# What are mineral resources and what makes them useful?

| In this reading: | Page |
| --- | --- |
| Mineral resources | 1 |
| Minerals | 1–2 |
| Common elements and silicate minerals | 2 |
| Mineral properties | 3–6 |
| Rocks and the rock cycle | 7–8 |
| Rocks, minerals and elements as commodities | 8 |
| Glossary | |

Learning outcomes:

1. Define mineral resources.
2. Define a mineral.
3. Give examples of mineral resources and products that contain them.
4. List the most abundant elements in Earth's crust, and describe how these relate to the most abundant minerals in the context of resource availability.
5. Summarize the mineral properties that make them useful.
6. Differentiate between rocks and minerals.
7. Name the three main rock families and the processes that form them.

**Mineral resources**

In this module, we'll consider a **mineral resource** to be a mineral or rock mined from the earth and used in the products we use daily. Brines (salty waters) are also mined for the elements they contain. These are not minerals but do form via rock-forming processes. Coal, oil, and natural gas are also mined, but these energy resources will be considered separately.

**Minerals** are any substances that meet all of the following criteria:

1. Solid

2. Inorganic (or identical to an inorganic mineral). Some minerals, like our teeth, wouldn't be here without our organic processes. But because the apatite (the mineral that makes up teeth) in our teeth is identical to inorganic apatite, we still consider our teeth apatite to be a mineral.

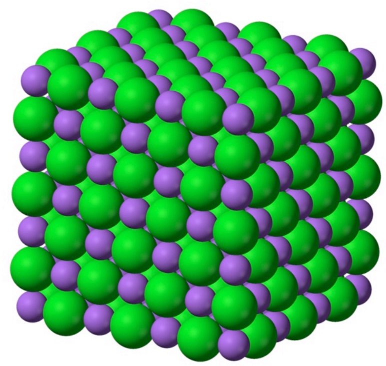
3. Natural (or made in a way that mimics nature). Some minerals are made in labs, by people, but because they are made using the same processes that nature uses, we can still consider them minerals. A "synthetic diamond" that is chemically and structurally the same as a natural diamond is still a mineral. However, cubic zirconia, which is made only by people and not by nature, is not a mineral.

4. Chemically homogeneous: This means that the mineral contains the same chemicals throughout. Another way to think of this is that you can write one chemical formula that describes the entire mineral. Minerals can contain tiny amounts of impurities—these are elements present in such small quantities that they don't change the mineral’s formula, but can change the mineral’s properties. For example, tiny amounts of impurities can change the color of quartz from clear to pink, or blue, or purple.

| Mineral | Chemical formula | Elements in these minerals |
| --- | --- | --- |
| **quartz** | $SiO_2$ | Si = silicon, O = oxygen (there are two oxygen atoms for every one silicon atom) |
| **hematite** | $Fe_2O_3$ | Fe = iron, O = oxygen (there are two iron atoms for every three oxygen atoms) |
| **diamond** | C | C = carbon |
| **halite** | NaCl | Na = sodium, Cl = chlorine |

5. Crystalline. This means that the atoms in a mineral are arranged in an orderly and repeating pattern.

*Figure 1*. Sodium (Na - purple) and chlorine (Cl - green) atoms form cubes, and these cubes repeat themselves to make the mineral halite. Image from Raj6, Wikimedia Commons.



Please note: the "minerals" in a bottle of vitamins and minerals are not real minerals. They are elements that may have been extracted from minerals. This is another example of a word that has a scientific definition that's different from the common-use definition.

**Common elements and common minerals**

Minerals are composed of **elements**. Eight elements make up the majority of Earth's crust and mantle: oxygen (O) is the most common, silicon (Si) the second, and potassium (K), calcium (Ca), sodium (Na), aluminum (Al), iron (Fe), magnesium (Mg) make up the other six. These elements can combine in a variety of ways to make different minerals. Not surprisingly, most minerals contain silicon and oxygen (plus other elements). These minerals are called **silicate minerals**. Why do we care about this?

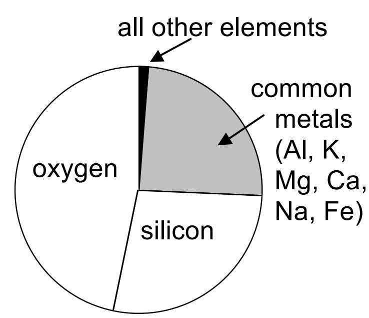



*Figure 2*. What's in the crust (by mass).

