

Chapter 1

Minerals and Mineraloids

When most people think of minerals, they usually imagine expensive gemstones like diamonds, emeralds and sapphires, or economic minerals like silver, gold and copper. While it is true that each of these substances is a mineral, they are all relatively unimportant as far as the make-up of the Earth is concerned. At last count, there were over 4000 minerals on and in the Earth, but only a handful are considered "valuable" in terms of financial reward (e.g., \$\$\$). Minerals that make you money are considered **economic** and their value is determined on the basis of aesthetic reasons (e.g., sapphires, emeralds) or technological/industrial applications (e.g., diamonds, copper, sulfur etc.). In reality, the most important minerals are those that are most common because they make up the rocks that comprise the Earth's crust. We live on the Earth's crust. The common minerals are called **rock-forming** for obvious reasons. One of the most important of the rock-forming minerals is quartz (SiO_2). Almost every sand grain on the beaches at Dauphin Island, Gulf Shores and Fort Walton is a fragment of a quartz crystal, a major component in continental-forming rocks like granite. Quartz isn't particularly valuable in financial terms, but where would we be without it?

Figure shows several schematics of crystals. From: Ford, W., 1932. Dana's Textbook of Mineralogy. John Wiley and Sons, New York, NY, 851p.

Now that you have been introduced to the variables that make a mineral valuable, it is probably a good idea to discuss what makes a mineral a mineral. Geologists consider a **mineral** to be a naturally occurring, inorganic solid that is characterized by a unique chemical composition and a definite crystal structure. This definition excludes a number of man-made substances commonly passed off as minerals including cubic zirconium (an inexpensive diamond substitute), synthetic corundum (red “ruby” and blue “sapphire” stones commonly found in high school graduation rings), and industrial diamond (a valuable abrasive). It also excludes a variety of natural substances that are found in and on the Earth. Some of these materials, such as chalcedony (SiO_2) and opal ($\text{SiO}_2 \cdot \text{H}_2\text{O}$) are non-crystalline (i.e., they lack a definite crystal structure much like window glass). Others, such as bauxite (Al_2O_3) and earthy limonite (FeOOH), are characterized by significant variation in chemical composition*. Otherwise, they satisfy the definition of a mineral. Geologists call these substances **mineraloids**. Another naturally occurring substance that is not considered to be a mineral is amber. Amber is fossilized tree sap and is therefore organic.

There are, however, some organically-produced materials that are minerals. The skeleton of corals and many of the shells found along the Alabama coastline and elsewhere are composed of the mineral aragonite (CaCO_3). A large number of others shells including oysters are composed of the mineral calcite (CaCO_3). Both of these minerals are products of **biomineralization**, but they are identical in terms of their composition and crystal structure to the aragonite and calcite formed through inorganic processes. Corals and shelled organisms essentially use organic blueprints to synthesize inorganic minerals. Incidentally, you will have noticed that aragonite and calcite have the same chemical composition (CaCO_3). The difference between the two minerals is their crystalline structure (discussed in section 1.1-6). Minerals with the same chemical composition but with different crystalline structures are called **polymorphs**. Another pair of polymorphs that you are responsible for in GY 111 are the minerals graphite and diamond (both are composed of elemental carbon).

As freshman geology students, you will be required to learn how to identify some of the most common and/or most important minerals on the Earth. Don't panic! Although there

* Significant variation as used here implies major compositional differences. For example, bauxite may be actually a combination of 3 minerals and may also contain significant amounts of FeO. Most minerals (and mineraloids) do contain very minute amounts of ions (less than 1%), but they are considered **trace elements** and their presence is generally ignored when discussing the overall chemical composition of a mineral or mineraloid.

are over 4000 minerals recognized, you will only be responsible for about 40 of them (most of which are considered rock-forming). This may still seem a bit daunting, especially at first, but it is a fairly straight-forward process to identify minerals. You simply have to recognize the series of physical properties or attributes which each mineral possesses. It may take a while, but you should soon be able to process diagnostic information about minerals so rapidly that mineral identification will seem almost immediate. In the mean time, use the mineral identification chart (Table 1.7) to help you in your task.

1.1 The Physical Properties

As stated earlier, there are several important physical properties by which to identify minerals. The most common of these, each of which is discussed further in the following sections, are color, streak, specific gravity, luster, hardness, crystal form and cleavage. Many minerals are distinguished on the basis of only one or two **diagnostic characteristics** (e.g., they may be unusually heavy or have a distinct color), however, others may require you to use several properties to identify what they are. Never jump to conclusions about minerals! Some look very much like others and it is up to you to discover which combination of properties best distinguishes them.

1.1-1 Color

The **color** of a mineral is usually the first physical property observed. Unfortunately, it is not always the most reliable property by which to identify minerals. The reason is that many minerals exhibit a wide range of color due to slight variations in the content of color-inducing trace elements called **chromophores**. Minerals that contain different chromophores and which are therefore subject to color variation are said to be **allochromic**. They include corundum (Al_2O_3). The presence of the trace element chromium (Cr) in corundum causes a red coloration to the mineral whereas titanium (Ti) and iron (Fe) induce the color blue. We know these **varieties** of corundum as, respectively, ruby and sapphire. Quartz (SiO_2) is another allochromic mineral. Several varieties of quartz based upon color have been distinguished. They include rose quartz (pink), citrine (yellow), smoky quartz (gray-black), amethyst (purple), milky quartz (white) and crystal quartz (clear).

Some minerals, including sulfur (S), azurite ($\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$) and graphite (C), are always the same color regardless of their trace element geochemistry. These minerals are

considered to be **idiomorphic** and for them, color can be considered a reliable and diagnostic property.

