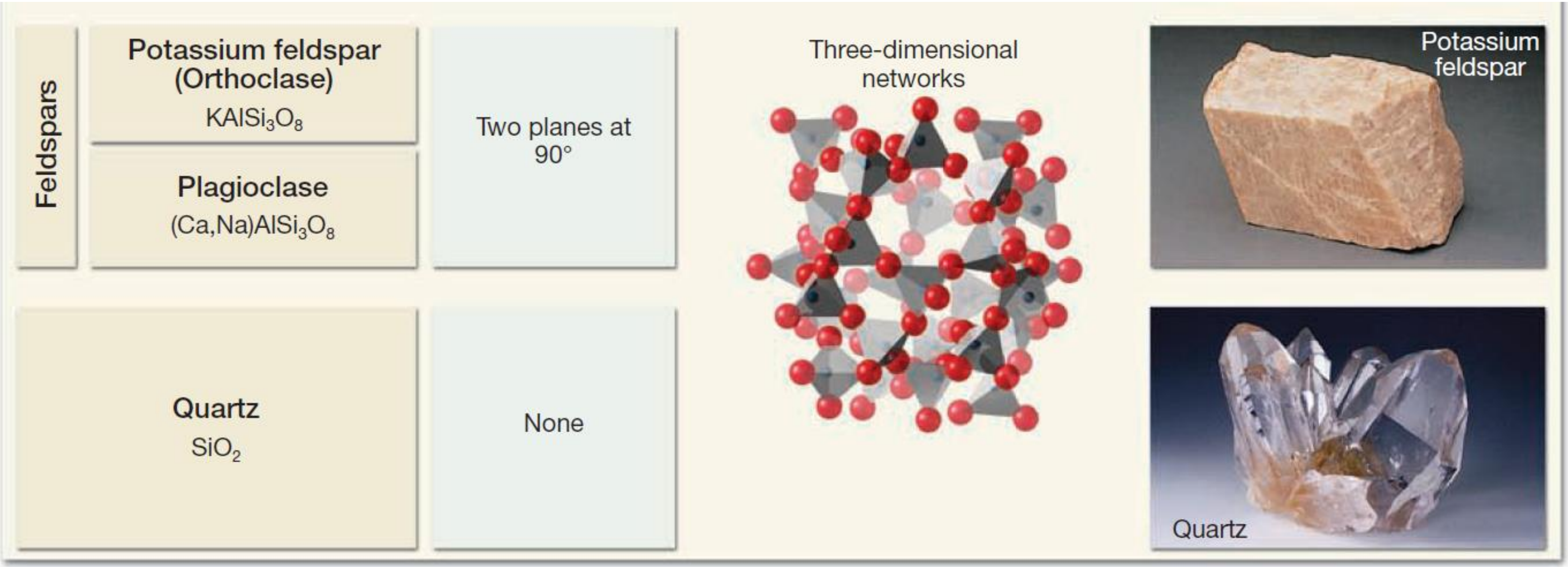


FIGURE 2.24 Common silicate minerals. Note that the complexity of the silicate structure increases from top to bottom. *(Photos by Dennis Tasa and E. J. Tarbuck)*

Important Nonsilicate Minerals

- Nonsilicate minerals are typically divided into groups, based on the negatively charged ion or complex ion that the members have in common.
- Although the nonsilicates make up only about 8 percent of Earth's crust, some minerals, such as gypsum, calcite, and halite, occur as constituents in sedimentary rocks in significant amounts.

Non silicate minerals

Common Nonsilicate Mineral Groups

Mineral Groups [key ion(s) or element(s)]	Mineral Name	Chemical Formula	Economic Use
Carbonates (CO_3^{2-})	Calcite	$CaCO_3$	Portland cement, lime
	Dolomite	$CaMg(CO_3)_2$	Portland cement, lime
Halides (Cl^{1-}, F^{1-}, Br^{1-})	Halite	$NaCl$	Common salt
	Fluorite	CaF_2	Used in steelmaking
	Sylvite	KCl	Fertilizer
Oxides (O^{2-})	Hematite	Fe_2O_3	Ore of iron, pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
Sulfides (S^{2-})	Galena	PbS	Ore of lead
	Sphalerite	ZnS	Ore of zinc
	Pyrite	FeS_2	Sulfuric acid production
	Chalcopyrite	$CuFeS_2$	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates (SO_4^{2-})	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements (single elements)	Gold	Au	Trade, jewelry
	Copper	Cu	Electrical conductor
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst

Common Nonsilicate Mineral Groups

Mineral Groups [key ion(s) or element(s)]	Mineral Name	Chemical Formula	Economic Use
Carbonates (CO_3^{2-})	Calcite	$CaCO_3$	Portland cement, lime
	Dolomite	$CaMg(CO_3)_2$	Portland cement, lime

Non silicate minerals

Halides (Cl^{1-}, F^{1-}, Br^{1-})	Halite	$NaCl$	Common salt
	Fluorite	CaF_2	Used in steelmaking
	Sylvite	KCl	Fertilizer

Non silicate minerals

Oxides (O^{2-})	Hematite	Fe_2O_3	Ore of iron, pigment
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water

Non silicate minerals

Sulfides (S^{2-})	Galena	PbS	Ore of lead
	Sphalerite	ZnS	Ore of zinc
	Pyrite	FeS_2	Sulfuric acid production
	Chalcopyrite	$CuFeS_2$	Ore of copper
	Cinnabar	HgS	Ore of mercury

Non silicate minerals

Sulfates (SO_4^{2-})	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud

Non silicate minerals

Native elements (single elements)	Gold	Au	Trade, jewelry
	Copper	Cu	Electrical conductor
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst