

Determinative Mineralogy and
Mineral Identification Lab: Native Elements - Sulfides*
(Much of this lab was created by Dr John Grace, Professor Emeritus, WMU)

Part I: Determinative Mineralogy: Definitions and Procedures

Determinative mineralogy is the system or scheme by which one uses the various physical and chemical properties of an unknown mineral in order to identify it. In practice it is a relatively simple matter to compile such properties as color, luster, hardness and cleavage and then sort through a comparative table that lists known minerals and their properties.

A detailed description of the various useful physical properties that may be used to identify unknown mineral samples is presented in the Simon and Schuster's guide starting on p. 31. Also, the Field Guide has all of the minerals that we will study listed with their diagnostic physical properties. HOMI (the Hands-On Mineral Identification CD) also has an elaborate "Mineral Database" that is very useful for the mineral identification process. Finally, the extensive "Mineral Data base" www site compiled by David Barthelmey has a "mineral properties" page, <http://webmineral.com/determin.shtml>, which can be used for determinative mineralogy. I will compile a table of determinative properties for your use in the lab practical exams (later).

Luster

Most all determinative tables first use *luster* and secondly use *hardness* to organize mineral identification. Luster is essentially a measure of how light is reflected off the surface of a mineral and in general can be said to be either metallic (a lot of light is reflected) or non-metallic. The following list might be helpful.

Some terms for luster:

Metallic: having the luster of a metal - e.g. reflects with brilliancy; can give a well-defined image - e.g. specular hematite, galena, gold.

Submetallic: having an imperfect metallic luster - e.g. magnetite.

Non-metallic vitreous - glassy - e.g. quartz

subvitreous - imperfect vitreous luster - e.g. calcite

resinous - having the luster of resin e.g. amber, sphalerite

adamantine - hard brilliant luster - e.g. diamond, sphene

labradorescence - will reflect a range of blues and greens in sunlight - e.g. labradorite

chatoyance - changing luster similar to the luster of the eye of a cat - e.g. tiger's eye

greasy - slightly iridescent - like a pearl - e.g. opal

silky - reflection from fine fibers - e.g. gypsum (satin spar)

earthy - dull, clay like look - e.g. bauxite, limonite

Hardness

Hardness is actually a measure of the strength of the chemical bond in a particular mineral and a relative scale of hardness called Mohs scale has long been used to determine this. It is a scale that varies from very soft minerals (1) to very hard minerals (10) and is discussed on page 40 in the Simon and Schuster's guidebook.

Shape/Appearance (Habit)

After a mineral has been categorized by luster and hardness then other properties will be discussed under individual entries. These properties are very important in helping to identify an unknown mineral. Some of these properties are discussed in general below to help you sharpen your observational powers.

Table 1. **Some descriptive terms to describe the informal term "crystal habit" (characteristic appearance of a crystalline solid due to crystal growth idiosyncrasies which may vary as a function of crystal growth conditions):**

<u>Acicular</u>	needle-like, slender crystals - e.g. rutile
<u>Fibrous</u>	crystals smaller than acicular - e.g. asbestos
<u>Radiated</u>	fibers radiating from a common center - e.g. wavellite
<u>Bladed</u>	crystals have a flattened blade or lath-like shape - e.g. kyanite
<u>Tabular (Lamellar)</u>	composed of flattened plates. Characteristic of minerals with a single perfect cleavage -e.g. selenite (a variety of gypsum)
<u>Foliated (Micaceous)</u>	when the plates of a lamellar crystal are very thin and easily separable - e.g. micas
<u>Columnar</u>	crystals fairly large and approximately equidimensional in cross section - e.g. tourmaline
<u>Prismatic</u>	having three or more similar faces parallel to a single axis with a long dimension - e.g. quartz
<u>Blocky</u>	similar to prismatic but without a single long dimension-length approximately equaling width - e.g. feldspar crystals
<u>Reticulated</u>	net like or lattice like appearance - e.g. cerussite
<u>Botryoidal</u>	having the form of a bunch of grapes - e.g. hematite, malachite
<u>Granular</u>	individual grains show no marked elongation; divided into coarse, medium and fine, depending on size of grains - e.g. olivine
<u>Massive</u>	no particular shape or structure can be discerned
<u>Dendritic</u>	tree like, branching appearance - e.g. silver, gold, manganese oxides
<u>Banded</u>	having distinct color bands - e.g. agate
<u>Rosettes</u>	bladed crystals grouped concentrically around a center to give a flower like appearance - e.g. barite
<u>Spherulitic</u>	a spherical or ellipsoidal shape consisting of many radiating fibers - oolites are groups of spherulite

Of course if you know the crystallography of the specimen then that should certainly be listed first and habit is only used when you cannot really be certain of the crystallography.