The minerals summarized in Table 1.7 are subdivided on the basis of **light** and **dark** color. Light-colored minerals are generally white, buff, or pastel and contain high percentages of Si, Al, O, and K. Dark minerals may be black, brown, gray, dark green or red and generally contain the ions which produce dark pigment in minerals including Mg, Ca, and Fe. In this very general way color can be used as a guide to mineral chemistry. BEWARE! The color range of some minerals, including, quartz, fluorite (CaF_2) and olivine ($(\text{Mg,Fe})_2\text{SiO}_4$) transcends the light-dark classification. If you cannot identify a seemingly "dark-colored" mineral based upon the criteria used in Table 1.7, consider checking those classified as "light-colored" (and vice versa).

1.1-2 Streak

The color of a mineral specimen may be variable, but its color in powdered form (its **streak**) is constant and is in many cases diagnostic. Streak is determined by scratching minerals against an unglazed porcelain streak plate (usually ordinary tile). Light-colored minerals usually produce white or colorless streaks which are seldom useful for identification purposes. Many dark-colored minerals also produce white/colorless streaks, but sometimes you get lucky. Minerals like hematite (Fe_2O_3) and sphalerite (ZnS) produce diagnostic streaks (red and yellow, respectively) which greatly aids in their identification. There are two things to consider when obtaining mineral streaks: (1) to obtain satisfactory results, the streak test can only be performed on specimens softer than the streak plate (hardness 5-6), otherwise the streak plate will powder instead of the mineral; (2) always be sure to streak a mineral along a clean surface. Some mineral specimens are relatively unpure and may contain other imbedded substances. The dark mica mineral biotite ($\text{K}(\text{Mg,Fe})_3(\text{Al,Fe})\text{Si}_3\text{O}_{10}(\text{OH,F})_2$) should produce a white/colorless streak, but if you scratch a portion of the mineral that contains limonite, the streak will appear yellow. Always test clean surfaces, good advice that should also be remembered when determining the hardness of a mineral (Section 1.1-5).

1.1-3 Specific Gravity

Some mineral properties are best established with your eyes closed. For example, when you first pick up a mineral (with or without closing your eyes), you will probably make note of its "weight". Whether or not a mineral specimen feels heavy depends upon its overall size and density. Large specimens, regardless of their density, will always seem heavier than

smaller specimens, so simply assessing specimen weight is useless. Geologists prefer to use **specific gravity** as a mineral property. A mineral's specific gravity is a comparison of the weight of a mineral to the weight of an equal volume of water so sample size is removed as a factor in the property. Water has a specific gravity of one, therefore minerals lighter than water have a specific gravity less than one (they float) and minerals heavier than water have specific gravities greater than one. Very "heavy" minerals, such as galena (PbS) or pyrite (FeS₂), have high specific gravities. For galena it is in the range of 7 to 7.6 which means that it is about seven and a half times heavier than an equal volume of water. Note: since specific gravity is a ratio (mineral to water), it is a unitless number. Mineral density is measured in units of g/cm³ or kg/m³.

1.1-4 Luster

Mineral **luster** is an easier property to observe than it is to describe. Officially luster is the way the surface of a mineral reflects light, but this explanation is a bit confusing to students who are new to the game of mineral identification. Analogy to other substances that you are more familiar with is a better way to describe luster. Picture a highly polished brass door knob or a new penny. Both are instantly recognizable as metals because they reflect light in a metallic way. Regardless of its color, glass always looks like glass because it reflects light like glass. Sugar-glazed donuts always look like sugar-glazed donuts... well, you get the idea. Minerals reflect light in similar ways to these substances. For example, some minerals, including pyrite, galena and specular hematite (Fe₂O₃), reflect light in a metallic fashion and are therefore said to have **metallic luster**. Most minerals do not reflect light in a metallic way. Some imitate glass or fabric or sugar-glazed donuts. They are said to have **non-metallic lusters**. Beware of minerals that have lusters that are transitional between metallic and non-metallic. This luster is called **sub-metallic** and is exemplified by the mineral muscovite (KAl₃Si₃O₁₀(OH)₂).

The non-metallic minerals are so large in number that it is necessary to sub-divide them into several subclasses (see Table 1.1). Alas, there is no sugar-glazed donut luster, but many of the subdivisions are just as self-explanatory. Unless otherwise informed by your instructor, be sure to use these sub-divisions when describing mineral luster.

Luster is largely determined by a mineral's atomic structure, its surface transparency and surface purity. Metallic minerals are opaque to light and reflect it all back toward the observer (hence their metallic luster). But a metallic mineral that is contaminated by another substance (e.g., earthy hematite, the planet's version of rust), may lack its typical

Table 1.1. Summary of common lusters and examples of minerals characterized by them.

Luster		Description	Mineral examples
Metallic		reflects light in the same way as a metal	pyrite, galena
Sub-metallic		reflects light somewhat like a metal	muscovite, chlorite
Non-metallic	Vitreous	reflects light similar to a glass window pane (most common type of luster)	quartz, fluorite
	Adamantine	reflects light similar to a diamond (very intense)	diamond, sulfur (rare)
	Resinous	a luster having the appearance of resin or crystallized tree sap	sphalerite
	Waxy	a surface which look like it has been coated in wax or sugar glazing	chert, milky calcite
	Pearly	exhibits mother-of-pearl quality in how it reflects light	gypsum
	Greasy	has an oily quality in the way it reflects light	talc
	Silky	reflects light in much the same way as silk fiber	gypsum (v. satin spar)
	Earthy-Dull	relatively non-reflective; looks like earth or chalk	kaolinite

luster. Be sure to examine only clean or fresh surfaces of minerals when attempting to establish luster.

Two points of caution are advisable concerning luster. (1) Beware of minerals that display more than one type of luster. Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) occurs in several forms. Most have a "milky" appearance and a waxy luster. The variety known as selenite is vitreous. The variety known as satin spar is silky. Other minerals with multiple lusters include calcite, hematite, limonite, quartz and fluorite. There are many others. (2) Never confuse luster with color as they are two completely different properties. There are silver, brass, gold, black and blue-colored metallic lusters and an equally diverse color suite of non-metallic minerals. From the luster point of view, copper pennies, brass door knobs and chrome bumpers are all the same. Only their colors differ.

