EENS1110	Physical Geology
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Minerals

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The Earth is composed of rocks. Rocks are aggregates of minerals. So minerals are the basic building blocks of the Earth. Currently there are over 4,000 different minerals known and dozens of new minerals are discovered each year. Our society depends on minerals as sources of metals, like Iron (Fe), Copper (Cu), Gold (Au), Silver (Ag), Zinc (Zn), Nickel (Ni), and Aluminum (Al), etc., and non-metals such as gypsum, limestone, halite, clay, and talc. Many minerals of of great economic importance and their distribution, extraction, and availability have played an important role in history. Minerals are composed of atoms. We'll start our discussion with the geological definition of a Mineral.

Definition of a Mineral:

A mineral is

- Naturally formed - it forms in nature on its own (some say without the aid of humans]
- Solid (it cannot be a liquid or a gas)
- With a definite chemical composition (every time we see the same mineral it has the same chemical composition that can be expressed by a chemical formula).
- and a characteristic crystalline structure (atoms are arranged within the mineral in a specific ordered manner).
- usually inorganic, although a mineral can be formed by an organic process.

A mineraloid is a substance that satisfies some, but not all of the parts of the definition. For example, opal, does not have a characteristic crystalline structure, so it is considered a mineraloid.

Note also that the "minerals" as used in the nutritional sense are not minerals as defined geologically.

Examples

- Glass - can be naturally formed (volcanic glass called obsidian), is a solid, its chemical composition, however, is not always the same, and it does not have a crystalline structure. Thus, glass is not a mineral.
- Ice - is naturally formed, is solid, does have a definite chemical composition that can be expressed by the formula H_2O, and does have a definite crystalline structure when solid.

Thus, ice is a mineral, but liquid water is not (since it is not solid).

- Halite (salt) - is naturally formed, is solid, does have a definite chemical composition that can be expressed by the formula NaCl, and does have a definite crystalline structure. Thus halite is a mineral.

Atoms

Since minerals (in fact all matter) are made up of atoms, we must first review atoms. Atoms make up the chemical elements. Each chemical element has nearly identical atoms. An atom is composed of three different particles:

- ***Protons*** -- positively charged, reside in the center of the atom called the ***nucleus***
- ***Electrons*** -- negatively charged, orbit in a cloud around nucleus
- ***Neutrons*** -- no charge, reside in the nucleus.

Each element has the same number of protons and the same number of electrons.

- Number of protons = Number of electrons.
- Number of protons = ***atomic number***.
- Number of protons + Number of neutrons = ***atomic weight***.

Isotopes are atoms of the same element with differing numbers of neutrons. i.e. the number of neutrons may vary within atoms of the same element. Some isotopes are unstable which results in radioactivity.

- Example:
    - K (potassium) has 19 protons. Every atom of K has 19 protons. Atomic number of K = 19. Some atoms of K have 20 neutrons, others have 21, and others have 22. Thus atomic weight of K can be 39, 40, or 41. ^{40}K is radioactive and decays to ^{40}Ar and ^{40}Ca.

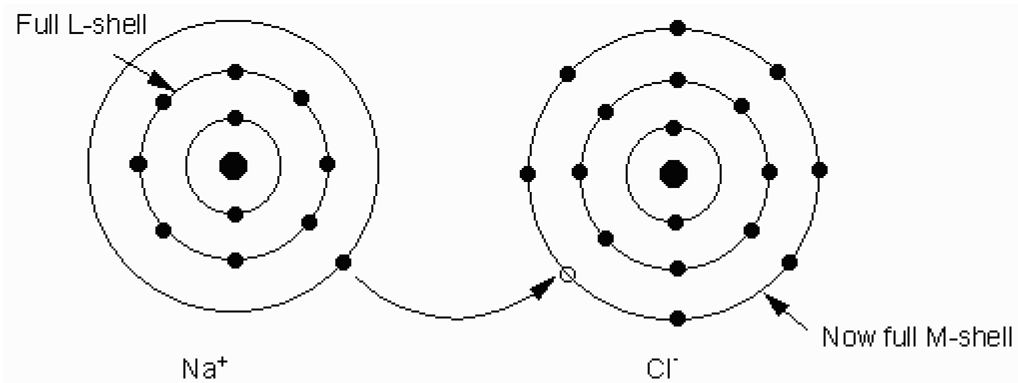
Structure of Atoms

Electrons orbit around the nucleus in different shells, A Stable electronic configuration for an atom is one 8 electrons in outer shell Thus, atoms often loose electrons or gain electrons to obtain stable configuration. Noble gases have completely filled outer shells, so they are stable. Examples He, Ne, Ar, Kr, Xe, Rn. Others like Na, K loose an electron. This causes the charge balance to become unequal. and produce charged atoms called ***ions***. Positively charged atoms are called ***cations***. Elements like F, Cl, O gain electrons to become negatively charged. Negatively charged ions are called ***anions***.

