Mineralogy Boot Camp Session #18

Oxide & Hydroxide Minerals: Part 2

In this session we will pick up a few more oxide minerals, and describe just a few common examples of the numerous species of hydroxide minerals. Recall from Session #17 that oxygen is the most abundant element in Earth's crust and appears frequently in mineral classes such as silicates, carbonates, and sulfates. Oxygen (O^{-2}) can also appear by itself, bonded to various metal cations such as iron (Fe^{+3}), magnesium (Mg^{+2}), aluminum (Al^{+3}) and manganese (Mn^{+2}) as well as other equally important metal cations, two of which described here are titanium (Ti^{+4}) and tin (Sn^{+4}).

Hydroxide minerals are those that use the hydroxyl complex [$(OH)^{-1}$], which is derived from water, as the anionic framework. These minerals are typically found at Earth's surface, and are a common product of rock weathering because of the abundance of available water.

Rutile

Titanium (Ti^{+4}) is an element found in a wide variety of minerals, often at low abundances. It composes 0.43% of the crust, making it the ninth most abundant element. As an oxide in the form of *rutile* (TiO_2) however, titanium makes up 60% of this mineral. Rutile is found commonly as an accessory mineral in granite and various metamorphic rocks. This reddish to brown mineral (Figure 1) is relatively hard (6 to 6.5 on Mohs scale) with a high specific gravity (near 4). Figure 2 is an example of rutile occurring as a needle within another mineral; this happens most frequently in quartz and mica minerals. Rutile is chemically rather stable during surface weathering, and because of the elevated specific gravity it can often be found in the "black sands" of stream sediments and beach sands, where it is associated with residual magnetite.

