

## Chapter 3: Minerals

Why do we study minerals? They are the building blocks of rocks, and the rock record is the key to the earth's past. We will not discuss the material on atomic structure in any detail - this should already be familiar, or if not it is nicely described in the text. The laboratory exercises are especially important for learning the material in this chapter. Among the important concepts/terms with which you should be familiar are:

1. Minerals:
  - what are the defining characteristics?
  - why are most silicates?
2. Important Physical Properties of Minerals
  - (e.g. habit, cleavage, hardness - these will be examined in more detail in lab)
  - how do physical properties relate to crystal structure and bond type?
3. Four Types of Bonds
  1. Ionic
  2. Covalent
  3. Metallic
  4. Van der Waals
4. Coordination Number and the Silicate Tetrahedron
5. Major Classes of Silicate Minerals, Basic Structural Formula, and Examples of Each
  1. Nesosilicates (olivine, garnet)
  2. Sorosilicates (epidote)
  3. Cyclosilicates (tourmaline)
  4. Inosilicates
    - Pyroxenes
    - Amphiboles
  5. Phyllosilicates (biotite, talc, muscovite)
  6. Tectosilicates
    - Quartz polymorphs
    - Alkali and Plagioclase Series
6. Carbonates and Important Non-Silicate Mineral Groups
7. Minerals and Tectonics

Some key terms: solid solution, polymerization, polymorph

## Introduction to Minerals Sept. 27, 2006

### What is a mineral?

A mineral is a naturally occurring solid with a definite (but not necessarily fixed) chemical composition that is generally formed by inorganic processes and that has an ordered atomic arrangement.

Some examples of materials that are/aren't minerals according to this definition.

- hematite ( $\text{Fe}_2\text{O}_3$ ) but not cast iron
- olivine ( $\text{Fe}_2\text{SiO}_4$  to  $\text{Mg}_2\text{SiO}_4$ ) - *solid solution* (we'll return to this later)
- halite ( $\text{NaCl}$ ) ppt but not cellulose (may be mediated by organisms)
- quartz but not silica glass (liquid)

### What evidence do we have for the ordered atomic structure of minerals?

- 1) crystal faces - *constancy of interfacial angles*
- 2) Xray - Bragg's equation
- 3) high resolution transmission electron microscopy

### Composition of crust and dominant minerals

Over 7000 minerals, more each day. Fortunately, we don't need to be concerned with most of these (about 20-30 will do). These geologically important minerals are primarily silicate minerals. The dominance of silicate minerals can be understood if we examine the composition of the bulk earth and of the continental crust.

<u>Bulk Earth</u>	<u>Cont. Crust (Table 3.2)</u>
Fe:35% (wt)	O: 46%
O:30%	Si: 28%
Si:15%	Al: 8%
Mg:13%	Fe: 5%
Ni,S,Ca,Al	Ca (3.6%), Na (2.8%), K(2.6%), Mg (2.1%), Ti (0.4%)

The bulk earth composition can be estimated from a variety of lines of evidence including:

- 1) analogy with meteorites (same composition as for planetary accretion)
- 2) average density - compare that with density of crustal materials  
must be a lot of Fe in interior

### Physical properties of minerals

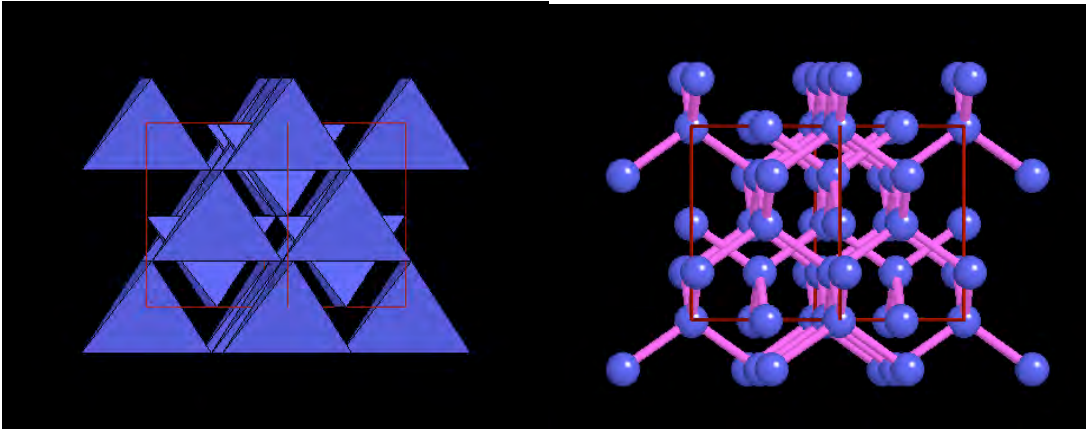
The atomic structure evidenced in a number of physical properties. We will examine these links between atomic structure and hardness, density, cleavage, habit. Emphasize those properties underlined, as these are the most useful in identifying minerals.

