LAB 2

Common Minerals

OBJECTIVES

- **To develop a logical and systematic approach to mineral identification**
- **To be able to recognize some of the common rock-forming minerals**
- **To become familiar with the classification system of minerals, particularly the silicate minerals**
- **To become familiar with some resource minerals**

In this chapter, we will work with minerals to identify them, recognize them, classify them, and think about them as resources. By approaching mineral *identification* systematically and logically, even a beginner can distinguish a surprising number of minerals. Minerals generally have no "fingerprint," or single property that sets them apart from others, but you can tell them apart by *combinations* of physical properties. The layout of identification tables (such as Tables 2.5 and 2.6, on pp. 24–28) lets you search through properties to find the name of a mineral.

In contrast to identification, for mineral *recognition* you must learn to connect a set of physical properties with the name of the mineral. This takes some practice, just as it takes a while to link names with faces in a new group of people.

More than 3000 different mineral species occur in rocks. The majority belong to the mineral classes or groups listed in ■ Table 2.1. Most of the 3000, however, are rare. Many of them are valuable resources. Silicates are the most abundant minerals. They include a large proportion of the rock-forming minerals, which make up the majority of rocks at the Earth's surface. Recognizing common rock-forming minerals is necessary to distinguish and interpret rocks correctly. You are only required to remember the most commonly occurring minerals, which will later aid in the identification of rocks, and perhaps a few common and easily recognized resource minerals (listed in ■ Tables 2.2 and 2.3). Your instructor may also ask you to identify a few minerals you have never seen before, to determine how well you have mastered the techniques of identification.

Table 2.1

Composition of Mineral Groups

Mineral Group	Chemical Makeup
Silicates	Contain silicon (Si) and oxygen (O) at least
Carbonates	CO_3 plus metal(s)
Sulfates	SO_4 plus metal(s)
Sulfides	S plus metal(s)
Oxides	O plus metal(s) without other nonmetals (no Si, C, P, S, V, or W)
Hydroxides	OH plus metal(s) without other nonmetals
Phosphates	PO_4 plus metal(s)
Halides	F, Cl, Br, or I plus metal(s) without other nonmetals
Native elements	Occur in elemental form (one element only)

Table 2.2

Common Rock-Forming Minerals — Silicate Mineral Group

Mineral	Chemical Formula	Silicate Subclass
1. Olivine[1]	$(Mg,Fe)_2SiO_4$	*Nesosilicates* (isolated Si tetrahedra)
Topaz	$Al_2SiO_4(F,OH)_2$	
2. *Garnet*[2]	$(Mg,Fe,Ca,Mn)_3(Al,Fe,Cr)_2(SiO_4)_3$	
Varieties: almandine, grossular		
Tourmaline	$(Na,Ca)(Li,Mg,Al)_3(Al,Fe,Mn)_6(BO_3)_3(Si_6O_{18})(OH)_4$	*Cyclosilicates* (ring silicates)
Beryl	$Be_3Al_2(Si_6O_{18})$	
Pyroxenes:		Inosilicates (chain silicates)
3. Augite	$(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$	*Single chain*
Diopside	$CaMgSi_2O_6$	
Amphiboles:		*Double chain*
4. Hornblende	$(Ca,Na)_{2\text{-}3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH)_2$	
Actinolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	
Talc	$Mg_3Si_4O_{10}(OH)_2$	*Phyllosilicates* (sheet silicates)
5. Kaolin	$Al_2Si_2O_5(OH)_4$	
Chlorite	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)_6$	
Micas:		
6. Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	
7. Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	
8. *Feldspars:*		*Tectosilicates* (framework silicates)
Alkali feldspars	$(K,Na)AlSi_3O_8$	
Plagioclase feldspars	$(Na,Ca)Al_{1\text{-}2}Si_{3\text{-}2}O_8$	
9. Quartz	SiO_2	
Varieties: amethyst, rock crystal, smoky quartz, milky quartz, rose quartz Microcrystalline and amorphous varieties: chert, flint, jasper, agate, chalcedony (Amorphous solids are not tectosilicates; in fact, they are not even minerals, and are called *mineraloids* instead. Recall that a mineral must be crystalline.)		

[1] Important rock-forming minerals are numbered and shown in bold.

[2] Mineral group names are shown in italics.

CLASSIFICATION OF MINERALS

Mineral species are primarily classified on the basis of their nonmetal elements (see Table 2.1). Exceptions include minerals made up of only one element; all such minerals belong to the mineral group called the native elements. In a chemical formula of a compound (not a native element), the first part usually lists the metals; the second part, the nonmetals. Table 2.1 shows the chemical makeup for the primary mineral groups. Notice that all the mineral groups ending with *-ate* contain oxygen, and those ending with *-ide* do not contain oxygen unless *ox* is part of the name. Table 2.2 has examples of silicates. We will study silicate classification in more detail in later exercises. Table 2.3 lists some minerals (with formulas) belonging to other groups. Many non-silicate minerals are important resources, which we will discuss in the last two exercises.

1. Look at the mineral formulas listed in ■ Table 2.4, and fill in the mineral group name based on the chemical formulas. Refer to Table 2.1. Your instructor may have samples of these minerals to show you.