1.1-5 Hardness

Hardness is one of the most important and diagnostic mineral properties. It is defined as the resistance of a mineral to mechanical abrasion, but you may prefer to think of hardness as the ease in which minerals can be scratched. As always, make sure you test this property along a fresh surface of your mineral.

Minerals display wide variation in hardness which is why it is such a useful property. Some minerals are so soft that by simply rubbing your fingers across them, they get "scratched". Others are so hard that they can scratch metal or glass. Very hard minerals make excellent abrasives for sanding wood, polishing metals or drilling through rock. The hardest known substance is the mineral diamond and it is frequently used to cut through a variety of natural and artificial substrates (e.g., rock and concrete). Very soft minerals are also useful. Talc ($\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$) for example, is so soft that it is used to powder babies' bottoms (talcum powder). Graphite is equally soft which is the reason why it can be used to lubricate metal locks or write on paper.

Long ago, the German mineralogist Friedrich Mohs quantified the hardness of 10 common minerals into what we now call the **Mohs' Hardness Scale** (Table 1.2). Talc, the softest of the ten was assigned a hardness of 1 and diamond, the hardest, was assigned a hardness of 10. The other minerals comprising Mohs' Hardness Scale are ranked in order of ascending hardness between talc and diamond. Each mineral on Mohs' Scale will scratch any lower ranking mineral and be scratched by any mineral of higher rank. All known minerals can be fitted between talc and diamond on this scale.

The hardness of unknown minerals may be determined by direct comparison with those on Mohs' Scale. If an unknown mineral scratches talc, which has a hardness of 1, and is scratched by gypsum, which has a hardness of 2, then the unknown mineral would have a relative hardness midway between the two (1.5). Unless you routinely carry around a pocket full of minerals, you may not be able to establish hardness in quite this way. However, it is possible to substitute more common items of variable hardness in place of Mohs' minerals. Your fingernail has a relative hardness of 2.5, a copper penny has a relative hardness of 3.5 and window glass has a relative hardness of 5.5 to 6. Knives are also useful for determining hardness, but be careful using them. Quality knives (e.g. Swiss Army variety) have relative hardnesses of 5.5, but low quality knives are closer to 5 on the Mohs' Scale. The transition between 5 and 6 is generally considered as the division between hard and soft minerals, so accuracy here is important. Get a good knife .

Mohs' scale is based on relative hardness; however, the increase in absolute hardness between minerals on this scale is not linear (Figure 1.1). At the lower end of Mohs' Scale the absolute hardnesses of talc, gypsum, calcite and fluorite increase only slightly, whereas much larger increases occur between the harder minerals such as corundum and diamond (Figure 1.1).

Table 1.2. Mohs' scale of hardness for minerals and other common substances.

Hardness	Mineral	Other materials
1	Talc	
2	Gypsum	
3	Calcite	2.5 Fingernail
4	Fluorite	
5	Apatite	3.5 Copper Penny
6	Orthoclase Feldspar	5.0-5.5 Steel, 6 Glass
7	Quartz	
8	Topaz	
9	Corundum	
10	Diamond	

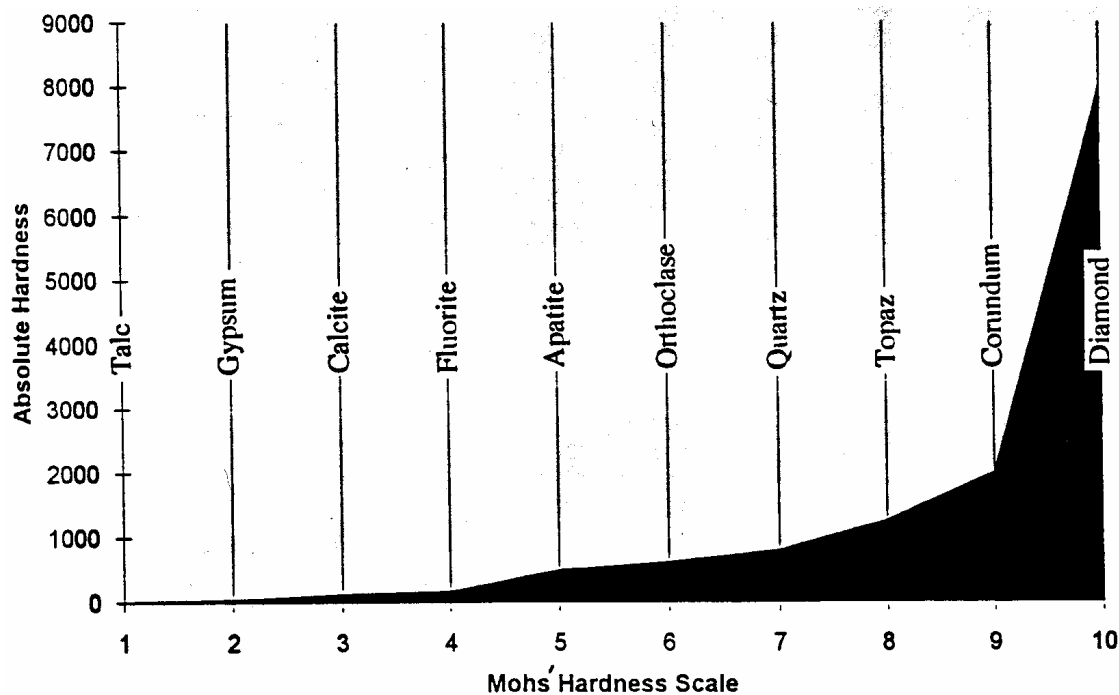


Figure 1.1. Absolute hardnesses of minerals featured in the Mohs' scale of hardness.

