Mineralogy Boot Camp Session #16

Native Elements

This session of Boot Camp is devoted to those elements that occur uncombined with any other elements to form a mineral (hence the term *native*). Most of the common ones are metals, and were some of the earliest metals used by humans. Three are nonmetals of particular economic importance to modern society.

Gold

The mineral gold (Au) has been the most sought-after metal in human history. Its physical properties are the reason it has always had such importance to civilization. Gold is relatively soft (2.5-3 on Mohs hardness scale) and very malleable, meaning it could be easily shaped for ornamental purposes. Pure gold has a specific gravity of 19, although it commonly has low levels of impurities such as silver, copper or iron which will slightly decrease this value. The high specific gravity allows gold to concentrate in stream sediments, forming placer deposits. The color is its characteristic gold shade, although it may appear paler as the quantity of silver increases. [Gold containing over 20% silver is called *electrum*.] The melting point of gold (about 1,950°F) is similar to copper but significantly less than iron (at 2,800°F). Gold seldom occurs in a crystal form, instead usually occurring as irregular-shaped masses, scale or plates (Figure 1).

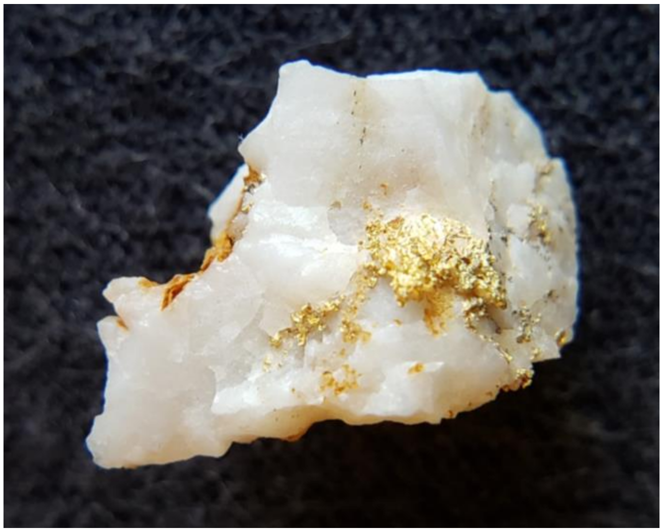

Figure 1. This specimen consists of native gold on quartz from Mariposa County, California. Long axis of the specimen is 0.5 inches.

The domestic gold production for 2021 was estimated by the U.S. Geological Survey to be 180 metric tons (approximately 5.8 million troy ounces) worth about $10 billion. Three-quarters of this production came from Nevada. Nearly half of annual gold production is used in jewelry, with the majority of the remainder being used in various forms by banking institutions. About 7% of gold production goes into the electrical industry.

Silver

The element silver (Ag) can also occur in native form, where again its physical properties explain why silver has been important to human civilization for thousands of years. Native silver is a relatively soft mineral (2.5-3 on Mohs hardness scale) and is malleable, making it easily worked. Its specific gravity typically ranges from 10 to 11, depending on the amount of impurities. The melting point of silver is about 200°F less than gold, making it relatively easy to process and upgrade the purity. While having a characteristic silver-white color on fresh surfaces, native silver will rapidly tarnish to gray-black upon exposure to the atmosphere (see Figure 2). Native silver is usually found in small quantities throughout oxidized sulfide ore deposits. The majority of mined silver comes from silver sulfide minerals such as *acanthite* (Ag_2S) and *pyrargyrite* (Ag_3SbS_4) or from other sulfide minerals such as *tetrahedrite* ($Cu_{12}Sb_4S_{13}$) where silver substitutes for copper.

Figure 2. This is an example of the tarnish coating that develops on native silver when exposed to the Earth's atmosphere. This tarnishing is the reason true silverware had to be polished frequently. The jagged surfaces shown along the edges of this specimen are called *hackly* fracture. From Mexico, this specimen is 0.8 inches long.

The U.S. Geological Survey estimates that 1,000 metric tons (approximately 32.2 million troy ounces) were produced by mines in the U.S., for a value of about $830 million in 2021. The production came from both silver mines and as a byproduct of base-metal (Cu-Pb-Zn) and gold mines. American consumption of silver was nearly 8,000 metric tons, so we must import (mostly from Mexico and Canada) over 80% to meet the demand. Half of this domestic consumption was either in physical investment ("silver bars") or in the electrical industry. It has a myriad of other uses, from jewelry to solar cells to wood treatments.

Copper

The element copper (Cu) is another native mineral long used by humans throughout the world. This use was based upon the malleable nature of the material, allowing it to be used in a variety of purposes. Modern societies rely on copper for electrical purposes, mostly as wire for electrical transportation from source (such as a power plant) to where it is consumed (such as homes and offices). The mineral can be easily recognized by its copper-red color on fresh surfaces (Figure 3), although it frequently tarnishes to a dull reddish-brown (Figure 4). Like the other native metals, it is relatively soft (2.5-3 on Mohs hardness scale) and has a high specific gravity compared to most minerals (near 9).

Figure 3. This specimen consists of native copper intergrown with calcite. The irregular form of the copper is a typical growth pattern for this metal. Specimen is from Michigan. Ruler at bottom is in inches.

Figure 4. This flat plate of native copper is formed by the leaching of copper-bearing sulfides, where the dissolved copper moves downward and redeposits as native copper at the water table. The flat aspect develops because the copper is precipitating along fractures within the rock. Note the “fin” of copper in lower right, indicating a perpendicular fracture also hosting part of the copper. Specimen is from the Chino Mine, Grant County, New Mexico.

