The word "mineral" means something very specific to Earth scientists. By definition, a mineral:
Is naturally formed;
Is solid;
Is formed by inorganic processes;
Has a specific chemical composition; and
Has a characteristic crystal structure
Though each of these aspects of a mineral may seem simple, they have important implications when considered together.

1. Naturally formed: Minerals form through natural processes, including volcanic eruptions, precipitation of a solid out of a liquid, and weathering of pre-existing minerals. Today, scientists, engineers, and manufacturers synthesize many ceramics, plastics, and other substances with a specific chemical composition and structure, but none of these synthetic substances is considered a true mineral.

2. Solid: Liquids and gases are not considered minerals, in large part because their structure is constantly changing, which means they do not have a characteristic crystal structure. A true mineral must be solid.

3. Formed by inorganic processes: Any material produced through organic activity – such as leaves, bones, peat, shell, or soft animal tissue – is not considered a mineral. Most fossils, although they were once living, have generally had their living tissues completely replaced by inorganic processes after burial; thus, they are considered to be composed of minerals as well.

4. Specific chemical composition: Most minerals exist as chemical compounds whose compositions can be expressed using a chemical formula. The chemical formula of salt, or halite, is NaCl, meaning each molecule of salt consists of one sodium atom (Na) and one chlorine atom (Cl). Other common minerals have much more complicated formulas, such as muscovite (KAl2(AlSi3O10)(OH)2). A few minerals, such as graphite, consist of only one type of atom (carbon, in this case); therefore, the chemical formula for graphite is written simply as C. All minerals are defined by their chemical composition. If we tried to change the composition of muscovite by replacing the aluminum with iron and magnesium, for instance, we would end up with a totally new and different mineral called biotite.

On the other hand, many minerals do contain impurities, and these impurities can vary. Quartz, for example, has the chemical formula SiO2 and generally does not have any color in its pure form. The presence of a minute amount of titanium (Ti), however, causes the slight pinkish coloration present in rose quartz, as seen in Figure 1. The amount of titanium relative to the amount of silicon and oxygen is on the order of parts per million, however, so this is considered an impurity rather than a change in the chemical composition. In other words, rose quartz is still quartz. Similarly, the gemstone amethyst is a form of quartz that is colored pale to deep purple by the presence of the impurity iron (Fe).

Figure 1: An example of rose quartz, colored by trace amounts of titanium.

It was not until the 1900s, 350 years after Agricola's book, that scientists were able to determine the specific chemical composition of minerals. The invention of the mass spectrometer, ever more powerful microscopes, and the use of diffraction techniques allowed the kind of highly detailed analysis that caused the science of mineralogy to flourish.

5**. Characteristic crystal structure:** Nicolaus Steno, a Dutch contemporary of Isaac Newton, made an important contribution to mineralogy in 1669 when he noted that the angles between faces (or sides) of quartz crystals were constant, no matter how big the crystals were or where they had formed. Today, we know that Steno's Law of Interfacial Angles concerning the external appearance of crystals reflects a regular, internal arrangement of atoms. The angles are constant between faces on quartz crystals because every single quartz crystal is made of the same atoms: one atom of silicon for every two atoms of oxygen, written with the molecular formula SiO2.

The chemical composition of a mineral is reflected internally in a regular, repeating arrangement of atoms, called the crystal structure of the mineral. The crystal structure of halite is shown in Figure 2. The internal structure (shown on the left) is reflected in a generally consistent external crystal form (shown on the right), as noted by Steno. The cubic shape of salt crystals very clearly reflects the right-angle bonds between the Na and Cl atoms in its atomic structure (see our Chemical Bonding module).

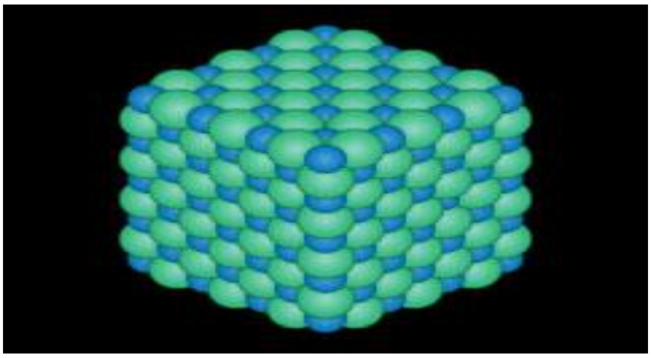

Figure 2a: A sodium chloride crystal.