1.1-6 Crystal Form

One of the major requirements for substances to meet the definition of a mineral is that they possess a specific crystal structure. The atoms and ions that comprise minerals are bonded together in precise ways and patterns based primarily upon size and charge. In halite (NaCl) each Na^+ - Cl^- bond is of a specific length and orientated at a specific angle relative to every other bond in the mineral. The bonds in halite are all at 90° giving rise to a cubic crystalline structure. For halite, this atomic structure is translated through the entire mineral to give it an overall cubic form. Many minerals (including halite) display distinct planar surfaces called **faces**. Minerals that display well developed faces that are arranged in recognizable patterns (including halite) are called **crystals**.

The number and arrangement of crystal faces frequently define geometric shapes (e.g., cubes, rhombs, dodecahedrons, octahedrons, prisms etc.), and several broad **crystal forms** have been distinguished by geologists (Table 1.3, Figure 1.2). Crystal symmetry is complex (as covered in GY 341), but basic crystal shapes can be of great value in mineral identification. BEWARE: Crystals are rare products of fortunate environmental circumstances at the time of mineral formation, and since these seldom occur, excellent crystal form is also rare.

1.1-7 Fracture and Cleavage

Most of the mineral specimens that you will encounter are fragments of larger pieces. Some will display jagged broken surfaces which geologists call **fracture**. Others will display quite planar surfaces called **cleavage**. How a mineral breaks depends largely on its atomic structure and the strength of the chemical bonds that characterize it.

Minerals that have equally strong bonds in all directions at the atomic scale usually break in a random patterns (fracture). Chalcopyrite (CuFeS_2), quartz and magnetite (Fe_3O_4) are all examples of minerals that display fracture. Some fracture patterns are not so random. For example, when window glass or soda bottles break, they often leave a characteristic concentric or **conchoidal fracture** pattern. Some specimens of quartz display conchoidal fracture, but it is best developed in cryptocrystalline varieties of this mineral (e.g., chert, agate, jasper etc.).

The planar surfaces called cleavage are developed in minerals that are glued together by chemical bonds of variable strength or direction. These minerals tend to break along **Table 1.3**. Common crystal shapes exhibited by minerals

Shape	Description	Example Minerals
Cubic	6 sided crystals which form right angles at the corners (Figure 1.2-A)	pyrite, halite, fluorite galena
Rhombohedral	6 sided crystals which do not form right angles at the corners (Figure 1.2-B)	calcite, dolomite
Dodecahedral	12 sided crystals, each face shaped like a diamond, hexagon or pentagon (Figure 1.2-C)	garnet
Octahedral	8 sided crystals shaped like two pyramids joined at the base (Figure 1.2-D)	magnetite
Prismatic	crystals shaped like a 6 sided hexagon with caps at each end (Figure 1.2-E)	quartz, corundum, apatite

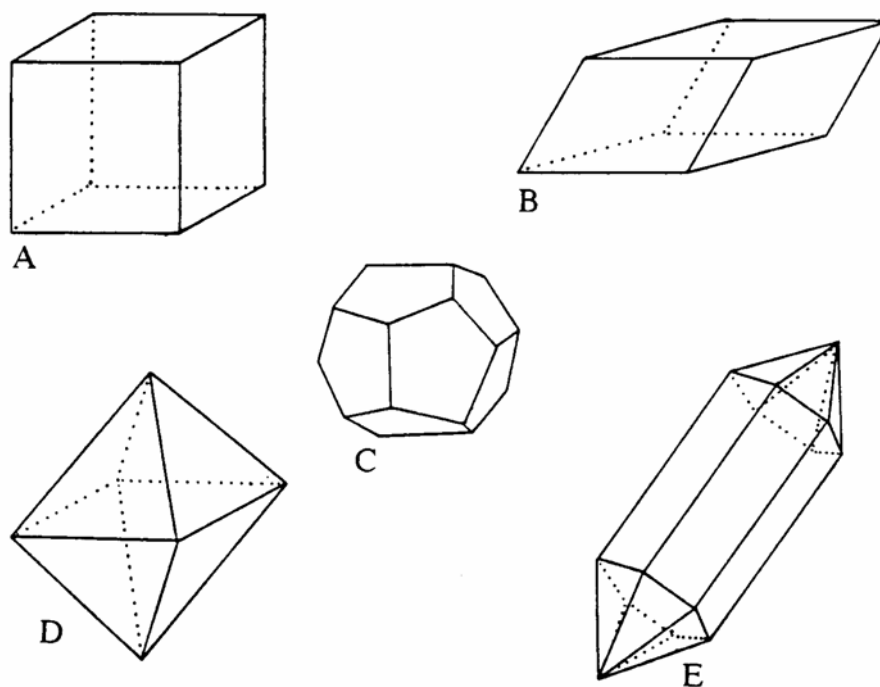


Figure 1.2. Schematic illustrations of common crystals shapes that you may encounter in GY 111. (A) Cubic (galena); (B) Rhombohedral (calcite); (C) Dodecahedral (garnet); (D) Octahedral (magnetite); (E) Prismatic (quartz).

cleavage planes because they are surfaces of comparable weakness all the way down to the atomic scale. The number and orientation of cleavage planes varies between minerals (Table 1.4, Figure 1.3). Biotite, for example, is characterized by a single cleavage plane which is the reason why this mineral can be peeled into paper-thin layers. Orthoclase feldspar (KAlSi_3O_8) has two cleavage planes that are arranged at 90° to one another. Galena and halite each have three cleavage planes orientated at 90° to one another. Calcite also has three cleavages, but they are orientated relative to one another at angles of 70° or 120° . This is hard to visualize, and most instructors just say that cleavage in calcite is *not* at 90° . The cleavage pattern in calcite is distinctly rhombohedral and this is often translated into rhombohedral crystal forms. **WARNING:** Students often confuse cleavage with crystal form but the two are completely different properties. Crystal faces were produced while the mineral was growing and the geometric shape into which a mineral grows is not necessarily the same as what its cleavage defines. Fluorite, for example, has a cubic crystal form yet can be cleaved into an octahedron along its cleavage planes. Minerals like quartz, corundum, pyrite, and garnet all have well-developed hexagonal, cubic or dodecahedral crystal forms (see Table 1.3), but they don't cleave at all; they fracture.