Table 2.3

Nonsilicate Mineral Groups, Common Rock-Forming Minerals and Some Resource Minerals

Mineral	Chemical Formula	Mineral Group
10. **Dolomite**	$CaMg(CO_3)_2$	Carbonates Basic unit: (CO_3)
11. **Calcite**	$CaCO_3$	
Varieties: Iceland spar, onyx, calcite chalk, travertine		
Malachite	$Cu_2CO_3(OH_2)$	
Azurite	$Cu_3(CO_3)_2(OH)_2$	
12. **Gypsum**	$CaSO_4 \cdot 2H_2O$	Sulfates Basic unit: (SO_4)
Varieties: alabaster, satin spar, selenite		
Galena	PbS	Sulfides S plus a metal(s)
13. **Pyrite**	FeS_2	
Sphalerite	ZnS	
Corundum	Al_2O_3	Oxides O plus a metal(s)
14. **Magnetite**	Fe_3O_4	
15. **Hematite**	Fe_2O_3	
Limonite	$FeO \cdot OH \cdot nH_2O$	Hydroxides (OH) plus metal(s)
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	Phosphates Basic unit: PO_4
Fluorite	CaF_2	Halides Halogen ion present
16. **Halite**	$NaCl$	
Metals:		Native elements Occur in elemental form
Silver	Ag	
Gold	Au	
Platinum	Pt	
Copper	Cu	
Iron	Fe	
Nonmetals:		
Diamond	C	
Graphite	C	
Sulfur	S	

Table 2.4

Group Identification (Exercise 1)

Mineral Name	Formula	Mineral Group
Sylvite	KCl	
Chalcopyrite	$CuFeS_2$	
Sulfur	S	
Tremolite	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	
Rutile	TiO_2	
Anhydrite	$CaSO_4$	

STRATEGY FOR MINERAL IDENTIFICATION

Successful mineral identification requires systematic application of the skills in determining physical properties you learned in Lab 1. Properties such as hardness, luster, streak, and cleavage usually indicate the identity of a mineral. ***Use of photographs***, such as those in Figures 1.9 and 1.10, ***cannot replace close examination of a mineral's physical properties***. For example, examine the photographs of talc and milky quartz in Figure 1.9e and m, on pp. 12–14, respectively. The hardness (1 versus 7) and even the luster (pearly versus vitreous) do not come across in the photographs. Avoid relying on a property such as color. Color is highly variable in many minerals, and different minerals can come in the same color. Would you identify a particular car as a Porsche, say, just because it was painted red? In the lab don't try to guess the mineral and then look up its properties. This would be like buying a red car, calling it a Porsche, and then being surprised when it wouldn't go 148 mph. In nature (and perhaps in your tests or quizzes) different specimens of the same mineral can display quite a wide variety of appearances, but many of their specific physical properties will always be the same.

A useful strategy is to use mineral tables methodically, as illustrated in the maze in ■ Figure 2.1. The mineral tables in this book are ▦ Tables 2.5 and 2.6, on pp. 24 and 25–28.

- Determine the luster of the mineral first (the top of the maze, Figure 2.1) and then go to the appropriate set of tables.
- For metallic minerals, the streak can be quite useful, so test the streak next; then proceed to identify the mineral, using Table 2.5.
- For nonmetallic minerals, test the hardness with glass (H = 5½) and check for cleavage; then go to the appropriate section in Table 2.6.
- You can probably now identify the mineral from the remaining possible choices simply by checking color, and further refining hardness, luster, and cleavage.

If you use the maze in Figure 2.1, you will successfully follow the procedure just described. Identification then becomes a process of elimination.

2. Practice the systematic method of mineral identification on the five samples provided by following the maze in Figure 2.1. Write your answers directly in the maze. Each sample in this set should guide you to follow a different path. For the last step in the maze, determining the mineral group, first use the chemical formula or composition information from the identification tables; then go to Tables 2.1 through 2.3 to determine the mineral group.

3. Finish the Mineral Identification Chart in Table 1.12, on p. 3 for a set of "unknown" minerals. Use the procedure in Exercise 2, following the maze in Figure 2.1, to recognize a mineral you may have already started mineral identification on in Lab 1. Now, by following the maze, you can finish the last two columns. Check your final identification by comparing your unknown sample with the properties listed in the Mineral Tables 2.5 and 2.6, and if available, with a mineral reference set of labeled samples provided by your instructor. The procedure will be slow at first, but it will go more quickly with practice.

USING THE MINERAL IDENTIFICATION TABLES (TABLES 2.5 AND 2.6)

Tables 2.5 and 2.6 on the following pages will help you identify unknown mineral specimens. The two main subdivisions are minerals with metallic lusters (Table 2.5) and minerals with nonmetallic luster (Table 2.6). Each section starts with the hardest mineral and ends with the softest. Follow the maze (Figure 2.1) for the first few specimens to learn the correct methodical approach. The abbreviations are CL = cleavage, P = parting, L = luster, S = streak, F = fracture, D = density (in g/cm^3) or specific gravity (no units).