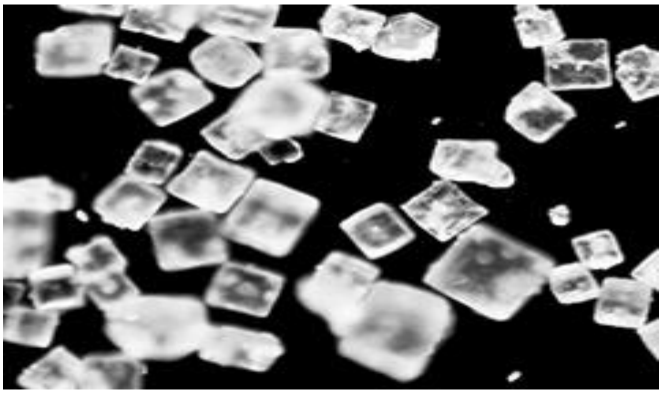

Figure 2b: The cubic shape of salt crystals results from the regular arrangement of atoms forming the crystal.

Most importantly, this structure repeats itself. As the halite crystal is broken into smaller and smaller pieces, it retains its cubic structure. Take a look at a dash of table salt under a microscope and you will confirm that this is the case.

The importance of crystal structure

The graphite-diamond mineral pair is an extreme example of the importance of crystal structure. These two very different minerals have exactly the same chemical formula (C), but the crystal structure of the two minerals is very different. In graphite, carbon atoms are bonded together along a flat plane, as shown in Figure 3. These sheets of carbon are loosely held together by weak attractive forces. However, the attractive forces between sheets can be easily broken, allowing them to slide past one another. Thus graphite is a soft, slippery mineral that is often used as a lubricant in machines (see Figure 4). When graphite is rubbed against another material, such as a piece of paper, it leaves a trail of small sheets that have broken free, thus it is also used in pencils.

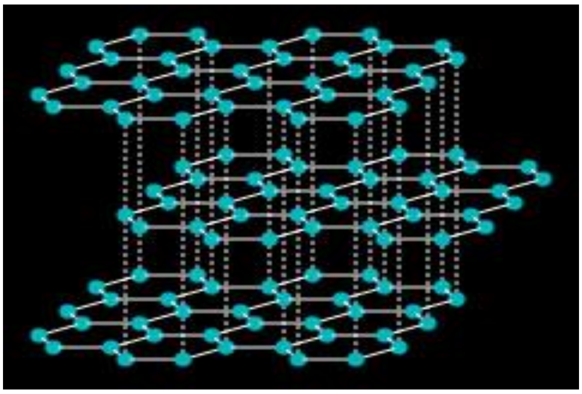

Figure 3a: The internal structure of graphite shows strong bonds within planes and weak forces between them.Sheet of graphite

Figure 3b: Graphite has a metallic sheen, is soft, and can be easily broken into thin sheets

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In diamond, by comparison, every single carbon atom is bonded strongly to four surrounding carbon atoms in a 3-dimensional structure (see Figure 5). This structure results in one of the hardest natural substances on the planet (see Figure 6), a property that contributes to its value. The structure of each of these minerals is crucial to determining their physical properties.

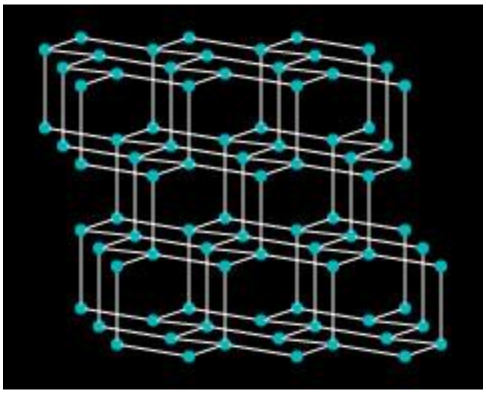

Figure 4a: The internal structure of diamond shows equally strong bonds in all directions. An uncut diamond crystal

Figure 4b: An uncut diamond crystal is clear and is the hardest substance known.

Chemical composition and crystal structure are the most important factors in determining the properties of a mineral, including shape, density, hardness, and color. Geologists use these properties to identify which minerals are present in rocks. Hardness and fracture characteristics can be easily determined in the field with a small magnifying lens and a hammer, allowing for rapid identification of the mineral.

The internal atomic structure of graphite and diamond, shown in Figures 3 and 5, explains the properties of the two minerals.

Key Concepts.

Minerals have specific chemical compositions, with a characteristic chemical structure.

Minerals are solids that are formed naturally through inorganic processes.

Chemical composition and crystal structure determine a mineral's properties, including density, shape, hardness, and color.

Because each mineral forms under specific conditions, examining minerals helps scientists understand the history of earth and the other planets within our solar system.