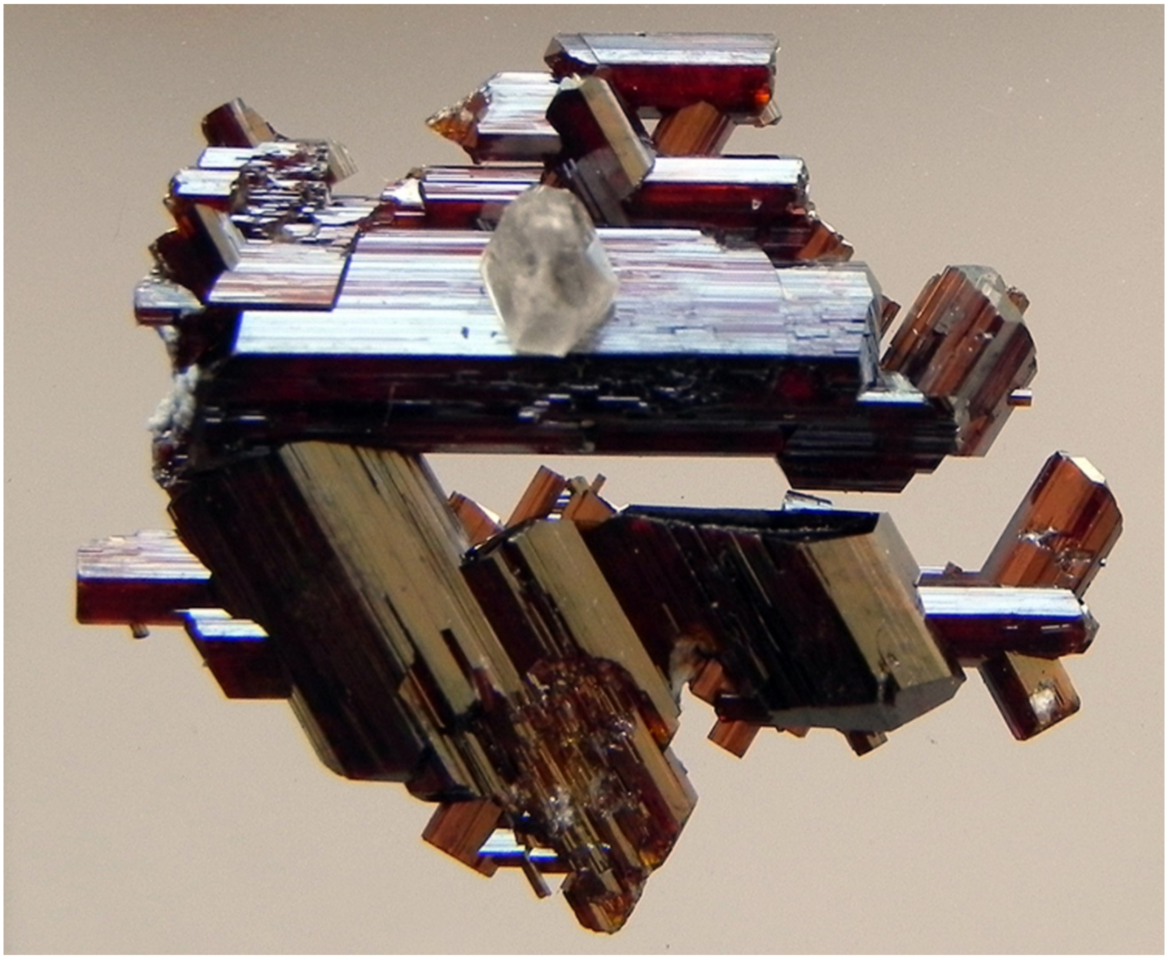

Figure 1. Rutile crystals often occur as twinned crystals, where two crystals typically form a “V” shape referred to as an “elbow twin”. Note that the smaller crystals have the characteristic dark red color whereas the larger crystals are more opaque and often have a metallic luster. This set of crystals, which is about 0.6 inches long, is from Minas Gerais, Brazil. Image from *mindat.org*.

Figure 2. This rutile needle (about 0.3 inches long) is in the iron carbonate *siderite*. Rutile needles as radiating acicular growths in quartz are so common that the term “rutilated quartz” is a standard description. This specimen is from Hiddenite, North Carolina.

Ilmenite

Elemental iron as Fe^{+2} is often associated with titanium, and when combining with oxygen may form the mineral *ilmenite* ($FeTiO_3$). Like rutile, ilmenite is relatively hard (5.5 to 6 on Mohs scale) with a significant specific gravity (4.5+). Unlike rutile however, ilmenite is black (Figure 3) and usually weakly magnetic. This mineral is also often found in black sands (Figure 4), and typically is more abundant than rutile, making ilmenite the main source of titanium recovered from these sands.

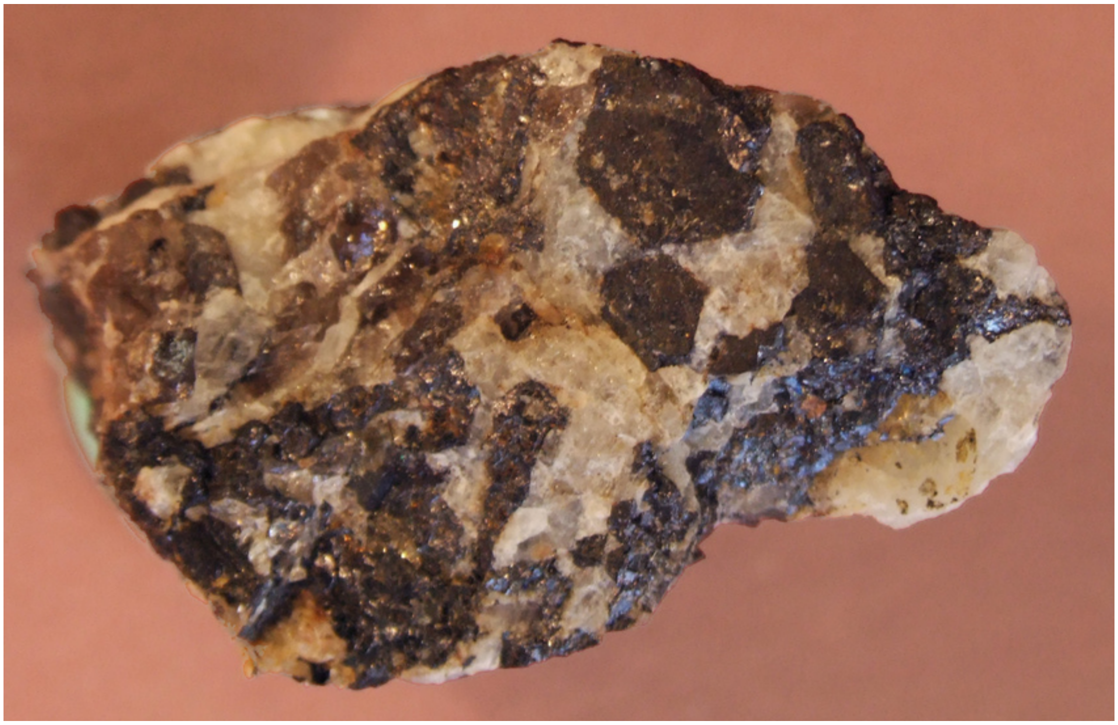

Figure 3. The ilmenite in this specimen from Agder, Norway occurs imbedded in white to gray feldspars. Note the 6-sided outlines formed frequently by well-formed crystals. Specimen is about 1.4 inches long. Image from *mindat.org*.