Text continued on p. 29

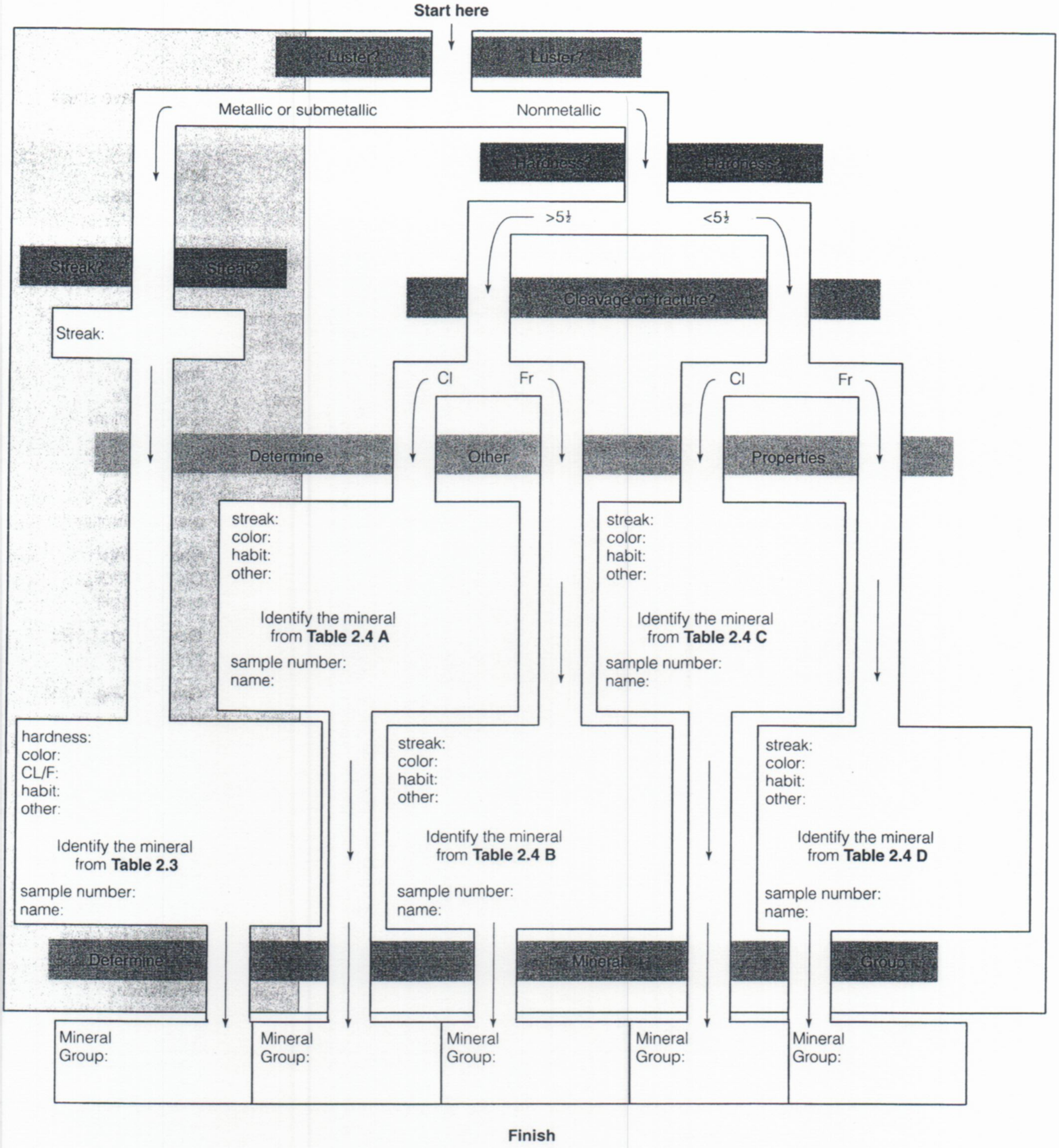


Figure 2.1

Maze for systematic mineral identification (and Exercise 2): Select a mineral sample and follow the maze with that sample in mind. At each shaded region, test the sample (or refer to the tests made in Lab 1 for that sample) and decide which path to follow based on the resulting mineral property.

Table 2.5

Minerals with Metallic and Submetallic Luster

Table 2.5 is divided into two subdivisions: dark streak and medium streak. Generally, minerals with metallic lusters have streak colors that are diagnostic. Especially diagnostic properties are shown in **bold**.

Streak	**Color**	**Hardness**	**Comments**	**Mineral** ***Composition***
Dark streak: green-black	Brass yellow	6–6½	"Fool's gold"; S = green-black; D = 5.0; cubic or pyritohedral crystals; F = irregular	**Pyrite** (Fig. 1.10d) *Fe sulfide*
	Black	6	**Strongly magnetic;** D = 5.2; S = black to gray-black; F = irregular; octahedral crystals; L = submetallic	**Magnetite** (Fig. 1.10f) *Fe oxide,* ore of iron
to	Iron-black	5½–6	S = black to brownish red; L = metallic to submetallic; D = 4.7; may be slightly magnetic; platy crystals, common accessory in sand, sandstone, and igneous rocks	**Ilmenite** *Fe, Ti oxide,* ore of titanium
dark brown	Iron-black to brownish black	5½	S = dark brown; submetallic luster; granular aggregates; D = 4.6. Color and streak are diagnostic.	**Chromite** *Fe, Cr oxide,* ore of chromium
to	Brass yellow	3½–4	Called "peacock ore" because of the iridescent purple tarnish; S = green-black; D = 4.1–4.3	**Chalcopyrite** *Cu, Fe sulfide,* ore of copper
	Gun metal gray	2½	CL = 3 at right angles (perfect cubic CL); S = lead gray; **D = 7.6;** very bright metallic luster	**Galena** (Fig. 1.10c) *Pb sulfide*
gray-black	Iron black/steel gray	**1–2**	Soils fingers; S = dark gray; D = 2.2; L = metallic to submetallic; greasy feel	**Graphite** (Fig. 1.10j) *Native C*
Medium streak: pale brown	Brown to black	6–6½	S = pale brown; D = 4.2; prismatic crystals, sometimes in quartz (*rutilated quartz*); found in black sand	**Rutile** *Ti oxide,* ore of titanium
to red-brown to	Steel gray	5–6½ flakes	Specular variety is bright metallic and steel gray. **S = red-brown to brown;** D = 5.3; F = irregular; aggregate of tabular crystals ("micaceous" hematite)	**Specular hematite** (Fig. 1.10g) *Fe oxide* ore of iron
yellow-brown	Dark to brown to black	5–5½	S = yellow-brown; D = 3.3–5½; F = irregular. Luster may be obscured by hydration. "Limonite" is often used to name any hydrous iron oxide.	**Limonite** *Hydrous Fe oxide,* ore of iron
to	Yellowish-bronze	3½–4	S = light bronze brown; octahedral parting; granular aggregates; D = 4.6	**Pentlandite** *Fe Ni sulfide,* ore of nickel
yellow	Dark brown to yellow	3½–4	Variegated appearance common; L = resinous, adamantine, or submetallic; **S = yellow to brown** and lighter than sample; D = 3.9–4.1; CL = 6 good planes	**Sphalerite** (Fig. 1.10 e) *Zn sulfide,* ore of zinc
to	Shades of yellow	2½–3	S = gold yellow — shiny; plates, flakes, or nuggets; D = 19.3 when pure; very malleable and ductile; color yellow, paler with increasing silver content	**Gold** *Native Au,* ore of gold
coppery red	**Copper (red)**	2½–3	Malleable and ductile; S = copper brown; D = 8.9; L = metallic, but surface is often tarnished and may be oxidized to blue; branching crystals	**Copper** *Native Cu,* ore of copper