- Sustainability: The eight elements just listed are the most plentiful. Other elements are more rare; we find them less frequently and have a lower overall supply of them.
- Ease of use: Silicate minerals tend to be **refractory**; they have high melting points and low solubilities, so it is hard to separate the elements within them.

- Although the majority of Earth's elements are found in silicate minerals, they are usually found in higher quantities in nonsilicate minerals, commonly oxide or sulfide minerals. It is more efficient to mine elements when they are found in higher concentrations.
- If mining companies want the element in the mineral (and not the mineral itself), then they seek nonsilicate minerals that contain the element. Even though those minerals are less common and harder to find, it is more efficient (fewer resources are needed) to extract elements from nonsilicate minerals. For example, the silicate mineral fayalite ($Fe_2SiO_4$) contains a lower percentage of iron than does the oxide mineral hematite ($Fe_2O_3$), so hematite, not fayalite, is mined for iron.

**Mineral properties**
A mineral's chemical and crystalline nature gives it properties that make it useful. Some of these properties also must be considered when determining how to best mine and process the mineral ore, and dispose of the mine waste. For example:

**Chemistry**. The elements within minerals give those minerals distinct and useful properties. For example, sulfur allows gunpowder to ignite at a lower temperature and provides fuel for the fire. Aluminum metal is very lightweight but strong. Sulfur can be found as a mineral, or as an element within other minerals like pyrite.  Aluminum does not form a mineral on its own but is beneficiated from the mineral gibbsite.


*Figure 3*. Sulfur (S) can be mined from native sulfur (*left*) or sulfide minerals such as pyrite (FeS, *right*).

**Hardness**. A mineral's hardness is determined by the crystalline nature of that mineral, the type and strength of bonds that hold the atoms together, and the nature of the repeating pattern. Very hard minerals (like diamond, corundum, and garnet) are useful as abrasives. For example, saw blades impregnated with diamonds can cut rock, and sandpaper is often made with garnet sand. Talc is used in baby powder because it is a very soft mineral.

**Color**. Some minerals have distinct and vibrant colors. This makes them incredibly useful as pigments in paints, cosmetics, colored plastic, etc. For example, hematite has a rust-red color and is used in blush and paints. Malachite has a bright green color.

*Figure 4*. The native people in Himba Village, Namibia, powder iron oxide minerals (like hematite and goethite) to color their skin and hair. Photograph by Ansu John.

*Figure 5*. The rust-red color of hematite (*left*) and rust-yellow color of limonite (a variety of goethite, (*right*) have long been used as pigments.

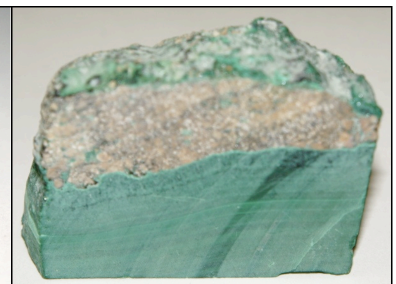


*Figure 6*. Malachite's green color has made it useful in paints.

**Specific gravity**. Specific gravity is a relative density, determined both by a mineral's chemistry (minerals containing more massive elements will have higher specific gravities) and how closely together the atoms are packed.

**Behavior of light in the crystal**. The crystalline structure determines how light passes through a mineral or *if* light passes through a mineral. Light reflects inside of diamond, which gives a diamond ring an exquisite sparkle. Other minerals (like rutile) are quite opaque, which makes titanium oxide (the chemical name of rutile) an important additive in things that need to be opaque, like paint. Luster describes how light interacts with the surface of a mineral. The mineral hematite can have both metallic or nonmetallic luster; hematite with metallic luster is used to make jewelry. Some minerals are also useful in blocking other wavelengths of light; barite and lead (from the mineral galena) block X-rays, for example.

**Crystal shape and cleavage** are determined by the nature of the crystalline structure. The sheet-like cleavage of muscovite allows it to be broken into tiny pieces of glitter.