Another difficulty in identifying cleavage patterns is that not all planes are equally well-developed. Cleavage planes vary in quality from "perfect" (very well developed in all specimens; e.g., biotite) to "poor" (seldom seen in any specimen; e.g., staurolite). Feldspars are characterized by two cleavage planes, but neither is "perfect" in quality. Both are said to be "good" which means that you can usually spot vestiges of cleavage in hand specimens, but not always. In some instances, cleavage and fracture look very similar to one another and for this reason, cleavage is among the least favorite of the mineral properties that students must learn. The best way to identify cleavage is by holding the mineral in such a way that it reflects light (as if you were examining luster). Slowly rotate the mineral so that it eventually reflects the light directly back toward your eyes. Since cleavage is a plane, when the angle is correct, you will see a flash of light in much the same way that a flat mirror reflects sunlight. If you see a flash, you are either looking at a cleavage plane or a crystal face (you have to distinguish between them). This method also works for minerals with less than perfect cleavage (like feldspar). These minerals may display a step-like surface consisting of some cleavage and some fracture. The cleavage planes will still reflect light back to you because they are parallel surfaces. Be sure to rotate the specimen around as many axes as possible so that you can find as many of the cleavage planes as possible.

Table 1.4. Cleavage in common minerals. Examples marked with asterisks generally display at least one plane of perfect to excellent cleavage. Those without asterisks are characterized by good to poor cleavage development.

Number and Directions of cleavage	Example Mineral
1 (basal)	muscovite*, biotite*, graphite, talc, chlorite
2 at 90°	feldspars, pyroxene
2 not at 90° (56° & 124°)	amphibole
3 at 90°	galena*, halite*
3 not at 90°	calcite*
4	fluorite*
6	sphalerite*

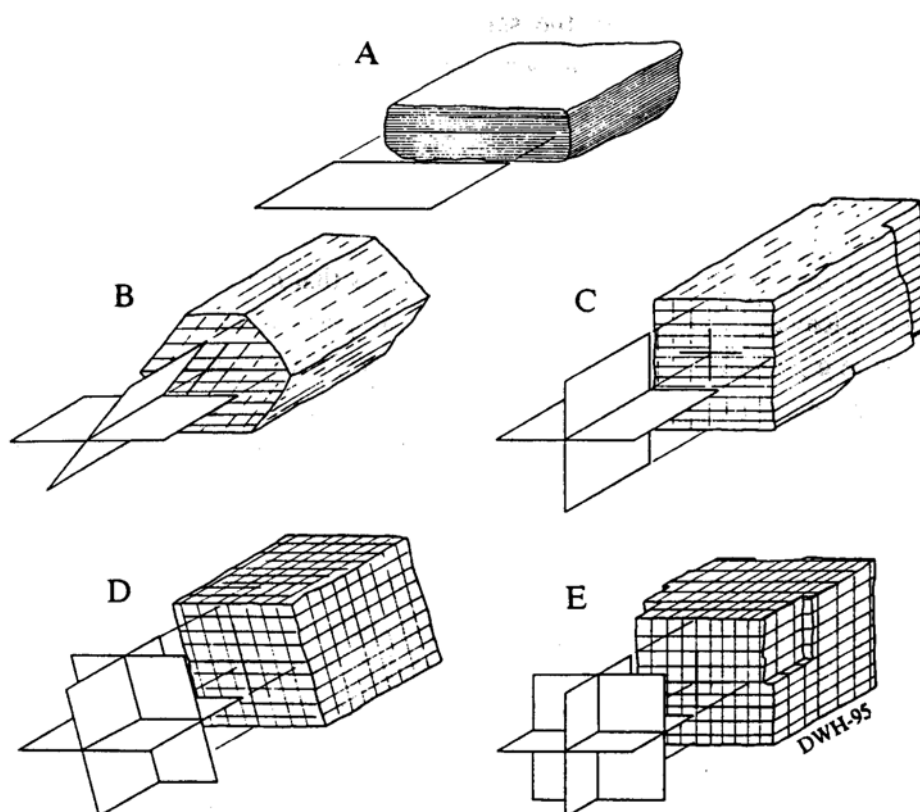


Figure 1.3. Schematic illustrations of GY111 minerals that contain one, two or three cleavage planes. (A) 1 perfect (basal) cleavage (e.g., muscovite, biotite, chlorite, graphite); (B) 2 cleavages *not* at 90° (amphibole); (C) 2 cleavages at 90° (feldspar, pyroxene); (D) 3 cleavages *not* at 90° (calcite); (E) 3 cleavages at 90° (galena, halite).

1.1-8 Optical Properties

Diaphaneity: Diaphaneity is the ability of a mineral to transmit light. **Opaque** minerals of normal thickness do not allow light to pass through them. They include pyroxene, amphibole and galena. **Translucent** minerals like fluorite allow light to pass through but a clear image is not obtained of objects on the other side. **Transparent** minerals such as quartz, halite and Iceland spar calcite transmit light as readily as glass.

Double Refraction: Iceland spar, an optically pure form of calcite, causes images viewed through it to appear double. Two images are produced in calcite because light is split into two rays as it passes through the mineral. The light ray is split because calcite allows light to vibrate faster in one direction than in another.

Internal refraction: This is an interesting property that is a combination of light transmission and reflectance. Light passes a short distance into the mineral before it is reflected back to the observer. In some cases, a wonderful play of colors is observed from just below the mineral's surface. Opal and some varieties of calcium plagioclase ($\text{CaAl}_2\text{Si}_2\text{O}_8$) display this property. Opal displays reds, greens, and yellows. Calcium plagioclase displays blues, greens and yellows. Both are used as gemstones if the color play is particularly attractive.