Table 2.6

Minerals with Nonmetallic Luster

Table 2.6 consists of four sections, one page each, as follows:

Section A: Minerals harder than glass with cleavage or parting	Section B: Minerals harder than glass with fracture
Section C: Minerals softer than glass with cleavage	Section D: Minerals softer than glass with apparent fracture

Section A: Minerals that show cleavage or parting and H ≥ glass*

Streak	Color	Hardness	Comments	Mineral *Composition*
No streak	Colorless to pale yellow, color varies	10 — hardest known substance	CL = 4 directions perfect ≠90°, octahedral cleavage; crystals usually octahedrons; D = 3.5; L = **adamantine to greasy**; high brilliance due to high index of refraction. Color commonly pale yellow to colorless but may be pale shades of red, orange, green, blue, or brown. Hardness, luster, and cleavage are diagnostic.	**Diamond** *Native C*
	Brown to pink; almost any color	9 — test on a fresh surface	P = basal. **Hardness is diagnostic**; D = 3.9–4.1; L = vitreous to adamantine. Hexagonal prismatic crystals that narrow toward the ends. Gem varieties include ruby (red) and sapphire (blue).	**Corundum** *Al oxide*
	Colorless, yellow, white, pink, blue, green	8	**CL = 1** direction, basal; D = 3.4–3.6; L = vitreous. Hardness is diagnostic.	**Topaz** *Al, F, OH silicate with single tetrahedra*
	Blue-green or yellow	7½–8	CL = 1 imperfect, uneven F is more apparent: D = 2.6–2.8. Some gem varieties are aquamarine, emerald (deep green), and rose beryl.	**Beryl** *Be, Al ring silicate*
	Pink reddish-brown, olive green	7½	CL = 2 directions near 90°; nearly square prisms; D = 3.2; L = vitreous; **dark cruciform cross in cross** section.	**Andalusite** *Al silicate*
	Blue to gray	**7 and 5** depending on direction	CL = 1 direction; bladed crystals; D = 3.6–3.7; L = vitreous to pearly; **H = 7** perpendicular to blades and **H = 5** parallel to blades; blue color and different hardness in different directions are diagnostic.	**Kyanite** *Al silicate*
	Colorless to brown or pale green	6–7	CL = 1 direction; fibrous to acicular; D = 3.2; L = vitreous.	**Sillimanite** *Al silicate*
	White, cream, gray, salmon to dark pink	6	**CL = 2** good planes at 90°; D = 2.5–2.6; L = vitreous. CL is diagnostic. A pink color often distinguishes K-rich feldspars. Amazonite is a rare blue-green variety of microcline.	Alkali **Feldspars** (Fig. 1.9i) *K, Na, Al Tectosilicate*
	White, gray, greenish or bluish gray	6	**CL = 2** good planes at ~90°; D = 2.6–2.8; L = vitreous. An iridescent play of colors may be seen in labradorite. Parallel, regular striations on a cleavage plane (twinning) are common in the plagioclase series. Albite (Na-rich) and anorthite (Ca-rich) are the end members.	Plagioclase **Feldspars** (Fig. 1.9j) *Na, Ca, Al tectosilicate*
	Greenish dark gray to black	5–6	**CL = 2** at 90° (not perfectly planar); D = 3.2–3.3; S = pale green to gray if any; L = vitreous (slightly duller than hornblende). Stubby crystals.	Augite (pyroxene) (Fig. 1.9c) *Single-chain silicate*
	Black	5–6	**CL = 2 at approx. 120° and 60°**; D = 3.0–3.3; S = pale gray if any; L = **vitreous.** Habit = prismatic with a diamond-shaped cross section.	**Hornblende** (amphibole)(Fig. 1.9d) *Double-chain silicate*
	Medium to dark green	5–6	CL = 2 at approx. 120° and 60° (may not be visible in fine acicular crystals); D = 3.1–3.3; S = light gray if any; L = vitreous. Color and acicular habit are diagnostic.	**Actinolite** (amphibole) *Double-chain silicate*

*See p. 22 for abbreviations and units. Properties that are especially diagnostic are shown in **bold**.

