3.5: Non-Silicate Minerals

The crystal structure of non-silicate minerals (see table) does not contain silica-oxygen tetrahedra. Many non-silicate minerals are economically important and provide metallic resources such as copper, lead, and iron. They also include valuable non-metallic products such as salt, construction materials, and fertilizer.

<table>
<thead>
<tr>
<th>Mineral Group</th>
<th>Examples</th>
<th>Formula</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native elements</td>
<td>gold, silver, copper</td>
<td>Au, Ag, Cu</td>
<td>Jewelry, coins, industry</td>
</tr>
<tr>
<td>Carbonates</td>
<td>calcite, dolomite</td>
<td>CaCO₃, CaMg(CO₃)₂</td>
<td>Lime, Portland cement</td>
</tr>
<tr>
<td>Oxides</td>
<td>hematite, magnetite, bauxite</td>
<td>Fe₂O₃, Fe₃O₄, a mixture of aluminum oxides</td>
<td>Ores of iron &amp; aluminum, pigments</td>
</tr>
<tr>
<td>Halides</td>
<td>halite, sylvite</td>
<td>NaCl, KCl</td>
<td>Table salt, fertilizer</td>
</tr>
<tr>
<td>Sulfides</td>
<td>galena, chalcopyrite, cinnabar</td>
<td>PbS, CuFeS₂, HgS</td>
<td>Ores of lead, copper, mercury</td>
</tr>
<tr>
<td>Sulphates</td>
<td>gypsum, epsom salts</td>
<td>CaSO₄·2H₂O, MgSO₄·7H₂O</td>
<td>Sheetrock, therapeutic soak</td>
</tr>
<tr>
<td>Phosphates</td>
<td>apatite</td>
<td>Ca₅(PO₄)₃(F,Cl,OH)</td>
<td>Fertilizer, teeth, bones</td>
</tr>
</tbody>
</table>

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3.4.1: Carbonates

Figure 1: Calcite crystal in shape of rhomb. Note the double-refracted word “calcite” in the center of the figure due to birefringence.

Figure 2: Limestone full of small fossils

Calcite (CaCO$_3$) and dolomite (CaMg(CO$_3$)$_2$) are the two most frequently occurring carbonate minerals, and usually occur in sedimentary rocks, such as limestone and dolostone rocks, respectively. Some carbonate rocks, such as calcite and dolomite, are formed via evaporation and precipitation. However, most carbonate-rich rocks, such as limestone, are created by the lithification of fossilized marine organisms. These organisms, including those we can see and many microscopic organisms, have shells or exoskeletons consisting of calcium carbonate (CaCO$_3$). When these organisms die, their remains accumulate on
the floor of the water body in which they live and the soft body parts decompose and dissolve away. The calcium carbonate hard parts become included in the sediments, eventually becoming the sedimentary rock called limestone. While limestone may contain large, easy to see fossils, most limestones contain the remains of microscopic creatures and thus originate from biological processes.

![Birefringence in calcite crystals](image)

Figure \(\PageIndex{3}\): Birefringence in calcite crystals

Calcite crystals show an interesting property called **birefringence**, meaning they polarize light into two wave components vibrating at right angles to each other. As the two light waves pass through the crystal, they travel at different velocities and are separated by refraction into two different travel paths. In other words, the crystal produces a double image of objects viewed through it. Because they polarize light, calcite crystals are used in special petrographic microscopes for studying minerals and rocks.

Many non-silicate minerals are referred to as salts. The term **salts** used here refers to compounds made by replacing the hydrogen in natural acids. The most abundant natural acid is carbonic acid that forms by the solution of carbon dioxide in water. Carbonate minerals are salts built around the carbonate ion (CO\(_3^{2-}\)) where calcium and/or magnesium replace the hydrogen in carbonic acid (H\(_2\)CO\(_3\)). Calcite and closely-related polymorph aragonite are secreted by organisms to form shells and physical structures like corals. Many such creatures draw both calcium and carbonate from dissolved bicarbonate ions (HCO\(_3^-\)) in ocean water. As seen in the mineral identification section below, calcite is easily dissolved in acid and thus effervesces in dilute hydrochloric acid (HCl). Small dropper bottles of dilute hydrochloric acid are often carried by geologists in the field as well as used in mineral identification labs.