1.1-9 Other Properties

Taste: Halite can be easily identified as ordinary table salt by its taste. Sylvite (KCl) is another mineral that also tastes salty, but it has a bitter aftertaste. Sylvite is the primary ingredient in commercial salt substitutes. Exercise caution when testing this property, especially if someone before you first tested the specimen for its reaction with HCL (see below). If you suspect that a mineral is halite or sylvite, scrape a bit of the mineral off of its surface and taste it rather than directly licking the specimen.

Reaction with Hydrochloric acid (HCl): Some minerals like calcite and to a lesser degree dolomite (when powdered), react with hydrochloric acid. When HCl is added to calcite it effervesces as bubbles of CO_2 gas are driven off into the atmosphere. Although dilute, HCl is a strong acid. Avoid contact with your eyes, skin or tongue (see above).

Feel: Minerals that are softer than your skin (Hardness = 1) rub off on your skin and consequently feel greasy or soapy. This is a useful property for identifying the minerals talc, graphite and kaolinite.

Pliability: The mineral kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) readily absorbs water. When wet, it can be molded, a useful property since this is one of the clay minerals used by potters to make pottery and sculptures.

Smell: Some minerals have a distinctive smell such as the earthy odor of kaolinite and the rotten egg (sulfurous) smell of powdered sphalerite. Don't be afraid to scratch and sniff a suspect mineral.

Magnetism: a few minerals (especially magnetite) have natural magnetic properties and form natural lodestones. A diagnostic test for magnetite is whether a magnet will be attracted to it.

Striations and exsolution: The plagioclase feldspars exhibit characteristic striations or parallel grooves on cleavage surfaces. Though plagioclase striations are often faint and close together they are obvious if examined under bright light with your hand lens. Striations are also formed on crystal faces of pyrite and quartz. Orthoclase feldspar and some sodium plagioclase have no striations but often exhibit a pattern of **exsolution**. Exsolution lines called "squiggles" are inside the mineral and look like two colors of paint (usually pink and white) trying to un-mix. These lines are actually caused by two varieties of feldspar that separated from a common magma during crystallization (see Chapter 2: Igneous Rocks).

1.2 Economic Uses

As mentioned in the preface, many common minerals have important economic uses. Some are sought after for their metallic properties (e.g., ores of zinc, copper and aluminum), whereas others are useful as building materials (e.g., gypsum for gyprock, calcite for cement etc.). Table 1.5 summarizes some of the economic uses of minerals in the GY 111 tray.

Table 1.5. Economic uses of some minerals

Mineral	Economic Use
bauxite	aluminum ore
calcite	Portland cement, chalk, antacids
dolomite	vitamins, antacid, garden lime
chalcopyrite	copper ore
galena	lead ore
garnet	gemstones, jewelry, sand paper
gypsum	sheetrock, plaster, cosmetics
graphite	lubricants, pencil lead
halite	table salt
olivine	jewelry (mineral peridot)
diamond	abrasives, girl's best friends
sulfur	pharmaceuticals, asphalt, plastics
fluorite	dental applications, steel flux
kaolinite	clay, pottery, tile, Kaopectate, cosmetics
hematite	iron ore
limonite	iron ore
magnetite	iron ore
malachite	jewelry, copper ore
quartz	electronic applications
sphalerite	zinc ore
talc	lubricant, talcum powder

1.3 Chemical Groups

As you will learn in the lecture component of GY 111, minerals are classified according to their chemical affinities. Chemical subgroups in the formula of each mineral such as PO_4^{3-} for phosphates, $\text{Si}_x\text{O}_y^{n-}$ for silicates, and O_2^{2-} for oxides indicate the chemical group in which each mineral belongs. Table 1.6 identifies many of the lab minerals with respect to its proper chemical group and characterizing anion. You are not expected to know all of the minerals which occur in these groups, but it is a good idea to know what the major chemical differences are between the groups. Some instructors also expect you to know chemical formulas of some of the important or common minerals (e.g., halite, quartz, pyrite, hematite). The properties of a mineral are largely dictated by its chemical and crystal structures so if you know a mineral's chemical formula, you can estimate its properties.

Table 1.6. Chemical groups and formulas of some important minerals.

Group	Mineral Name	Mineral Formula
Elements (no anions)	Diamond, Graphite Gold Copper Silver Sulfur	C Au Cu Ag S
Oxides (O ²⁻)	Hematite Magnetite Corundum Limonite Bauxite	Fe ₂ O ₃ Fe ₃ O ₄ Al ₂ O ₃ FeOOH Al ₂ O ₃
Silicates (Si _x O _y ⁿ)	Quartz Opal Orthoclase Ca/Na Plagioclase Muscovite Biotite Kaolinite Amphibole Pyroxene Olivine Chlorite Garnet Talc Kyanite Staurolite	SiO ₂ SiO ₂ •H ₂ O KAlSi ₃ O ₈ CaAl ₂ Si ₂ O ₈ / NaAlSi ₃ O ₈ KAl ₂ Si ₃ O ₁₀ (OH) ₂ K(Mg,Fe) ₃ Si ₄ O ₁₀ (OH) ₂ Al ₂ Si ₂ O ₅ (OH) ₄ Ca ₂ (Mg,Fe) ₅ Si ₈ O ₂₂ (OH) ₂ Ca(Mg,Fe)SiO ₃ (Mg,Fe) ₂ SiO ₄ (Mg,Fe,Al) ₆ (Al,Si) ₄ O ₁₀ (OH) ₈ (Ca,Mg,Fe,Al)SiO ₄ Mg ₃ Si ₄ O ₁₀ (OH) ₂ Al ₂ SiO ₅ Fe ₂ Al ₉ Si ₄ O ₂₂ (OH) ₂
Carbonates (CO ₃ ²⁻)	Calcite, Aragonite Dolomite Malachite	CaCO ₃ CaMg(CO ₃) ₂ Cu ₂ (OH) ₂ CO ₃
Sulfates (SO ₄ ²⁻)	Anhydrite Gypsum	CaSO ₄ CaSO ₄ •2H ₂ O
Sulfides (S ²⁻)	Galena Pyrite Chalcopyrite Sphalerite	PbS FeS ₂ CuFeS ₂ ZnS
Halides (Cl ⁻ or F ⁻)	Halite Sylvite Fluorite	NaCl KCl CaF ₂
Phosphates (PO ₄ ³⁻)	Apatite	Ca ₅ (F,Cl)(PO ₄) ₃