Table 2.6—cont'd

Section B: Minerals that fracture and H ≥ glass*

Streak	Color	Hardness	Comments	Mineral *Composition*
No streak	Red-brown to brownish black	7–7½	L = resinous to vitreous; D = 3.6–3.8; prismatic crystals — obtuse prisms, with common **crossing twins.**	**Staurolite** *Fe Al silicate*
	Dark brown to black common	7–7½	F = conchoidal; D = 3–3.3; L = resinous to vitreous. Most commonly black prismatic with triangular cross sections. Tourmaline may be transparent green, yellow, red, pink, or blue and of semiprecious gem quality (e.g., rubellite [red or pink]).	**Tourmaline** *Chemically complex ring silicate*
	Almandine is deep red to brown	6½–7½	**F = hackly** to conchoidal; D = 3.5–4.3; L = adamantine to vitreous to waxy on parting. **Habit = equant** well-formed **dodecahedral crystals.** Colors vary with composition. Grossular garnet is often tan, pale yellow, pink or green.	**Garnet** (Fig. 1.9b) *Mg, Fe, Mn, Al, with single-silicate tetrahedra*
	Highly variable	7	**F = conchoidal;** D = 2.65; L = vitreous to waxy in microcrystalline varieties. The conchoidal F and H are diagnostic. Hexagonal crystals show striations perpendicular to prism (Fig. 1.9k). Macrocrystalline (with visible crystals) quartz varieties: Rock crystal: transparent, colorless, distinct crystals (Fig. 1.9k, l) Milky quartz: translucent white (Fig. 1.9m) Smoky quartz: gray to almost black, smoky yellow to dark brown, transparent to translucent (Fig. 1.9n) Rose quartz: pink to rose colored, transparent to translucent (Fig. 1.9o) Amethyst: purple, often transparent and in crystals (Fig. 1.9p) Citrine: pale yellow, transparent/translucent Tiger eye: yellow, fibrous, and chatoyant Microcrystalline (microscopic crystals) quartz varieties: Chalcedony; translucent, has a waxy luster; light gray to brown Agate: thin concentric layers of varying colors (Fig. 4.31b) Onyx: straight parallel layers of colors Heliotrope or bloodstone: green with red patches of jasper (Fig. 4.31b) Flint: dark siliceous nodules of quartz often found in calcareous soils and rocks (Fig. 4.31b) Chert: like flint but lighter and more variable in color (Fig. 4.31a) Jasper: red, dull luster, and granular	**Quartz** (Fig. 1.9k–p) *pure silica tectosilicate*
	Light to dark olive green	6½–7	**F = conchoidal;** may appear irregular due to small grain size; D = 3.3–4.4; L = vitreous. Habit is commonly granular aggregates.	**Olivine** (Fig. 1.9a) *Mg, Fe with single-silicate tetrahedra*
White	Brown to black (rarely yellow or white)	6–7	Imperfect cleavage; D = 6.8–7.1; L = adamantine to submetallic to dull. **High density for a nonmetallic mineral.**	**Cassiterite** *Sn oxide,* ore of tin

*See p. 22 for abbreviations and units. Properties that are especially diagnostic are shown in **bold**.

Table 2.6 — cont'd

Section C: Minerals that show cleavage and H < glass*

Streak	Color	Hardness	Comments	Mineral *Composition*
	Blue to gray	7 and 5 depending on direction	CL = 1 direction; bladed crystals; D = 3.6–3.7; L = vitreous to pearly; H = 7 perpendicular to blades and H = 5 parallel to blades; blue color and different hardness in different directions are diagnostic.	**Kyanite** *Al silicate*
	White, colorless to gray	5–5½	CL = 2 directions at 84°, splintery to hackly; prismatic to fibrous; L = vitreous to pearly; D = 2.8–2.9.	**Wollastonite** *Ca silicate*
White	Often white, yellow, violet, pale green	**4**	**CL = 4,** perfect, in shape of an octahedron (≠90°); D = 3.2; L = vitreous to waxy. Often transparent, fluorite is known by its CL and H. May fluoresce under black light. Color is highly variable.	**Fluorite** (Fig. 1.10h) *Ca, F halide*
Yellow	Dark brown to yellow	3½–4	L = resinous to adamantine sub-metallic; CL = up to 6 good planes. Variegated appearance common; D = 3.9–4.1; ore of zinc.	**Sphalerite** (Fig. 1.10e) *Zn sulfide*
White	Yellowish white to pink	3½–4	CL = 3 perfect rhombohedral (may be obscure due to small crystal size); D = 2.8; L = vitreous. **Effervesces in dilute HCl when powdered** (Fig. 4.27 inset). Color varies with impurities.	**Dolomite** *Ca, Mg carbonate*
Intense sky blue	Bright **azure blue**	3½–4	Usually fine grained with earthy fracture; D = 3.8; L = vitreous to dull. Effervesces in HCl. Color is diagnostic and often mixed with the bright green of malachite.	**Azurite** *Cu, OH carbonate,* ore of copper
White	Highly variable, usually colorless to yellowish white to white to pink	**3**	**CL = 3** perfect rhombohedral (≠90°); D = 2.7; L = vitreous. **Strongly effervesces with dilute HCl.** Varieties include *Iceland spar:* transparent, shows double refraction (Fig. 1.8); *chalk:* soft, fine grained and earthy (Fig. 4.24); *onyx marble,* and *Mexican onyx:* banded marble; *travertine:* finely layered deposits (Fig. 4.25). (Note that the fine-grained varieties may not show cleavage, but all will effervesce freely with dilute HCl.)	**Calcite** (Fig. 1.10a) *Ca Carbonate*
Light brown	Dark reddish brown to black	2½–3	**CL = 1** perfectly planar; D = 2.8–3.2; **L = resinous to vitreous.** Elastic and flexible in thin sheets. Transparent. May break apart when testing streak. Marked with fingernail by creasing sheets rather than scratching.	**Biotite (mica)** (Fig. 1.9g) *K, Al sheet silicates*
White	Colorless to white to light greenish brown	2–2½	**CL = 1** perfectly planar; D = 2.7–2.9; **L = resinous to vitreous to pearly.** Elastic and flexible in thin sheets. Transparent. May break apart when testing streak.	**Muscovite (mica)** (Fig. 1.9h) *K, Al sheet silicates*
White	Colorless to white	2½	**CL = 3 perfect at 90°** (cubic); D = 2.1–2.3; L = waxy to vitreous. **Salty taste.** Transparent. **Dissolves in water and on fingers.** Tan to reddish with impurities.	**Halite** (Fig. 1.10i) *NaCl halide*
White to pale green	**Medium to dark green**	2–2½	CL = 1 perfect, but folia are small in relation to micas; D = 2.6–3.3; may disaggregate when testing streak; L = vitreous to pearly. **Thin sheets are flexible but not elastic.**	**Chlorite** *Mg, Fe, OH sheet silicate*
White	Colorless to white to pale blue	2	**CL = 3 perfect at 90°** (cubic); D = 2.0; L = waxy to vitreous. **Bitter salty taste.** Transparent. **Dissolves in water and on fingers.** Yellow or reddish with impurities. Much rarer than halite.	**Sylvite** *KCl halide*
White	Colorless to white	**2**	**CL = 1** perfect (in sheets), and 2 more irregular; D = 2.3; L = vitreous to pearly. Flexible in thin sheets, sectile, transparent to translucent. **Can scratch with fingernail.**	**Gypsum (selenite)** (Fig. 1.10b) *Ca sulfate*