Specific Gravity (Density)

The ***specific gravity*** or density is another helpful property that can be used to distinguish one mineral from another. It is the relative weight of the specimen compared to the weight of an equivalent volume of water. This can be expressed as:

$$D = \text{weight in air} / \text{weight in air} - \text{weight in water.}$$

The following table gives some typical values for some common minerals.

Table 2

<i>Light</i>	<i>Intermediate</i>	<i>Heavy</i>
Borax 1.7 (a borate)	Kaolinite 2.6 (a clay)	Pyrite 5.0 (a sulfide)
Halite 2.2 (salt)	Calcite 2.7 (a carbonate)	Cassiterite 7.0 (an oxide)
Gypsum 2.3 (a sulfate)	Biotite 3.0 (a silicate)	Gold 19.0 (native element)

There are a number of ways in which the density of a mineral can be determined utilizing a simple balance and a beaker of water. There are some balances such as the Jolly Balance that are specifically constructed to determine the specific gravity of minerals. Your HOMI CD has a very nice presentation (suitable for use in a classroom setting) on ***Density and Specific Gravity***.

You can get an additional 10% extra credit on lab #3 by answering the questions on the CD for this section and turning them in with your lab.

Another common method for determining density is the use of "heavy" liquids. They are particularly useful for separating a mixture of light minerals and heavy minerals one from the other simply by having one (say quartz 2.6) float and the other (say garnet 4.2) sink in the liquid bromoform (2.9). This technique is often used for the commercial separation of grains of a desired ore mineral from undesired gangue minerals.

It is also possible to calculate a theoretical density for a substance if one knows the chemical composition and the structure. Since we know the atomic weight for a given atom and if we then know the number of atoms within a unit cell of a mineral then we can calculate the density with the aid of the following formula.

$$D = \frac{Z \times M}{N \times V}$$

Where Z is the number of formula units per unit cell; M = molecular weight of the unit cell; N is Avogadro's number (6.02×10^{23}) and V is the volume of the unit cell. We will do an exercise using these relationships a little later in the first section of the course.

CLEAVAGE

Cleavage is one of the easiest properties to explain and yet one of the hardest things to get a newcomer to determinative mineralogy to observe accurately.. Cleavage is the tendency for minerals to break along plans of weakness in a crystal. Cleavage may be good or poor or indeed it may be absent altogether. A mineral such as mica has good cleavage but quartz has no cleavage what so ever. Quartz can be broken of course but the break or fracture is uneven or conchoidal since there are no weak bonding directions in this mineral.

It is important to state not only the fact that a mineral has cleavage but also state how many cleavages there are and the angular relationship between them. Please study Figure 1 with great care!

Figure 1 - Cleavage

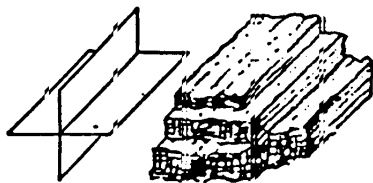
Perfect cleavage in one direction



Good cleavage in one direction poor cleavage in another



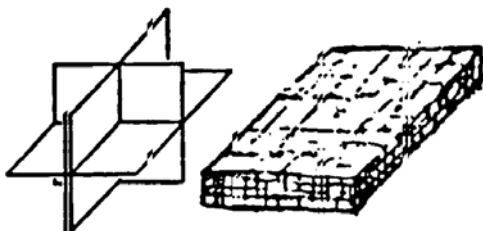
Good cleavage in two directions,



Good cleavage in two directions, poor cleavage in one direction



Good cleavage in three directions



It is also desirable to state the angular relationship between the cleavage planes. For instance, halite has 3 direction of cleavage at right angles (cubic cleavage) white calcite has 3 directions of cleavage at angles of approximately 102° (rhombic cleavage).