Figure 4. These black beach sands from Lake Bullen Merri, Victoria, Australia are composed primarily of ilmenite. Photo long axis is about 1.4 inches. Image from *mindat.org*.

In the U.S. during 2021 ilmenite and rutile were recovered from coastal areas of Georgia and Florida, but the vast majority of titanium mineral concentrates were imported. According to the U.S. Geological Survey, the largest import sources come from South Africa, Australia, and Madagascar. The estimated value of all titanium mineral concentrate imported during 2021 is estimated to be $690 million. Nearly 95% of these concentrates were used in pigment production, typically for paint, paper and plastics (ground TiO_2 has the perfect white color to use as the paint base, where specific colors are made by adding particular pigments to the white base). The remaining titanium is used for coatings on welding rods and in the metal fabrication and chemical manufacturing sectors.

Cassiterite

Tin (Sn^{+4}) is not a common element in Earth's crust, averaging an abundance of about 2 parts per million (0.0002%), similar to the abundance of arsenic. In its most common mineral form, it combines with oxygen to form the oxide mineral *cassiterite* (SnO_2). This brown to black mineral has a white streak, Mohs hardness in the range of 6 to 7, and the unusually high specific gravity near 7. Cassiterite occurs within granites, commonly as veins hosted by quartz (Figure 5). Because of its resistance to weathering, cassiterite also occurs as stream sediment concentrates when weathered from the host granite.

Figure 5. Cassiterite crystals in this specimen are hosted by quartz. Long axis of this specimen is about 3 inches. This example is from the Mount Bischoff Mine, Tasmania, Australia. Image from *mindat.org*.

Tin has not been mined in the United States since 1993. The major uses of tin in this country are in the chemical industry, as tinplate for food containers, as alloys with other metals (for example, tin is blended with copper to create *bronze*), and with lead in solder. According to the U.S. Geological Survey, the U.S. consumed about 45,000 metric tons of tin worth $1,600 per ton in 2021. We imported about 78% of this amount, with the remainder coming from domestic recycled sources. Refined tin is imported primarily from Indonesia, Peru, Malaysia, and Bolivia.

Goethite

Hydroxide minerals are a large and complex group, often occurring in fine-grained masses that are difficult to identify without detailed analyses. The most common of these is the mineral *goethite* [FeO(OH)]. This mineral ranges from yellowish-brown to darker brown (Figure 6 and Figure 7), although the color is often modified by the intergrowth of other minerals such as hematite. The specific gravity ranges from a high of 4.4 down to 3.3, again depending on the included impurities. Mohs hardness is about 5. While having some physical similarities to hematite, the streak of goethite is yellowish-brown, which is a good way to tell the two apart.

Figure 6. This close-up view of goethite is a good example of the range of colors that occur in this hydroxide mineral, from dark yellow on the left to reddish-brown on the right. Both colors display the characteristic botryoidal habit common for this mineral. Long axis of photo is about 0.8 inches. Specimen is from Setubal, Portugal. Image from *mindat.org*.