*See p. 22 for abbreviations and units. Especially diagnostic properties are shown in **bold.**

Table 2.6 — cont'd

Section D: Minerals with apparent fracture and H < glass*

Streak	Color	Hardness	Comments	Mineral *Composition*
White	Commonly green to red-brown	5	Variable color; **F = conchoidal;** poor basal cleavage. D = 3.1–3.2; L = vitreous. May occur in **hexagonal prisms** or granular aggregates.	**Apatite** *Phosphate*
White	Yellowish white to pink	3½–4	CL = 3 perfect rhombohedral (may be obscure due to small crystal size); D = 2.8; L = vitreous. **Effervesces in dilute HCl when powdered** (Fig. 4.27 inset). Color varies with impurities	**Dolomite** (Fig. 4.27) *Ca, Mg carbonate*
White	Light green to dark green	3–5	Massive; L = greasy to waxy; D = 2.5–2.6; color often variegated, light green to nearly black. May be fibrous = asbestos.	**Serpentine** (Fig. 5.9f) *Mg OH sheet silicate*
Pale green	Bright green	3½–4	L = adamantine to vitreous to earthy; commonly botryoidal or stalactitic; D = 3.9–4.0; recognized by its **distinctive bright green color and effervescence in HCl.**	**Malachite** *Cu carbonate,* ore of copper
Pale blue	Bright blue	3½–4	L = vitreous to earthy; D = 3.8; recognized by its **distinctive intense azure blue color and effervescence in HCl.**	**Azurite** Hydrous *Cu carbonate,* ore of copper
Yellow to brown	Yellow ocher to dark brown	2–5½	S = yellow-brown; D = 3.3–5.5 or less if porous; F = irregular. L = earthy. "Limonite" is often used to name any hydrous iron oxide.	**Limonite** *Hydrous Fe oxide*
Pale green	Apple green	2–3	L = greasy to waxy; D = 2.2–2.8; recognized by its **distinctive apple green color.**	**Garnierite** *Ni Mg OH sheet silicate*, ore of nickel
White	White to pink	2	Satin spar is the fibrous variety — white with **L = silky** and **F = fibrous** (cleavage is not apparent due to its fibrous habit). D = 2.3; sectile.	**Gypsum (satin spar)** (Fig. 1.10b) *Ca sulfate*
White	White to pink	2	Alabaster is **compact and massive;** L = vitreous to pearly and F = uneven (cleavage is not apparent due to its small crystals). D = 2.3; sectile.	**Gypsum (alabaster)** (Fig. 1.10b) *Ca sulfate*
Red-brown	Red brown	1–6	F = uneven; (Hardness is variable due to variations in grain size); D = 4.8–5.3; L = dull to earthy. Small (egg-shaped) ooids are usually seen; Streak and color are diagnostic.	**Oolitic hematite** (Fig. 1.10g) *Fe oxide,* ore of iron
Pale yellow	**Yellow**	1½–2½	F = uneven to conchoidal; D = 2.1; L = resinous to vitreous. Known by its bright yellow color (when pure) and its distinctive odor.	**Sulfur** *Native S*
Variable but commonly red-brown to yellow brown	Highly variable even in one sample white, gray, yellow-brown, red	1–5	L = dull to earthy; D = 2–2.6; recognized by its **spherical concretionary grains** (pisolites). Not really a mineral, but important as aluminum ore.	**Bauxite** *Al oxides and hydroxides,* ore of aluminum
White	White	1–2	**F = uneven;** D = 2.6; **L = dull,** earthy. **Powdery** and claylike, earthy smell. Microscopically has one perfect cleavage. **No effervescence.**	**Kaolin** (Fig. 1.9f) *Al OH sheet silicate*
White, flakes when powdered	White to gray-green	1	CL = 1 perfect (may be microscopic); D = 2.7–2.8; L = **pearly** to dull. **Greasy feel.** If compact and massive, the variety is soapstone. Talc is often associated with tremolite, an amphibole with H = 5–6, and therefore may appear harder.	**Talc** (Fig. 1.9e) *Mg OH sheet silicate*

*See p. 22 for abbreviations and units. Especially diagnostic properties are shown in **bold.**

RECOGNITION OF MINERALS

On your exams or quizzes, and when identifying rocks, you will need to recognize minerals, not simply identify them using mineral tables. Tables 2.2 and 2.3 list some common rock-forming minerals. To recognize a mineral you need to learn (1) *diagnostic properties* that are always present in combinations that allow you to distinguish the mineral from others; (2) the mineral's name; and (3) when a property is consistent, such as the color of olivine or azurite, and when it can vary, such as the color of quartz or feldspar.

4. Your instructor should inform you of the minerals you are required to know (15 are listed in ■ Table 2.7). The table has room for you to add any additional ones required by your instructor. For each one assigned, study the examples provided so you can recognize the mineral. In the "Memory Aid" column of Table 2.7, write down a strategy to help you remember the mineral name. Try to think of a word or phrase that sounds like the name and possibly refers to some property of the mineral. For example, "Olivine is olive green," or "Pirates like gold" (for pyrite). Also list a few key diagnostic properties that will help you recognize the mineral.

5. How well do you know your minerals now? Your instructor will give you a set of minerals for a self-quiz. Test the samples and write down their important or key properties and names in ■ Table 2.8 without looking at the mineral identification tables. Watch out — some tricky samples may be included.