Figure 2

- a) conchoidal fracture; quartz, glass, olivine
- b) basal cleavage; mica and chlorite
- c) prismatic cleavage; pyroxene and feldspar
- d) prismatic cleavage; amphibole
- e) cubic cleavage; halite and galena
- f) rhombohedral cleavage; calcite
- g) octahedral cleavage; fluorite
- h) dodecahedral cleavage; sphalerite

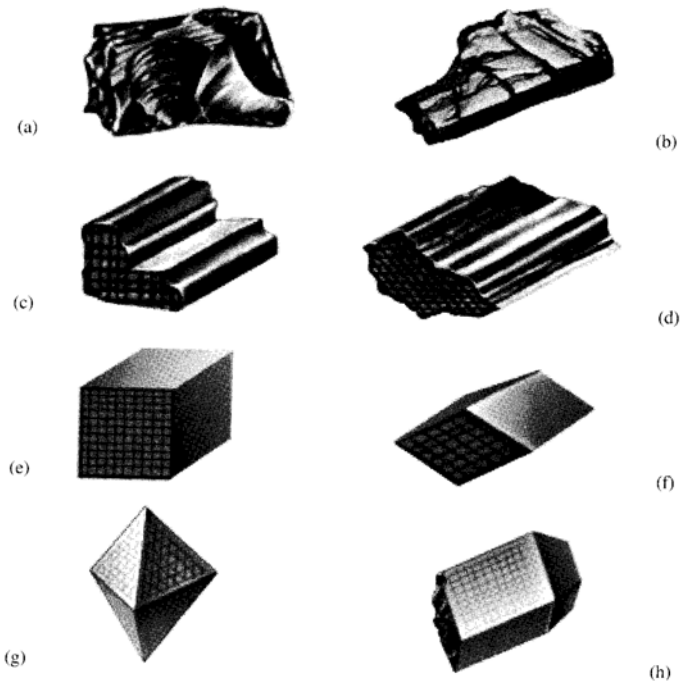


FIGURE 4.9 Fracture and Cleavage of Minerals

Questions for Part 1

1. In each of the "Mineral Properties" displays in the Geosciences Museum (Luster, Hardness, Cleavage/Fracture, Color and Streak) list the example minerals and write down the appropriate physical properties. Please do this on a separate piece of paper.

2. Also, memorize the Mohs Hardness scale and the relative hardness of the familiar objects: a fingernail, a copper coin, a steel knife, and glass.

Part II: Native Elements - Sulfides

We will work with a classification scheme of minerals and study systematic mineralogy in the class lecture sessions soon, but for our lab activities this week we will start with some unknown mineral identification exercises. The typical mineral identification lab exercise begins with the *Native Elements - Sulfides*. These minerals are relatively easy to identify on the basis of physical properties, are relatively less complicated, mineralogically, than the more abundant rock forming minerals, and have great economic significance despite their minor volumetric occurrence on Earth.

Some elements are sufficiently non-reactive in the earth's crust that they can remain uncombined with other atoms and thus exist as a mineral. Some are metallic and others nonmetallic. The common metallic native metals are copper, silver, gold, platinum, bismuth and mercury. Iron only occurs in the native state as an iron nickel alloy in meteorites. The nonmetallic native elements include carbon (as both graphite and diamond) and sulfur.

Gold and platinum are found as primary deposits associated with igneous rocks but are also found and easily worked as placer deposits. The well-known image of an old timer panning for gold in the California gold rush has become a virtual symbol of pioneer days in the west. Copper is most often found as a sulfide mineral but is known to occur as a native element. The native copper deposits of the Keweenaw Peninsula of Michigan are known throughout the world and are unique in being one of the few major copper deposits in which the ore occurs in the native state rather than as copper sulfide minerals. The metal is found in Pre-Cambrian basalt flows that dip to the north-west under Lake Superior. They outcrop again on Isle Royale on the other side of the lake.

There is evidence that ancient Indian tribes (3000-1000 b.c.) mined the native deposits of Michigan and traded various copper artifacts widely throughout north-eastern North America. It was not until 1844 that modern mining began in the area and soon thereafter Michigan became the principle copper-producing state in America. It was not until the turn of the century that porphyry copper deposits of the western United States (mostly Arizona) surpassed Michigan in importance. Today, unfortunately, none of the native copper mines of the Keweenaw Peninsula are in operation but there is, however a copper sulfide ore body being mined in the White Pine district of the U.P. Figure 3 illustrates the location and a cross section of the area.

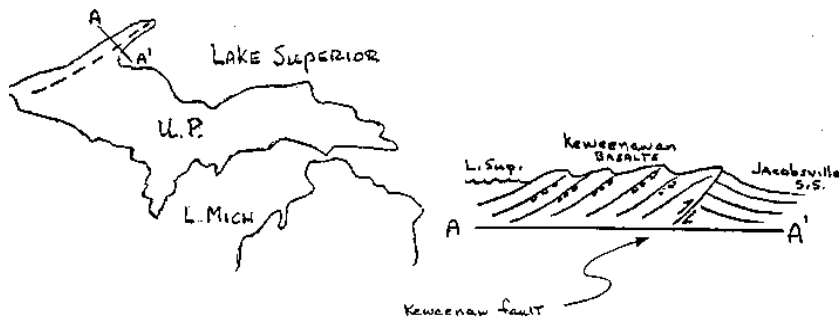


Figure 3 - Native Copper Deposits of Michigan copper

Sulfur is an important industrial mineral and large tonnages are mined to produce sulfuric acid. The Salt dome area of Texas and Louisiana on the gulf coast is an important producing region but a lot of the element is now being produced as a byproduct of making low sulfur petroleum products.