The drive to attain a stable electronic configuration in the outermost shell along with the fact that this sometimes produces oppositely charged ions, results in the binding of atoms together. When atoms become attached to one another, we say that they are bonded together.

Types of bonding:

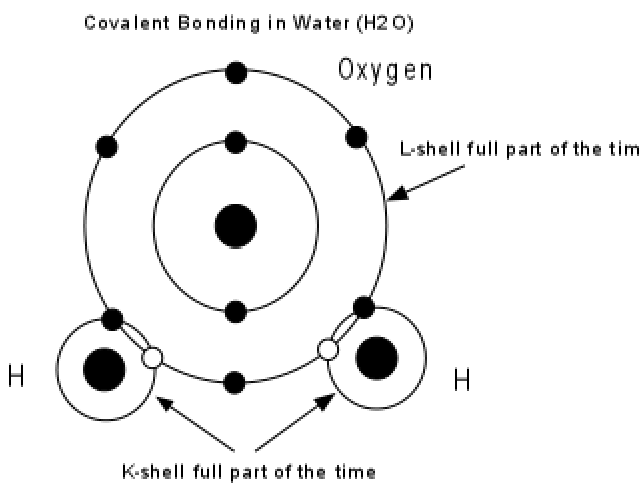
- ***Ionic Bonds*** - caused by the force of attraction between ions of opposite charge.



Example Na^{+1} and Cl^{-1}. Bond to form NaCl (halite or salt).

Ionic bonds are moderately strong.

- ***Covalent Bonds*** - Electrons are shared between two or more atoms so that each atom has a stable electronic configuration (completely filled outermost shell) part of the time.

  Example: H has one electron, needs to 2 to be stable. O has 6 electrons in its outer shell, needs 2 to be stable. So, 2 H atoms bond to 1 O to form H_2O, with all atoms sharing electrons, and each atom having a stable electronic configuration part of the time.

  Covalent bonds are very strong bonds.

- ***Metallic Bonds*** -- Similar to covalent bonding, except innermost electrons are also shared. In materials that bond this way, electrons move freely from atom to atom and are constantly being shared. Materials bonded with metallic bonds are excellent conductors of electricity because the electrons can move freely through the material.

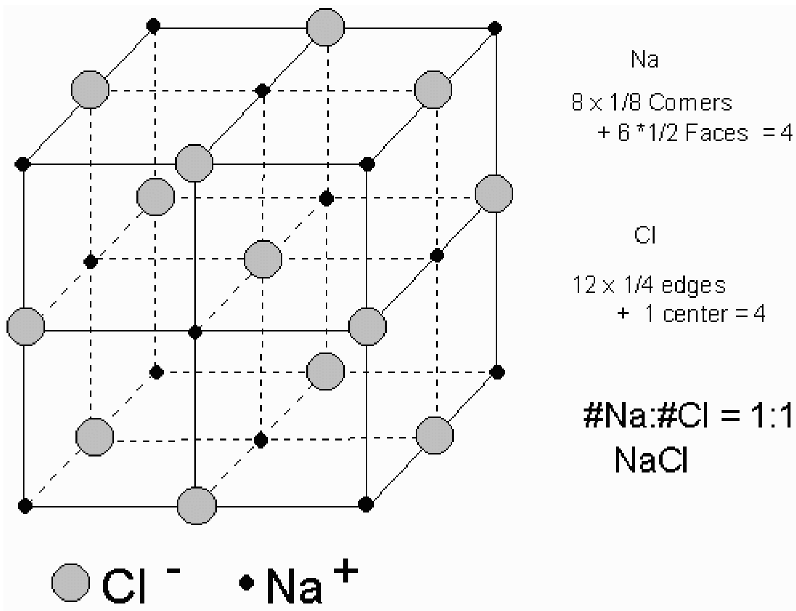
- ***Van der Waals Bonds*** -- a weak type of bond that does not share or transfer electrons. Usually results in a zone along which the material breaks easily (***cleavage***). Good examples's graphite and micas like biotite and muscovite.

Several different bond types can be present in a mineral, and these determine the physical properties of the mineral.