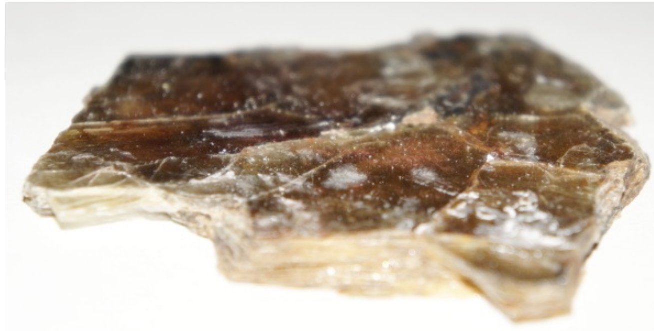


*Figure 7.* Muscovite's cleavage causes it to break into sheets.

**Solubility**. Another property of the crystalline structure (the type of bonds) and chemistry causes different minerals to dissolve (turn into the ions that compose them) differently. Some dissolve quickly in water, whereas others are very stable. The pH of water also affects solubility; some minerals will dissolve faster in acidic water, whereas others might dissolve more readily in alkaline waters. For some applications, an insoluble mineral is preferred. For example, the Eads Bridge that crosses the Mississippi River is faced below the water line with rock made of insoluble minerals, whereas more decorative limestone (made of the more soluble mineral calcite) faces the support above the water line. Other applications favor soluble minerals. If a mineral is being mined from the element it contains, then it will be easier to extract that element from a soluble mineral.

**Magnetism**. The chemistry of certain minerals allows them to store an applied magnetic field. For example, magnetic minerals in a hard drive can be programmed to store information.

**Electric conductivity**. The electrical conductivity is mainly determined by the types of chemical bonds; metallic bonds cause metals to have high electrical conductivity, and these are favored for wires. Minerals that have low electric conductivity will be used for insulators, to block or confine the electric current.

*Figure 8*. Copper's electrical conductivity and resistance to corrosion make it ideal for electric wiring. Although copper can be found as a pure metal (native copper, *upper right*), it is often beneficiated from minerals like chalcopyrite ($CuFeS_2$, *lower right*).

**Thermal conductivity**. Minerals can also be used to conduct heat or confine heat. Thermal conductivity is determined by both a mineral's chemistry and crystalline structure.

**Melting point**. Different minerals melt at different temperatures. Minerals with high melting points are used for high-temperature applications. For example, asbestos was used in fire-resistant fabrics because of its high melting point.

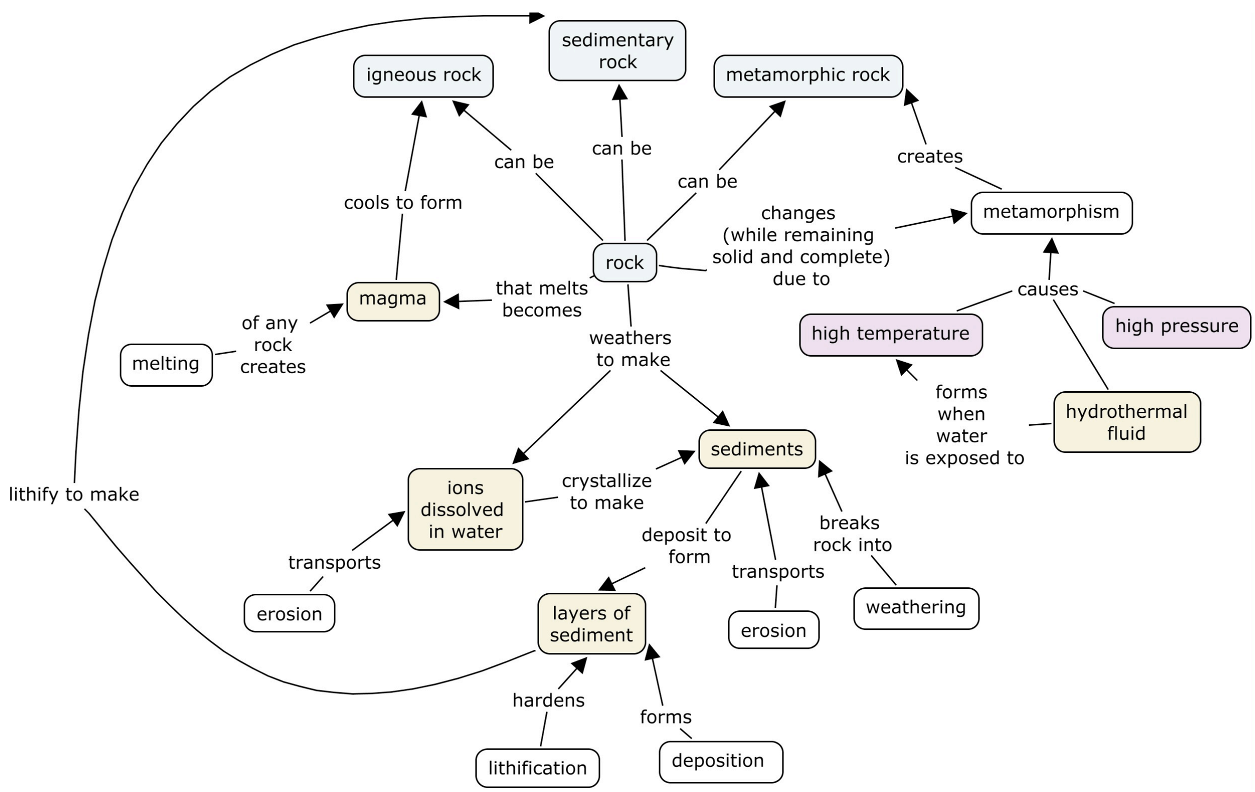
**Behavior in response to stress**. Some minerals/rocks are brittle, some are ductile. For example, gold is malleable, which allowed early people to easily shape it into ornaments. An electric current is generated in piezoelectric minerals when a stress is applied. For example, a hammer hits a piezoelectric crystal, and this will generate a spark to ignite a cigarette lighter. The piezoelectricity of quartz allows it to be used to tell time (in quartz crystal watches), and piezoelectricity is also useful in transformers and motors.