Small occurrences of native copper are frequently found in the oxidized parts of large copper deposits, often with the copper carbonates malachite and azurite and/or the copper sulfide chalcocite. The Keweenaw Peninsula in Michigan has produced large amounts of native copper, where it was deposited in basalt flows.

Sulfur

The element sulfur (S) has a wide range of possible valence charges, and thus can combine with several other elements in a number of different forms. It can combine with oxygen to form the basis of the sulfate mineral group and with metals to form the sulfide mineral group. Sulfur can also combine with itself to form a native element mineral by the same name. As a mineral, sulfur is rather soft (1.5-2.5 on Mohs hardness scale) with a quite low specific gravity (about 2.1). The striking yellow color (Figure 5) combined with the distinctive odor (often described as “rotten eggs”) allows sulfur to be readily identified.

Figure 5. This is an example of massive sulfur from Pershing County, Nevada. This specimen is approximately 3.5 inches by 3.2 inches.

Sulfur deposits frequently are formed around the craters and rims of active volcanoes. This material is likely deposited from sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) in fumes given off by the magma. It is also found in sedimentary rocks associated with gypsum, anhydrite, and limestone in beds above salt (halite) layers and structures.

Industry uses are usually in the form of sulfuric acid (H_2SO_4). Manufacturing of fertilizers from phosphate rock requires a major part of the sulfur market. Additional uses are in the manufacturing of insecticides, medicines, textiles, and paints to name just a few. Mined sulfur used to provide most of the demand in industry, but in recent decades the need has been met solely by recovering sulfur from such sources as petroleum refineries and natural gas processing plants. Byproduct sulfuric acid is also recovered from metal smelters. The U.S. Geological Survey estimates that 2021 domestic consumption of sulfur was 10 million metric tons, with an average price of $90 per ton.

Diamond

Elemental carbon (C) can crystallize into two different relatively common minerals, depending on the depositional environmental conditions. The two different forms (which are called *polymorphs* because they have the same chemical compositions but different atomic structures) are *diamond* and *graphite*. Diamond is formed under conditions of very high temperature and pressure, apparently achieved below the crust in the upper mantle (possibly from a depth of 100 miles). Tiny diamond grains have been reported in some meteorites and from meteorite impact structures. [*Note on a common misconception:* You may be familiar with the old *Superman* comics, television series, or movies where the “Man of Steel” takes a fist-sized lump of coal and squeezes it so tightly that it is changed to diamond. This has led to the mistaken idea that diamonds are created through metamorphic processes from carbon-rich material such as coal. Science has conclusively shown that the temperature and pressure conditions required to precipitate carbon as diamond are well above those encountered during metamorphic processes. Artificial diamond (lab-grown) uses a tiny “seed” diamond to give the carbon atoms an existing structure onto which they can attach.]

Diamond is the hardest naturally-occurring mineral, ranked as 10 on Mohs hardness scale. Its resistance to abrasion and higher-than-average specific gravity (3.5) allows it to be concentrated in stream sediments, where it has traditionally been found. Diamond is hosted in the unusual igneous rock *kimberlite* (Figure 6), named for Kimberley, South Africa, a historically large diamond producer. Kimberlite is frequently found as a vertical pipe-like structure, where it is thought that the kimberlite traveled rapidly from the upper mantle through the crust.

Figure 6. This octahedral South African diamond is hosted in the igneous rock kimberlite. Image is from Smithsonian National Museum of Natural History Department of Mineral Sciences Collections.

Domestic diamond consumption is of two varieties: gem-quality stones and industrial diamond, where it is used in stone cutting and polishing, drill bit and other diamond tools, and computer chip production. Since the U.S. has no domestic mine production, both of these diamond types must be imported. The U.S. Geological Survey estimates that in 2021 we imported $21 billion of gem-quality diamonds and $46 million in industrial diamonds.

Graphite

Although graphite has the same chemical composition as diamond, physically it is so different that it's hard to believe they share the same composition. Graphite has a metallic luster and frequently occurs as foliated or scaly masses (Figure 7). The hardness is so low (1-2 on Mohs hardness scale) that it will easily mark on paper or your fingers. The specific gravity is rather low (2.2) and it has both a black color and black streak. Both the color and streak are useful to distinguish it from molybdenite.

Figure 7. This is an example of foliated graphite from Saint Lawrence County, New York. Image is from Smithsonian National Museum of Natural History Department of Mineral Sciences Collections.

Graphite most commonly occurs in metamorphic rocks such as marble, schist, and gneiss. The carbon was probably present in the original sedimentary rock as scatter organic material that crystallized to graphite during metamorphism (Figure 8). Coal layers that have been caught in metamorphism have been found to be partially or completely converted to graphite.

Figure 8. This is a graphitic marble from the Lead Hill Mine, Ticonderoga, New York. The graphite occurs as scattered tabular grains throughout the calcite host. Source of the carbon may well have been organic matter deposited with the limestone, and later metamorphosed to coarse-grained calcite with graphite. This specimen is 1.5 inches by 1.1 inches. Image is from *mindat.org*.

The U.S. imports all of the natural graphite used in domestic industry. In 2021 the U.S. Geological Survey estimates that 45,000 metric tons valued at about $41 million were consumed. Uses include batteries, brake linings, lubricants and steelmaking. Graphite is an important part of lithium-ion electric vehicle batteries, and consumption of graphite for this purpose is expected to grow in the future.