Crystal Structure

All minerals, by definition are also crystals. Packing of atoms in a crystal structure requires an orderly and repeated atomic arrangement. Such an orderly arrangement needs to fill space efficiently and keep a charge balance. Since the size of atoms depends largely on the number of electrons, atoms of different elements have different sizes.

Example of NaCl :



For each Na atom there is one Cl atom. Each Na is surrounded by Cl and each Cl is surrounded by Na. The charge on each Cl is -1 and the charge on each Na is +1 to give a charged balanced crystal.

The structure of minerals is often seen in the shape of crystals. The ***law of constancy of interfacial angles*** --- Angles between the same faces on crystals of the same substance are equal. This is a reflection of ordered crystal structure (See figure 5.5 in the textbook).

Crystal structure can be determined by the use of X-rays. A beam of X-rays can penetrate crystals but is deflected by the atoms that make up the crystals. The image produced and collected on film, can be used to determine the struture. The method is know as X-ray diffraction.

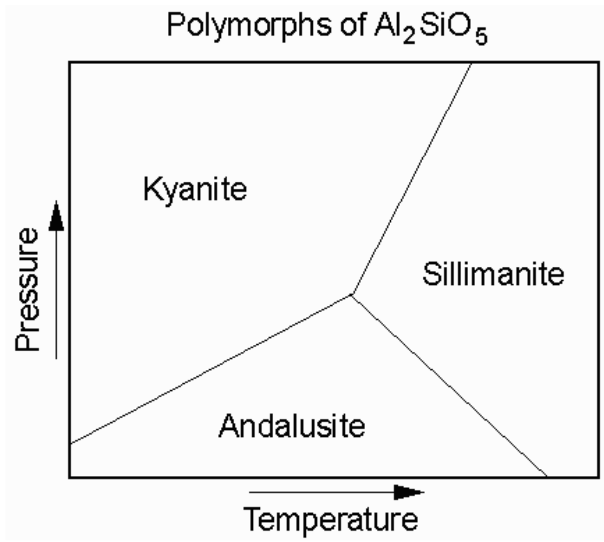
Crystal structure depends on the conditions under which the mineral forms. ***Polymorphs*** are minerals with the same chemical composition but different crystal structures. The conditions are such things as temperature (T) and pressure (P), because these effect ionic radii.

At high T atoms vibrate more, and thus distances between them get larger. Crystal structure changes to accommodate the larger atoms. At even higher T substances changes to liquid and eventually to gas. Liquids and gases do not have an ordered crystal structure and are not minerals.

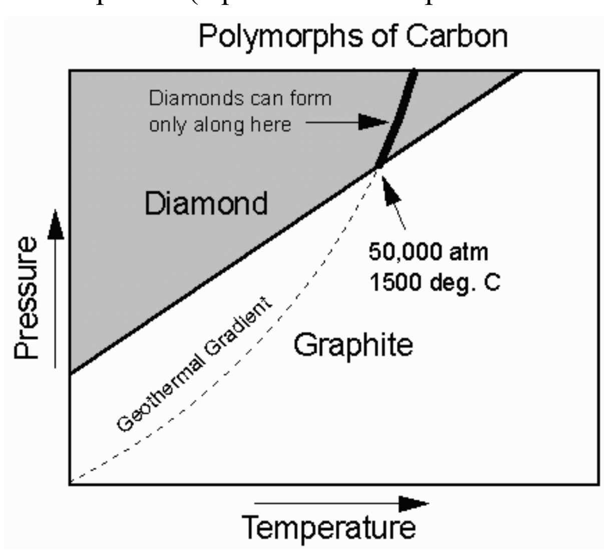
Increase in P pushes atoms closer together. This makes for a more densely packed crystal structure.

Examples:

- The compound Al_2SiO_5 has three different ***polymorphs*** that depend on the temperature and pressure at which the mineral forms. At high P the stable form of Al_2SiO_5 is kyanite, at low P the stable from is andalusite, and at high T it is sillimanite.



- Carbon (C) has two different polymorphs. At low T and P pure carbon is the mineral graphite, (pencil lead), a very soft mineral. At higher T and P the stable form is diamond, the hardest natural substance known. In the diagram, the geothermal gradient (how temperature varies with depth or pressure in the Earth) is superimposed on the stability fields of Carbon. Thus we know that when we find diamond it came from someplace in the Earth where the temperature is greater than 1500^{o}C and the pressure is higher than 50,000 atmospheres (equivalent to a depth of about 170 km).