**Rocks** are:

1. Natural
2. Coherent: a rock doesn't fall apart when you pick it up. This means that sand is not a rock.
3. Solid

**The Rock Cycle**

Rocks are divided into three groups—**igneous**, **metamorphic** and **sedimentary**—based on how they formed. On Earth, an existing rock can undergo processes and become a different type of rock, which means that rocks are recycled and that different rock types are all connected according to the rock cycle.




The concept map shows how the different rock families form. In the map, white boxes show processes, tan and blue boxes show substances, and purple boxes show forces. Each rock type will be covered in more detail. Here are some defintions of terms in the concept map:

magma = liquid rock

weathers = breaks into pieces (called sediments) or sometimes ions (the charged atoms/molecules that make up the mineral)

erodes = pieces are transported (picked up and carried elsewhere)

deposits = pieces are dropped, forming a layer (on a sand dune, or on the bottom of a stream, lake, or ocean, for example)

lithifies = sediments harden to become rock (to become coherent)

We’ll see that the processes in the rock cycle can concentrate mineral resources and turn them into mineral reserves.

**The use of minerals and rocks in products**

Sometimes actual minerals and rocks are used in products or to make things. The rock granite is mined to make countertops, and the mineral halite is mined, crushed, and sold as table salt. Other times, minerals and brines are processed to extract one specific element, and these individual elements are often called **mineral commodities**. For example, the commodity aluminum is extracted from the rock bauxite, which contains aluminum-bearing minerals like gibbsite. The process of extracting the desired mineral or element from an ore is called **beneficiation**.

**Photo credits**

Figure 1. Halite crystal by Raj6 (Agency: Wikimedia Commons, Image source: http://commons.wikimedia.org/wiki/File:NaCl.png, Accessed August 20, 2014), CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)

Figure 2. Pie chart with elemental abundances. Data from Stephen Marshak, *Earth: Portrait of a Planet, Second Edition*. W. W. Norton and Company, 2005.

Figure 3. Photos of sulfur and pyrite, taken by J. Branlund

Figure 4. Photo of woman in Himba Village, Namibia, taken by Ansu John, CC-BY-SA-3.0

Figure 5. Photos of hematite and goethite, taken by J. Branlund

Figure 6. Photo of malachite, taken by J. Branlund

Figure 7. Photo of muscovite, taken by J. Branlund

Figure 8. Photos of copper wire, native copper, and chalcopyrite, taken by J. Branlund

Concept map created by J. Branlund