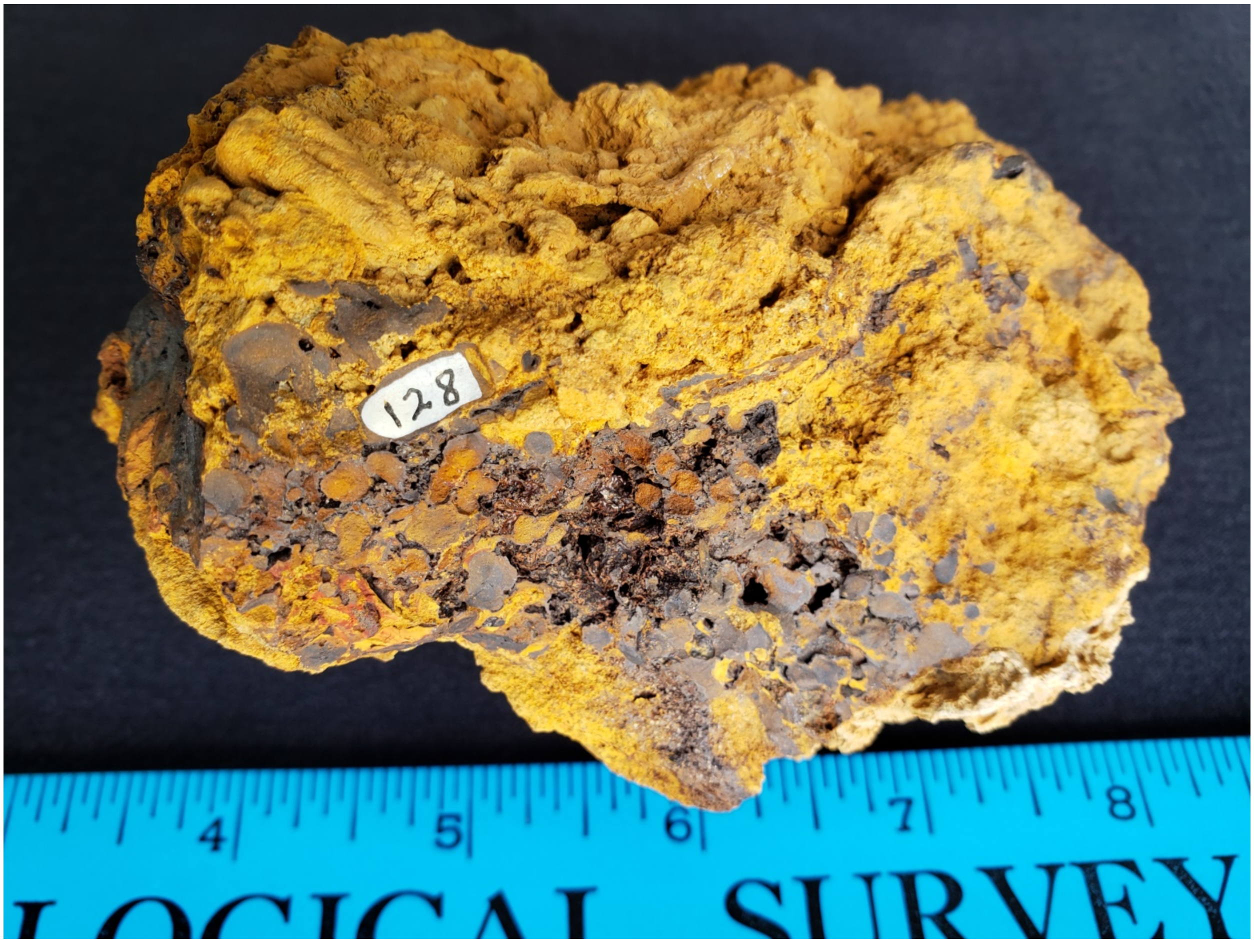

Figure 7. The brownish-red center of this specimen is more likely to be hematite, coated by fine-grained yellowish-orange crust composed primarily of goethite. This appearance of goethite is often describe with the field term “limonite”, which is actually a mixture of various iron oxides and hydroxides developed during prolonged weathering. Specimen is from Phelps County, Missouri.

Bauxite

This material is actually a rock because it is composed of a variety of hydrous aluminum oxides and aluminum hydroxides in varying proportions. It is discussed here because it is the main source of aluminum in modern society. Both the hardness (1-3) and specific gravity (about 2) are relatively low. Bauxite can be off-white, grayish to yellowish or reddish and appears earthy. The chief characteristic for identification is the presence of pea-sized concretionary grains, giving it a *pisolitic* texture. It commonly forms at Earth's surface in tropical to sub-tropical environments where prolonged weathering has leached much of the silica from aluminum-bearing rocks such as granites or shales.

Figure 8. This fist-sized specimen of bauxite from Bolivar, Venezuela, shows the characteristic pisolitic texture common to the rock. Image from *mindat.org*.

No significant mine production of bauxite has occurred in the United States since the mid-1980s. Arkansas, Georgia, and Alabama hosted the main deposits, but none are currently economic to produce. The U.S. Geological Survey reports that about 3.6 million metric tons of bauxite was consumed in 2021, worth an estimated $115 million. In addition, about 1 million tons of *alumina* (Al_2O_3) was produced and imported (worth about $450 per ton), which is used primarily as an abrasive and in the cement and chemical industries. The major countries supplying the U.S. with bauxite and alumina include Jamaica, Brazil, and Australia.