Table 1.7 GY 111 mineral catalog grouped according to luster, streak, hardness and cleavage. Minerals that display significant variation in properties (especially color) are shaded. Suite indicated the most common rock types in which these minerals occur: I: igneous; S: sedimentary; M: metamorphic; H: hydrothermal; A: all rock types. Use caution when testing for mineral hardness. Some minerals (e.g. kyanite) display distinctly different hardness depending upon orientation or surface condition.

		MINERAL CHARACTERISTICS AND DESCRIPTIONS		SUITE*	MINERAL NAME
METALLIC LUSTER	Grey, black, greenish-black streak	Greenish yellow color, may tarnish. H=3.5-4. S.G.=4.2. Streak greenish black. Usually massive, no visible crystal form or cleavage. May be associated with other sulfide minerals, especially pyrite.		I, H	Chalcopyrite
		Lead gray color. H=2.5. S.G.=7.6. Streak lead gray. Three directions of perfect cleavage at 90°. Cubic crystal form with a step-like appearance to broken surfaces.		I, S, H	Galena
		Gray to black color. H=1. S.G.=2. Streak black. One direction of cleavage. Marks paper and fingers. Greasy feel.		M	Graphite
		Gray to black color, occasionally with reddish highlights. H=6. S.G.=5.2. Streak black. No cleavage. Usually occurs in massive form. Rare crystals are octahedral. Strongly magnetic, a diagnostic property.		A	Magnetite
		Pyrite brass; yellow color. H=6-6.5. S.G.=5. Streak greenish black. No cleavage. Cubic crystal form is common. Striations common on crystal faces.		A	Pyrite
	Copper streak	Pure specimens and fresh surfaces are metallic copper in color. Most specimens are dark brown to green in color. H=2.5 - 3. S.G.=8.9.		V, H	Copper
Pale yellow streak	Dark brown to yellow brown color. H=3.5-4. S.G.=4. Resinous luster. Streak pale yellow. Six directions of cleavage, but seldom well developed. Powdered mineral (when streaked) smells like sulfur.		I, S, H	Sphalerite	
NON-METALLIC LUSTER (DARK-COLORED)	Harder than Glass	Cleavage	Pale green to dark green to black color. H=5.5-6. S.G.=3.3. Vitreous luster. Two directions of cleavage at 124° and 56°, but not always well developed. Lined surface due to parting.	I, M	Amphibole (Hornblende)
			Pale green to dark green to black color. H=5.5-6. S.G.=3.5. Waxy to vitreous luster. Two directions of cleavage at 90°, but not always well developed. Short blocky crystals.	I, M	Pyroxene (Augite)
			Color: gray for Ca variety (versus white for Na variety). Some Ca specimens show purple iridescence. H=6. S.G.=2.7. Vitreous luster. Cleavage in two directions at 90°. Striations common on cleavage planes.	I, M	Plagioclase (Calcium-variety)
			White to brown color, fibrous habit. H=6-7. S.G.=3.3. Luster is pearly to satiny, but is not consistent. A polymorph of kyanite.	M	Sillimanite
			Red, gray to black. H=7-7.5. S.G.=3.7. Classic cross-shaped crystals (rhombs in section). 1 poor cleavage.	M	Staurolite
	Variable hardness	Blue-Grey bladed crystals displaying variable hardness: 4-5 along the long axis of crystals; 6-7 across crystals.		M	Kyanite
	Harder than Glass	No cleavage	Color highly variable. H=7. S.G.=2.65. Waxy luster. No cleavage. Conchoidal fracture. Varieties include jasper, flint, chert, opal and agate. Most petrified wood has been replaced by cryptocrystalline quartz.	A	Cryptocrystalline Quartz ("chert")
			Variable color; brown, grey, blue, pink or purple. H=9. S.G.=4. Vitreous to adamantine luster, but commonly earthy. No cleavage, but does form six sided prismatic crystals that may resemble cleavage.	M	Corundum
			Commonly red, brown, green or pink. H=7. S.G.=3.5-4.5. Vitreous luster. No cleavage. Exhibits parting which may look like cleavage. Frequently forms classic dodecahedral crystals.	M	Garnet
	Softer than Glass	Cleavage	Dark brown to black color. H=2.5-4. S.G.=3. Vitreous luster. Perfect cleavage in one direction. Cleaves into thin flexible sheets which may be translucent.	I, M	Biotite
			Dark green, commonly with iron stains. H=2-2.5. S.G.=3. Pearly luster. Streak white-green. Perfect cleavage in one direction which results in scaly appearance. Often contaminated with other minerals (e.g., garnet).	M	Chlorite
			Green, blue, brown to yellow crystals. H=5, S.G.=3.1. Vitreous luster. White streak. Cleavage in one direction; poorly developed. Forms hexagonal crystals. Also commonly in masses of crystals.	I, M	Apatite
			Dark brown to yellow brown color. H=3.5-4. S.G.=4. Resinous luster. Streak pale yellow. Six directions of cleavage. Powdered mineral smells like sulfur.	I, S, H	Sphalerite
		No cleavage	Red color. Highly variable hardness (H=1 - 6), S.G.=5.5. Earthy luster. Streak red. No cleavage.	S	Hematite
Brown to ochre in color. H=1-3. S.G.=3.5. Earthy luster. Streak yellow brown. No visible cleavage.			S	Limonite	
Lawn green colored, commonly fibrous or laminated aggregate; of crystals. H=3.5-4. S.G.=4.0. Distinctive pale green streak. Commonly associated with blue azurite. A popular gem stone when polished.			H	Malachite	
NON-METALLIC LUSTER (LIGHT COLORED)	Harder than Glass	Cleavage	Color is usually pink but may be white, turquoise or green. H=6. S.G.=2.56. Vitreous luster. Cleavage in two directions at 90°. Exsolution "squiggles" common.	I, M	Orthoclase (Potassium feldspar)
			Color: white for the Na variety (versus gray for Ca variety). H=6. S.G.=2.7. Vitreous luster. Cleavage in two directions at 90°. Striations common on cleavage planes. Exsolution "squiggles" are rare to common.	I, M	Plagioclase (Sodium variety)
		No cleavage	Colorless but may be purple v. amethyst, pink v. rose, white v. milky or gray brown v. smoky quartz. H=7. S.G.=2.65. Vitreous luster. No cleavage. Conchoidal fracture on broken surfaces. Crystals- 6 sided prisms. Crystal aggregates common.	A	Quartz (many varieties)
	Softer than Glass	Cleavage	Olive green, yellowish-green to dark green. H= 6.5. S.G.=3.3. Vitreous luster. Occurs as an aggregate of small grains which gives a sugary appearance to the mineral.	I	Olivine
			Colorless to white. H=3. S.G.=2.7. Vitreous luster. Cleavage good- 3 directions not at 90°. Streak white. Effervesces in HCl. Transparent Iceland spar v. shows double refraction.	S, M	Calcite
			Pink, white or light brown in color. H=3.5-4. S.G.=2.7. Vitreous luster. Cleavage in 3 directions not at 90°. Streak white. Saddle dolomite forms pink saddle shaped crystals. Brown sugary masses are also common.	S	Dolomite
			Transparent, purple, pink, yellow, green or blue in color. H=4, S.G.=3.18. Vitreous luster. Perfect cleavage in three or four directions. Streak white. Crystals cubic.	S, H	Fluorite
			Transparent to white. H=2. S.G.=2.32. One good cleavage direction, poor in two others. Streak white. Selenite gypsum is transparent with a vitreous luster. Satin spar appears fibrous and has a silky luster.	S	Gypsum
			Transparent to white. H=2.5. S.G.=2.5. Vitreous or waxy luster. Perfect cleavage in 3 directions at 90°. Streak white. Tastes salty.	S	Halite
			Transparent in thin sheets. H=2.5-4. S.G.=2.8. Vitreous luster. Perfect cleavage in one direction. Streak white. Cleaves into thin flexible sheets.	I, M	Muscovite
		No Cleavage	Pale yellow to lemon yellow crystals. H 1.5-2.5. S.G.=2.0. Perhaps the easiest mineral to identify.	I	Sulfur
			Commonly green, gray or white in color. H=1. S.G.=2.8. Pearly luster. Good cleavage in one direction. Streak white. Feels greasy or soapy.	M	Talc
			White, beige, brown or reddish-yellow in color. H=1-5. S.G.=3. Earthy luster. Cleavage not visible. Forms spherical or pisolitic aggregates.	S	Bauxite
			White color, occasionally mottled with red stain. H=1 - 2. S.G.=2.6. Earthy luster with no visible cleavage. Streak white. Becomes pliable when wet. Sticks to moistened tongue.	S	Kaolinite

