Matter and Minerals

Minerals: Building Blocks of Rocks

We begin our discussion of Earth materials with an overview of mineralogy because minerals are the building blocks of rocks. In addition, minerals have been employed by humans for both useful and decorative purposes for thousands of years. The first minerals mined were flint and chert, which people fashioned into weapons and cutting tools. Egyptians began mining gold, silver, and copper; and humans discovered how to combine copper with tin to make bronze, a strong, hard alloy. Later, humans developed a process to extract iron from minerals such as hematite—a discovery that marked the decline of the Bronze Age. The term *mineral* is used in several different ways. For example, those concerned with health and fitness extol the benefits of vitamins and minerals. The mining industry typically uses the word when referring to anything taken out of the ground, such as coal, iron ore, or sand and gravel.

Geologists define mineral as *any naturally occurring inorganic solid that possesses an orderly crystalline structure and can be represented by a chemical formula.* Thus,Earth materials that are classified as mineralsexhibit the following characteristics:

**1. Naturally occurring.** Minerals form by natural, geologic processes. Synthetic materials, meaning those produced in a laboratory or by human intervention, are not considered minerals.

**2. Solid substance.** Only solid crystalline substances are considered minerals. Ice (frozen water) fits this criterion and is considered a mineral, whereas liquid water and water vapour do not. The exception is mercury, which is found in its liquid form in nature.

**3. Orderly crystalline structure.** Minerals are crystalline substances, which means their atoms are

arranged in an orderly, repetitive manner. This orderly packing of atoms is reflected in the regularly shaped objects called crystals. Some naturally occurring solids, such as volcanic glass (obsidian), lack

a repetitive atomic structure and are not considered minerals.

**4. Generally inorganic.** Inorganic crystalline solids, such as ordinary table salt (halite), that are found

naturally in the ground are considered minerals. (Organic compounds, on the other hand, are generally not. Sugar, a crystalline solid like salt but which comes from sugarcane or sugar beets, is a common example of such an organic compound.) Many marine animals secrete inorganic compounds, such as calcium carbonate (calcite), in the form of shells and coral reefs. If these materials are buried and become part of the rock record, they are considered minerals by geologists.

**5. Can be represented by a chemical formula.** Most minerals are chemical compounds having compositions that can be expressed by a chemical formula. For example, the common mineral quartz has the formula SiO2, which indicates that quartz consists of silicon (Si) and oxygen (O) atoms in a ratio of one-to-two. This proportion of silicon to oxygen is true for any sample of pure quartz, regardless of its origin. However, the compositions of some minerals vary *within specific, well-defined limits.* This occurs because certain elements can substitute for others of similar size without changing the mineral’s internal structure.

An example is the mineral olivine in which either the element magnesium (Mg) or the element iron (Fe) may occupy the same site in the crystal structure. Therefore, olivine’s formula, (Mg, Fe)2SiO4, expresses variability in the relative amounts of magnesium and iron. However, the ratio of magnesium plus iron ( ) to silicon (Si) and oxygen (O) remains fixed at 2:1:4. In contrast to minerals, rocks are more loosely defined. Simply, a rock is any solid mass of mineral, or mineral-like, matter that occurs

naturally as part of our planet. Most rocks, like the common rock granite, occur as aggregates of several different minerals. The term *aggregate* implies that the minerals are joined in such a way that their individual properties are retained. Note that the mineral constituents of granite can be easily identified. However, some rocks are composed almost entirely of one mineral.

Atoms: Building Blocks of Minerals

When minerals are carefully examined, even under optical microscopes, the innumerable tiny particles of their internal structures are not discernable. Nevertheless, all matter, including minerals, is

composed of minute building blocks called atoms—the smallest particles that cannot be chemically split. Atoms, in turn contain even smaller particles—*protons* and *neutrons* located in a central nucleus that is surrounded by *electrons*.

Properties of Protons, Neutrons, and Electrons

Protons and neutrons are very dense particles with almost identical masses. By contrast, electrons have a negligible mass, about 1/2000th that of a proton. For comparison, if a proton or a neutron had the mass of a baseball, an electron would have the mass of a single grain of rice. Both protons and electrons share a fundamental property called *electrical charge.* Protons have an electrical charge of +1, and electrons have a charge of -1. Neutrons, as the name suggests, have no charge. The charge of protons and electrons are equal in magnitude, but opposite in polarity, so when these two particles are

paired, the charges cancel each other. Since matter typically contains equal numbers of positively

charged protons and negatively charged electrons, most substances are electrically neutral.

Elements: Defined by Their Number of Protons

The simplest atoms have only one proton in their nuclei, whereas others have more than 100. The number of protons in the nucleus of an atom, called the atomic number**,** determines its chemical nature. All atoms with the same number of protons have the same chemical and physical properties. Together, a group of the same kind of atoms is called an element**.** There are about 90 naturally occurring elements and 23 that have been synthesized. You are probably familiar with the names of many elements including carbon, nitrogen, and oxygen. All carbon atoms have six protons, whereas all nitrogen atoms have seven protons, and all oxygen atoms have eight. Elements are organized so that those with similar properties line up in columns. This arrangement, called the periodic table**,** Each element has been assigned a one- or two-letter symbol. The atomic numbers and masses are also

included for each element. Atoms of the naturally occurring elements are the basic building blocks of

Earth’s minerals. A few minerals, such as native copper, diamonds, and gold, are made entirely of atoms of only one element. However, most elements tend to join with atoms of other elements to form

chemical compounds**.** Most minerals are chemical compounds composed of atoms of two or more elements.

Isotopes and

Radioactive Decay

The mass number of an atom is simply the total number of its protons and neutrons. All atoms of a particular element have the same number of protons but they may have varying numbers of neutrons. Atoms with the same number of protons but different numbers of neutrons are isotopes of that element. Isotopes of the same element are labeled by placing the mass number after the element’s name or symbol. For example, carbon has three well-known isotopes. One has a mass number of 12 (carbon-12), another has a mass number of 13 (carbon-13), and the third, carbon-14, has a mass number of 14. Carbon-12 must also have six neutrons to give it a mass number of 12. Carbon-14, on the other hand, has six protons plus eight neutrons to give it a mass number of 14. In chemical behavior, all isotopes of the same element are nearly identical. To distinguish among them is like trying to differentiate identical twins, with one weighing slightly more than the other. Because isotopes of the same element exhibit the same chemical behavior, they often become parts of the same mineral.

For example, when the mineral calcite (CaCO3) forms, some of its carbon atoms are carbon-12, and some are carbon-14. The nuclei of most atoms are stable. However, many elements do have isotopes

in which the nuclei are unstable— carbon-14 is one example of an unstable isotope. In this context, *unstable* means that the nuclei change through a random process called radioactive decay**.** During

radioactive decay, unstable isotopes radiate energy and emit particles. The rates at which unstable isotopes decay are measurable. Therefore, certain radioactive atoms are used to determine the ages of fossils, rocks, and minerals.