Ionic Substitution (Solid Solution)

Ionic substitution - (also called solid solution), occurs because some elements (ions) have the same size and charge, and can thus substitute for one another in a crystal structure.

Examples:

- Olivines Fe_2SiO_4 and Mg_2SiO_4. Fe^{+2} and Mg^{+2} are about the same size, thus they can substitute for one another in the crystal structure and olivine thus can have a range of compositions expressed as the formula $(Mg,Fe)_2SiO_4$.
- Alkali Feldspars: $KAlSi_3O_8$ (orthoclase) and $NaAlSi_3O_8$, (albite) K^{+1} can substitute for Na^{+1}
- Plagioclase Feldspars: $NaAlSi_3O_8$ (albite) and $CaAl_2Si_2O_8$ (anorthite) $NaSi^{+5}$ can substitutes for $CaAl^{+5}$ (a complex solid solution).

Composition of Minerals

The variety of minerals we see depend on the chemical elements available to form them. In the Earth's crust the most abundant elements are as follows:

1. O, Oxygen 45.2% by weight
2. Si, Silicon 27.2%
3. Al, Aluminum 8.0%
4. Fe, Iron 5.8%
5. Ca, Calcium 5.1%
6. Mg, Magnesium 2.8%
7. Na, Sodium 2.3%
8. K, Potassium 1.7%
9. Ti ,Titanium 0.9%
10. H, Hydrogen 0.14%
11. Mn, Manganese 0.1%
12. P, Phosphorous 0.1%

Note that Carbon (one of the most abundant elements in life) is not among the top 12.

Because of the limited number of elements present in the Earth's crust there are only about 4000 minerals known. Only about 50of these minerals are common. The most common minerals are those based on Si and O: the ***Silicates.*** Silicates are based on SiO_4 tetrahedron. 4 Oxygens covalently bonded to one silicon atom

Properties of Minerals

Physical properties of minerals allow us to distinguish between minerals and thus identify them, as you will learn in lab. Among the common properties used are:

- ***Habit*** - shape

- Color
- ***Streak*** (color of fine powder of the mineral)
- ***Luster*** -- metallic, vitreous, pearly, resinous (reflection of light)
- ***Cleavage*** (planes along which the mineral breaks easily)
- ***Density*** (mass/volume)
- ***Hardness***: based on Mohs hardness scale as follows:

1. Talc
2. gypsum (fingernail)
3. calcite (penny)
4. fluorite
5. apatite (knife blade)
6. orthoclase (glass)
7. quartz
8. topaz
9. corundum
10. Diamond

Formation of Minerals

Minerals are formed in nature by a variety of processes. Among them are:

- Crystallization from melt (igneous rocks)
- Precipitation from water (chemical sedimentary rocks, hydrothermal ore deposits)
- Biological activity (biochemical sedimentary rocks)
- Change to more stable state - (the processes of weathering, metamorphism, and diagenesis).
- Precipitation from vapor. (not common, but sometimes does occur around volcanic vents)

Since each process leads to different minerals and different mineral polymorphs, we can identify the process by which minerals form in nature. Each process has specific temperature and pressure conditions that can be determined from laboratory experiments. Example: graphite and diamond, as shown previously.

Rocks - Mixtures of Minerals

Mixtures or aggregates of minerals are called rocks. There are three basic kinds of rocks, each type is determined by the process by which the rock forms.

- Igneous Rocks - form by solidification and crystallization from liquid rock, called magma.
- Sedimentary Rocks - form by sedimentation of mineral and other rock fragments from water, wind, or ice and can also form by chemical precipitation from water.

- Metamorphic Rocks - form as a result of increasing the pressure and/or temperature on a previously existing rock to form a new rock.

Each of these rock forming processes results in distinctive mineral assemblages and textures in the resulting rock. Thus, the different mineral assemblages and textures give us clues to how the rock formed. An understanding of the rock forming processes and the resulting mineral assemblage and texture will be the main goal of the next part of this course.

Questions on this material that could be asked on an exam.

1. What it a mineral? Give some examples of minerals and non-minerals, and explain why each is or is not a mineral.
2. What are the 4 types of chemical bonds. Which of these is stronger and which is the weakest.
3. What are polymorphs? Give two examples of minerals that show polymorphism.
4. What are top 4 elements in the Earth's crust and how does this determine which minerals are most abundant in the Earth's crust.
5. What is a solid solution? Give at least two examples of minerals that show solid solution.
6. Give at least 6 examples of physical properties that can be used to identify minerals.
7. What are the five processes by which minerals form in nature?

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