Other salts include halite (NaCl) in which sodium replaces the hydrogen in hydrochloric acid and gypsum (Ca[SO\(_4\)] \(\cdot\) 2 H\(_2\)O) in which calcium replaces the hydrogen in sulfuric acid. Note that some water molecules are also included in the gypsum crystal. Salts are often formed by evaporation and are called evaporite minerals.
The figure shows the crystal structure of calcite (CaCO₃). Like silicon, carbon has four valence electrons. The carbonate unit consists of carbon atoms (tiny white dots) covalently bonded to three oxygen atoms (red), one oxygen sharing two valence electrons with the carbon and the other two sharing one valence electron each with the carbon, thus creating triangular units with a charge of -2. The negatively charged carbonate unit forms an ionic bond with the Ca ion (blue), which as a charge of +2.
3.4.2: Oxides, Halides, and Sulfides

After carbonates, the next most common non-silicate minerals are the oxides, halides, and sulfides.

Oxides consist of metal ions covalently bonded with oxygen. The most familiar oxide is rust, which is a combination of iron oxides (Fe₂O₃) and hydrated oxides. Hydrated oxides form when the iron is exposed to oxygen and water. Iron oxides are important for producing metallic iron. When iron oxide or ore is smelted, it produces carbon dioxide (CO₂) and metallic iron.

The red color in rocks is usually due to the presence of iron oxides. For example, the red sandstone cliffs in Zion National Park and throughout Southern Utah consist of white or colorless grains of quartz coated with iron oxide which serve as cementing agents holding the grains together.
Other iron oxides include limonite, magnetite, and hematite. Hematite occurs in many different crystal forms. The massive form shows no external structure. Botryoidal hematite shows large concentric blobs. Specular hematite looks like a mass of shiny metallic crystals. Oolitic hematite looks like a mass of dull red fish eggs. These different forms of hematite are polymorphs and all have the same formula, Fe₂O₃.

Other common oxide minerals include:

- Ice (H₂O), an oxide of hydrogen
- Bauxite (Al₂H₂O₄), hydrated oxides of aluminum, an ore for producing metallic aluminum
- Corundum (Al₂O₃), which includes ruby and sapphire gemstones.

The halides consist of halogens in column VII, usually fluorine or chlorine, ionically bonded with sodium or other cations. These include halite or sodium chloride (NaCl), common table salt; sylvite or potassium chloride (KCl); and fluorite or calcium fluoride (CaF₂).
Halide minerals usually form from the evaporation of seawater or other isolated bodies of water. A well-known example of halide mineral deposits created by evaporation is the Bonneville Salt Flats, located west of the Great Salt Lake in Utah (see figure).

Many important metal ores are **sulfides**, in which metals are bonded to sulfur. Significant examples include galena (lead sulfide), sphalerite (zinc sulfide), pyrite (iron sulfide, sometimes called “fool’s gold”), and chalcopyrite (iron-copper sulfide). Sulfides are well known for being important ore minerals. For example, galena is the main source of lead, sphalerite is the main source of zinc, and chalcopyrite is the main copper ore mineral mined in porphyry deposits like the Bingham mine (see chapter 16). The largest sources of nickel, antimony, molybdenum, arsenic, and mercury are also sulfides.
3.4.3: Sulfates

Sulfate minerals contain a metal ion, such as calcium, bonded to a sulfate ion. The sulfate ion is a combination of sulfur and oxygen (SO$_4^{2-}$). The sulfate mineral gypsum (CaSO$_4$?2H$_2$O) is used in construction materials such as plaster and drywall. Gypsum is often formed from evaporating water and usually contains water molecules in its crystalline structure. The ?2H$_2$O in the formula indicates the water molecules are whole H$_2$O. This is different from minerals like amphibole, which contain a hydroxide ion (OH$^-$) that is derived from water but is missing a hydrogen ion (H$^+$). The calcium sulfate without water is a different mineral than gypsum called anhydrite (CaSO$_4$).
3.4.4: Phosphates

Phosphate minerals have a tetrahedral phosphate unit $(\text{PO}_4^{-3})$ combined with various anions and cations. In some cases arsenic or vanadium can substitute for phosphorus. Phosphates are an important ingredient of fertilizers as well as detergents, paint, and other products. The best known phosphate mineral is apatite, $\text{Ca}_5(\text{PO}_4)_3(\text{F,Cl,OH})$, variations of which are found in teeth and bones. The gemstone turquoise $[\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8\cdot4\text{H}_2\text{O}]$ is a copper-rich phosphate mineral that, like gypsum, contains water molecules.

3.4.5: Native Element Minerals

Native element minerals, usually metals, occur in nature in a pure or nearly pure state. Gold is an example of a native element mineral; it is not very reactive and rarely bonds with other elements so it is usually found in an isolated or pure state. The non-metallic and poorly-reactive mineral carbon is often found as a native element, such as graphite and diamonds. Mildly reactive metals like silver, copper, platinum, mercury, and sulfur sometimes occur as native element minerals. Reactive metals such as iron, lead, and aluminum almost always bond to other elements and are rarely found in a native state.
Figure \PageIndex{12}): (left) Native copper. (right) Native sulfur deposited around a volcanic fumarole