1.4 Exercises

Check with your instructor to determine which of the optional exercises (if any) that you are responsible for in the lab component of GY 111. Regardless of these exercises, all students should be familiar with the tests for determining the physical properties described in this manual. During the lab sessions, make sure that you examine each of the minerals in your lab tray for these physical properties and learn how to identify them using Table 1.7.

For the exam you will have to be able to identify unknown mineral specimens. You will also have to know the following for known and unknown specimens:

- (a) Mineral names (Table 1.7)
- (b) Chemical groups to which each mineral is assigned (Table 1.6)
- (c) Economic uses of the common minerals (Table 1.5)
- (d) Cleavages (Table 1.4).
- (e) Crystal forms and mineral examples (Table 1.3).
- (f) Lusters and hardnesses of minerals on Mohs' scale (Tables 1.1 and 1.2)
- (e) Silicate structures of minerals covered in class.

Optional exercises:

- 1) What are the best ways to distinguish between the following mineral pairs:
 - a) amphibole and pyroxene
 - b) Ca-plagioclase and Na-plagioclase
 - c) quartz (v. amethyst) and fluorite
 - d) halite and sylvite

- 2) What are some of the other economic uses for the minerals in your trays? There are lots more than those listed in Table 1.5.

- 3) Like math? Here is a good question for you. Suppose that you found a huge deposit of the mineral chalcopyrite. You estimate that it contains 100,000 tons of pure ore. How much copper would you get out of the deposit if it was refined? (Hint: you might need a periodic table of the elements).

- 4) Some of the uses that minerals are put to are rather unorthodox. Quartz is believed by some people to cure ailments. Hematite is thought to purify the blood. Do you know of any other "new age" uses for the minerals?

- 5) Chances are that one day you will buy or be given a diamond ring. The best diamonds usually have the nicest cuts, but just how do you cut the hardest substance known?

- 6) Why is streak a more useful property than color when attempting to identify minerals?
- 7) What extraction processes are necessary to obtain copper metal from chalcopyrite ore? How do you extract pure gold from gold ore? (Both questions may require library research).
- 8) What is your birthstone? What are its diagnostic properties? Which properties make it valuable?
- 9) Why do some minerals have,
 - a) different lusters for different specimens?
 - b) different colors for different specimens?
 - c) different crystal forms for different specimens?
- 10) What is your favorite mineral in the GY 111 tray and why? What is your least favorite mineral in the GY 111 tray and why?

Notes