Table 2.7

Mineral Recognition Memory Aids (Exercise 4)

Mineral	Memory Aid	Diagnostic Properties
Olivine		
Garnet		
Augite		
Hornblende		
Kaolin (or kaolinite)		
Biotite		
Muscovite		
Feldspar		
Quartz		
Calcite		
Gypsum		
Galena		
Pyrite		
Magnetite		
Halite		

Table 2.8

Mineral Practice Quiz (Exercise 5)

Sample Number	Key Property 1	Key Property 2	Key Property 3	Mineral Name

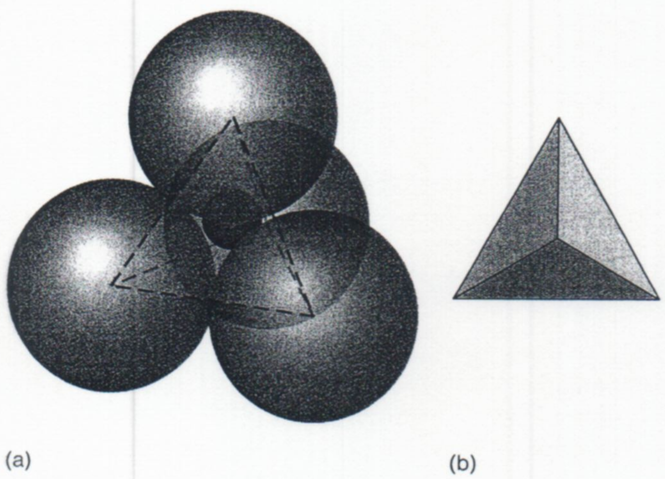


Figure 2.2

Two ways of illustrating a silica tetrahedron: (a) This figure illustrates the configuration of the atoms (red for oxygen and gray for silicon). Dashed lines from the center of one oxygen atom to another show the location of the tetrahedron, illustrated in (b). (b) Diagrammatic representation of a silica tetrahedron: The corners are at the centers of the oxygen atoms, and the center of the tetrahedron corresponds to the location of the silicon atom.

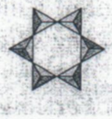
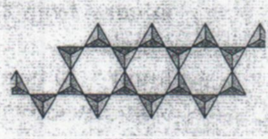
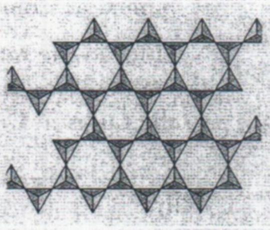
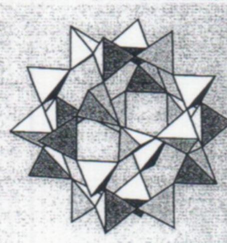
SILICATE MINERALS

The most important and most complex mineral group is the silicates. The variety of crystal structures of silicate minerals leads to the wide variety of physical properties seen in this large mineral group. Grouping silicates by subclasses based on crystal structure makes sense because it also groups the mineral according to their properties.

The basic structural unit for the silicates is the silicate or silica tetrahedron (SiO_4), as shown in ■ Figure 2.2a. This basic building block is often illustrated as lines connecting the oxygen atoms, with no atoms shown, as in ■ Figure 2.2b and as in each of the diagrams for the silicate subclasses in ■ Table 2.9. These lines connect to make a triangular pyramid called a **tetrahedron,** thus the name *silica tetrahedron.* Imagine an oxygen atom at each corner and a silicon atom in the center. The silicate subclassification is based on the arrangement of the silica tetrahedra (plural) in the atomic structure of the mineral. Notice that silica tetrahedra only share corners, not edges (Table 2.9). To a large extent, this internal structure of the silicates influences each mineral's

Table 2.9

Tetrahedral Structures of Silicate Subclasses

Silicate Subclass	Structure
Nesosilicates (Isolated Si Tetrahedra)	
Cyclosilicates (Ring silicates)	
Inosilicates (Chain silicates)	
Single Chain	
Double Chain	
Phyllosilicates (Sheet silicates)	
Tectosilicates (Framework silicates.) Every tetrahedron in this structure is connected to four others; many are not shown.	

physical properties, as we shall see. First let's try to understand the structural types involved.

6. In the following activity each student will build a model of the smallest silicate unit, the tetrahedron. Then you will join your model with those of other students to make structures representing various silicate groups. If your instructor has also assigned Exercise 7, you should stop as you complete each silicate subclass and answer the questions related to that subclass in Exercise 7.

a. Using stale mini-marshmallows and half-toothpicks, make one silica tetrahedron (like the one shown in Figure 2.2b), with the toothpicks outlining the edges of the tetrahedron and the marshmallows playing the role of oxygen atoms (Figure 2.2). These toothpicks do not represent chemical bonds. If available, place a smaller candy at the center of the tetrahedron to represent the silicon atom. What subclass of silicates would have this arrangement of silicon and oxygen?

Fill in answers for Exercise 7 related to this subclass.

b. Next, join your tetrahedron to that of another student, either by removing one oxygen (marshmallow) or by building a third tetrahedron to join the two. Each tetrahedron should be connected to the next by sharing an oxygen. With your classmates, choose to build either a cyclosilicate structure or a single-chain silicate structure with six tetrahedra (Table 2.9). Continue joining tetrahedra until you have six connected. Notice that for single chains the shared oxygens all line up, and the tetrahedra are on alternating sides of the line. In the cyclosilicate, the shared oxygens are all on the inside of the ring. It may be easier to join two already-constructed parts by making additional tetrahedra to join them than to remove "oxygens" where tetrahedra will be joined. Which type of silicate did your group make?

Fill in answers for Exercise 7 related to this subclass. If other students built the other subclass, use their structure to answer the appropriate parts of Exercise 7.

c. Connect your single chain or cyclosilicate together with others of like kinds made by other members of your class to make a double row of silicate tetrahedra. What subclass of silicates is this?

d. If your class is smaller than about 20 students, make some additional tetrahedra. Join all of the tetrahedra for the whole class to make a planar arrangement of tetrahedra with 6-membered rings all joined together in almost a honeycomb pattern (Table 2.9). What subclass of silicates is this?

____

What do the toothpicks represent in your model?

