Mineralogy Boot Camp Session #13

Sulfate Minerals

Sulfates are those minerals composed of the anionic complex of \((\text{SO}_4)^{2-}\). Sulfate minerals tend to most commonly occur where sulfur (S) is available dissolved in water, such as seawater or hot hydrothermal fluids circulating in the crust. Thus sulfates form abundantly during the evaporation of seawater in shallow continental basins, and frequently during creation of metallic mineral deposits hosting sulfide minerals (to be discussed in upcoming Boot Camp sessions). The cations involved with creating sulfate minerals are those frequently found dissolved in water: calcium (Ca), barium (Ba), and strontium (Sr), all of which have a +2 valence charge and the proper size to nicely form structures with the \(\text{SO}_4\) anionic complex.

As a mineral class, these minerals are typically rather soft (hardness less than 4) and commonly have light colors. Dark-colored sulfate specimens generally indicate impurities. A couple of sulfates have unusually high specific gravities for nonmetallic minerals. Some are soluble in water.

Specimens of sulfate minerals are sometimes confused with carbonates (discussed in the previous Boot Camp session) because they may have a similar appearance and occur together in certain settings. The physical differences between these two classes are that the sulfates have a lack of reaction with dilute hydrochloric acid (HCl) and a lack of rhombohedral cleavage. Although not as abundant as carbonates at Earth’s surface, sulfates do include two economically important minerals, as discussed below: gypsum and barite.

Gypsum

Because calcium is so abundant in the Earth’s crust, the mineral gypsum is by far the most common sulfate mineral found at the surface. Its formula includes water \([\text{CaSO}_4\cdot2\text{H}_2\text{O}]\) for structural stability. The water molecules occur as parallel sheets between the \(\text{SO}_4\) framework, creating weak bonds that give gypsum its one direction of perfect cleavage (see Figure 1) and very low hardness (2 on Mohs scale of hardness). Gypsum is soft enough that it can be scratched with a fingernail, a simple test for this mineral. The low specific gravity (2.3) combined with the other physical features makes gypsum a relatively easy mineral to identify in hand sample.
Figure 1. This is a large, relatively clear sheet of gypsum about 0.5-inch thick. Large, clear specimens like this are often referred to as *selenite*. The lines visible in this specimen that are approximately parallel and perpendicular to the pen are cleavage traces. The primary cleavage direction is the flat surface this specimen is resting upon and the flat surface we are viewing. Collection location is unknown.

Gypsum frequently occurs with several different habits. Common habits include bladed masses (Figure 2) which may be called *gypsum rosette* when the blades resemble flower petals; as a fibrous variety called *satin spar* (Figure 3); and a fine-grained mass called *alabaster*. The term *selenite* is used to describe clear individual crystals of gypsum or colorless transparent sheets, such as shown in Figure 1.
Figure 2. Blades of gypsum grown together in a mass resembling flower petals may be called a *gypsum rosette* or *desert rose*. Specimen is 5 inches long. Collection location is unknown.

Figure 3. Gypsum grown into long slender fibrous crystals that exhibit a silky luster is referred to as *satin spar*. Collection location is unknown.
Evaporation of seawater in hot closed basins eventually results in deposition of gypsum, often in layers measuring tens to hundreds of feet thick. As gypsum is buried by additional deposition, the added pressure and heat of the overlying layers drives out the contained water, converting hydrous gypsum \( \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \) to its anhydrous cousin, the mineral *anhydrite* \( \text{CaSO}_4 \). Estimates are that once the gypsum is buried to a depth of about 10,000 to 12,000 feet, the conversion to anhydrite is nearly complete. Active erosion of the overlying beds allows the anhydrite to rise closer to the surface, resulting in rehydration and conversion back to gypsum.

Gypsum is a heavily-used industrial mineral in the United States. The U.S. Geological Survey estimated that 2021 production of crude gypsum was 23 million metric tons, with a value of about $210 million. This material is used primarily in agriculture (soil treatment), cement production (setting additive), wallboard production, and various plaster products (“Plaster of Paris”). Gypsum is also produced synthetically during flue gas desulfurization at many coal-fired power plants, and this gypsum source is used extensively in the wallboard industry.

**Barite**

Although barium is more common in Earth’s crust than more familiar elements such as gold, silver, nickel, copper, and lead, it does not frequently form Ba-rich minerals. The atomic size and charge of barium (as \( \text{Ba}^{+2} \)) allows it to frequently substitute for calcium (\( \text{Ca}^{+2} \)) in common minerals and thus is widely distributed but not commonly concentrated. Of the barium minerals, *barite* \( \text{BaSO}_4 \) probably occurs most frequently.

Barite commonly occurs in bladed masses (Figure 4) and as brick-shaped laths (Figure 5). It has one direction of perfect cleavage with a second direction that is good. While barite has a Mohs hardness (3 to 3.5) typical of sulfates, its specific gravity (4.5) is one of the highest for a nonmetallic mineral. Relatively pure crystals are clear to translucent, and barite often occurs with other minerals (Figure 6).
Figure 4. Blades of barite are a common habit for this mineral. Many times these may appear as radiating laths (barite rosette), giving it a similar appearance to gypsum (such as Figure 2). The hardness and specific gravity is a reliable way to distinguish these two minerals. Specimen is 4 inches by 3 inches. Collection location is unknown.

Figure 5. Blocky laths such as these are not an uncommon habit for barite. Specimen is from Leeville Mine, Eureka County, Nevada.
Figure 6. Barite often shows two directions of cleavage. The primary direction is visible as the flat tabular form of these crystals. The secondary cleavage direction is perpendicular to the primary, and can be observed as the light-reflecting surfaces in this specimen. The small metallic grains are pyrite. This specimen, from Peru, is 2.9 inches long.

The U.S. Geological Survey estimates about 1.5 million metric tons of crushed barite was sold during 2021 at an average price of $180 per metric ton. Nearly 90% of this material is used as a weighting agent in fluids used during the drilling of oil and gas wells (increasing the weight of the drill mud helps prevent surface blowouts caused by high subsurface pressure). Nevada is the major source of mined barite, which is sold primarily in the Central and Western U.S. Because of higher transportation costs of truck and rail shipping, offshore drilling operations in the Gulf of Mexico rely on imported barite (primarily China and India). Barite is also used as a filler, extender, or weighting agent in paints, plastics, and rubber. X-rays are significantly blocked by barite, which is why it is used in concrete shielding for nuclear power plants.

Celestite

Strontium (Sr$^{+2}$) is another element in greater abundance in Earth’s crust than many commonly-known metals, but Sr$^{+2}$ can easily substitute for Ca$^{+2}$ or Ba$^{+2}$ and therefore only occasionally
forms its own minerals. Of the limited number of Sr minerals, *celestite* [SrSO$_4$] is probably the most common. While it has many physical similarities to barite, the specific gravity is lower (about 4.0). It also frequently has a faint bluish tint (Figure 7) which is the source of its name; celestite is derived from the Latin *caelestis* meaning *heavenly*.

Figure 7. These celestite crystals are part of a larger geode lined with these crystals from Madagascar. Specimen is 3.5 inches long.

Deposits of strontium minerals, particularly celestite, are scattered throughout the U.S., but according to the U.S. Geological Survey none have been mined since the late 1950s. We rely on imports, mostly from Mexico and Germany (which in 2021 amounted to about 4,800 metric tons). Uses of celestite and other strontium minerals are mostly in ceramic magnets and in pyrotechnics and signal flares. The brilliant red color so admired in fireworks is due to strontium. Ground celestite can also substitute for barite as a weighting agent in drilling fluids.