Diamond is a most interesting and obviously quite rare mineral. The thermodynamics of carbon indicate that it must form at great depths where there is sufficient pressure and temperature to produce this dense ($SG=3.5$) form of carbon. Indeed the source area for diamonds are "kimberlite pipes" that are similar to volcanic necks but have included rock types (peridotites) in them that indicate a very deep upper mantle source.

Some Kimberlite pipes are known to exist in the U.S. but only one, located in Arkansas, has produced diamonds. Recent finds of Kimberlite pipes in Michigan's upper peninsula has created quite a stir but as yet no announcement has been made indicating whether or not they are diamondiferous.

Graphitic is the low density ($G = 2.2$) form of carbon found in metamorphic rocks. It is a very soft mineral and is used as a lubricant.

SULFIDES

The sulfides are a group of minerals, predominantly metallic in character, in which one or more metal atoms (A , see below) are typically bonded with the large (1.84 \AA) S^{-2} anion (S , below). Many sulfides have relatively simple structures with the metal atoms fitting into the interstices of a close packed sulfur lattice. For instance, galena has the face centered cubic structure similar to halite and sphalerite has a diamond-like cubic structure.

Minerals formed from the chalcophilic elements, those that most commonly bond with sulfur; such as Cu, Ag, Zn, Ni, Co, Hg (be sure to know which elements these symbols represent!); usually have great economic value so sulfide minerals are often referred to as the economic minerals, or ore minerals and often have an entire mineralogy course devoted exclusively to them. Mining Companies are of course very interested in these minerals and field identification is important as well as the ability to identify them in reflected light microscopy. A list of common sulfide minerals is provided in the following Table.

Table 3

(A represents smaller metal cations in combination with sulphur, S; also arsenic, As)

Common Sulfide Minerals

A_2S	A_3S_2	AS	AS_2	A_2S_3
<u>Argentite</u> Ag ₂ S	<u>Bornite</u> (peacock ore) Cu ₅ FeS ₄	<u>Galena</u> PbS	<u>Pyrite</u> (fools gold) FeS ₂	<u>Stibnite</u> Sb ₂ S ₃
<u>Chalcocite</u> Cu ₂ S		<u>Sphalerite</u> Zinc Blend or Black Jack (Zn,Fe)S	<u>Marcasite</u> FeS ₂	Realgar (Orpiment) As ₂ S ₃
			<u>Chalcopyrite</u> <u>Arsenopyrite</u> FeAsS	
		<u>Pyrrhotite</u> Fe _{1-x} S	<u>Molybdenite</u> MoS ₂	
		<u>Covellite</u> CuS	<u>Cabaltite</u> CoS ₂	
		<u>Cinnabar</u> HgS		

Sulfide minerals frequently occur in vein like deposits and their origin is presumed to be due to the precipitation of these minerals from very hot aqueous (hydrothermal) solutions. These "hot water" originate in association with a nearby igneous body. Hydrothermal veins are often zoned with certain minerals associated with hot, deep seated (hypothermal) assemblages, intermediate depth and temperature (mesothermal), and some with shallow, low temperature (epithermal) deposits.

Table 4

<u>Area</u>	<u>Metal</u>	<u>Types</u>
Butte Montana	Cu	Mesothermal
Coeur d'Alene Idaho	Ag	Mesothermal
Cripple Creek Colorado	Au	Epithermal
Homestake South Dakota	Au	Hypothermal
Lead Belt area Missouri	Pb	Epithermal

For instance, pyrrhotite and arsenopyrite are frequently associated with hypothermal deposits, chalcopyrite, pyrite and galena might be found in mesothermal deposits and sphalerite, galena, and Cinnabar are typically found in Epithermal deposits.

Ore deposits weather in a unique way because of the breakdown of the ubiquitous pyrite into hematite-sulfuric acid in the exposed or upper regions of the ore body. As the solutions trickle down toward the water table there is a change in the mineralogy of the ore body as illustrated in Fig. 4 (below).