____

____

Fill in answers for Exercise 7 related to this subclass.

e. In this configuration, some of the smaller candies at the center of tetrahedra would represent aluminum atoms. Look at the chemical formulas of the minerals in this subclass in Table 2.2. What additional atoms might be available to join separate sheets together into a three-dimensional structure?

____

7. Use the marshmallows and candies from Exercise 6 and complete ■ Table 2.10, or construct ball-and-stick or ball-and-glue models of the silicon and oxygen atoms of each of the silicate subclasses listed in Column 1 in Table 2.10. Use small balls for silicon atoms and large ones for oxygen atoms. For Tectosilicates your instructor may only want you to construct five tetrahedra, with one in the center connected to the other four. The tetrahedra may not stand up well if you are using only slightly stale marshmallows. Fill in Table 2.10 with the following information, using Table 2.9 to help you, and recalling that each tetrahedron represents four oxygens at the corners bonded to one silicon atom in the center:

Column 2: How many oxygen atoms in a tetrahedron are shared with other tetrahedra in each subclass?

Column 3: What is the silicon:oxygen ratio? Count the number of oxygens for one silicon atom by counting unshared oxygens as 1 and shared oxygens as ½. For single chain, sheet, and tectosilicates, use silica tetrahedra that are on the inside (not the edges) of your structure.

Column 4: In the blank cells, name one mineral from Table 2.2 belonging to each subclass.

Column 5: What is the silicon:oxygen ratio from the chemical formula of the mineral named in Column 4?

How do the ratios of silicon to oxygen in the mineral formulas in Column 5 compare to the ratios in Column 3?

____

Why?

____

____

____

____

Table 2.10

Mineral Structures (Exercise 7)

Column 1	Column 2	Column 3	Column 4	Column 5
Silicate Subclass	**Number of Oxygen Atoms Shared**	**Silicon: Oxygen Ratio in Structure**	**Mineral Belonging to This Subclass**	**Silicon: Oxygen Ratio in Chemical Formula**
Nesosilicates (single tetrahedra)		1:______		
Cyclosilicates		1:______		
Single-chain silicates		1:______	Diopside	
Sheet silicates		2:______	Talc	
Tectosilicates (3D framework or network)		1:______	Quartz	

8. Of the models you constructed, which silicate subclass structures theoretically go on and on indefinitely?

Most silicon-oxygen structures have a negative charge, but complete crystals must have a neutral charge. A bunch of negative charges don't usually hang around by themselves.

9. What balances the negative charge and holds the tetrahedra together where they are not linked by shared oxygens?

(The formulas in Table 2.2 may give you a hint.)

10. The ratio of silicon to oxygen in silicates is related to the quantity of silica present in the mineral. Silicates with lots of oxygen in proportion to silicon are low in silica, and those with less oxygen compared to silicon are higher in silica. What mineral from Table 2.2 has the lowest silica content?

What mineral has the highest?

11. Now let's look at alkali feldspar in Table 2.2. It is a framework silicate, like quartz, yet its ratio of silicon to oxygen is ____________. This does not match the ratio in Table 2.10, Column 3 for tectosilicates. Augite and chlorite also have low silicon:oxygen ratios for their subclass. Some of the tetrahedra in feldspar and these other minerals have aluminum (Al) instead of silicon. Add up the Al and Si in the formula for alkali feldspar. ________ What is the ratio of Al + Si to oxygen in feldspar? ____________ Now, does this match the ratio in Column 3 for tectosilicates? ________

12. Let's see how different silicate structures influence a mineral's properties. What mineral has single chains?

What type of cleavage does it have?

What is an example of sheet silicate?

What type of cleavage does it have?

Notice that most silicates are found in Tables 2.6A and B. This is because the strong bonds in these silicates make them hard. However, sheet silicates occur in Tables 2.6C and D. How do you account for this?

Silicate minerals of various structures make up the most common rock-forming minerals, but with the exception of quartz, feldspar, and kaolin, they are not as commonly used as resources. On the other hand, nonsilicates are important sources of many resources, especially carbonates and sulfates for building materials and oxides and sulfides for metals.

GEOLOGIC RESOURCES AND MINERALS

A **geologic resource** is a naturally occurring substance that comes from the Earth and is useful to people. For example, diamond is a naturally occurring mineral resource and an important industrial abrasive. Concrete, made of cement and aggregate, is a product manufactured from resources such as limestone, which is mostly calcite. Limestone and calcite are resources, while concrete and cement are products. So a geologic resource may be an element, a mineral, or a rock (or in some cases a natural liquid substance such as petroleum), but it is not a manufactured product. Resources from plants and animals are considered biological.

Minerals are the building blocks of most solid natural substances that make up the Earth. They provide us with many resources we need to produce the common objects we take for granted in our modern society. We will explore this topic more thoroughly in Lab 20.

13. Work together in a group of five or more. Discuss a simple object such as a doorknob or handle. What is the doorknob made of?

Are some doorknobs made of other substances? What mineral resources are needed to produce one? List these resources. The most obvious resources involved in doorknob production are ones that provide materials actually found in the doorknob. Include these in your list. But a much larger set of resources is used indirectly, in the processes of mining, manufacture, transportation, and marketing. Also include these in your list. Which of these resources are minerals? Write down sample numbers next to the ones for which you have examples in the lab.

Many minerals have several and varied uses. The concrete, steel, glass, and plaster that make up modern buildings are made from such minerals as calcite, magnetite, quartz, and gypsum. You may have mentioned some of these as needed to make a doorknob. Our coins and jewelry come from other minerals, such as argentite (ore of silver), native copper, native gold, diamonds, and corundum (rubies and sapphires are gem varieties of corundum).

14. Continue working in a group. List in ▨ Table 2.11 all the minerals you can think of for which you know at least one use, and list their uses. Write down sample numbers next to the ones for which you have examples in the lab.

Table 2.11

Mineral Uses (Exercise 14)

Mineral	**Use**