#### 1. Crystal habit [NaCl model]

The shape of crystals (habit) is closely linked to the atomic structure. Note that well formed crystal faces will be formed only under certain conditions (e.g. unimpeded growth into a cavity, early crystallization from a melt). In most rocks, crystals have to compete for space and so are not euhedral. Use NaCl model to illustrate resulting high symmetry (cubic).

#### 2. Cleavage

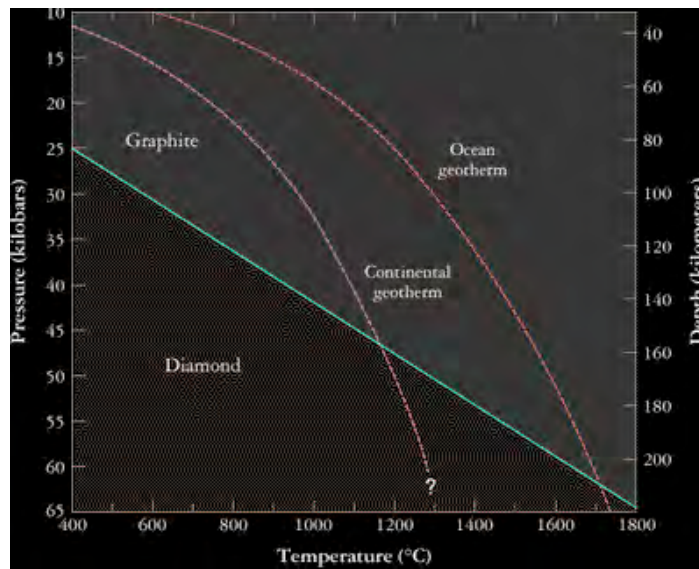




Two illustrations of the diamond structure (tetrahedrons, C atoms with bonds). From [http://www.geo.utexas.edu/courses/347k/redesign/Gem\\_Notes/Diamond/diam\\_anim.htm](http://www.geo.utexas.edu/courses/347k/redesign/Gem_Notes/Diamond/diam_anim.htm) which has a nice animation of the diamond structure illustrating the cleavage directions.

Graphite: Sheets of covalently bonded C held together by weak van der Waals forces. Each C in sheet shares e with three neighboring C, 4th e- by hopping (conductive). The weak van der Waals forces result in low hardness (1-2), one perfect cleavage.

Sketch phase diagram for diamond/graphite (H&K, p232). Phase boundary lies at about 50 km for room temperature. The geotherm crosses this boundary at about 1500C and 130 km. Mechanisms for getting diamonds to the surface (kimberlite pipes). P leads to polymorphism in variety of mineral phases (calcite - aragonite, Q, aluminosilicates).



Phase diagram for graphite/diamond with typical geotherms for continental and oceanic crust. (From <http://www.amnh.org/exhibitions/diamonds/formation.html>).

### **Ionic radius and the atomic structure of minerals**

90% of minerals have dominantly ionic bonds. A useful concept in understanding the structure of ionic materials is that of ionic radii (1926 Goldschmidt - treat ions as hard spheres in contact).

### what controls ionic radii?

1. size increases with number of electrons  
Na<sup>+</sup> (atomic number = 11) = 0.097 nm  
K<sup>+</sup> (atomic number = 19) = 1.33
  2. size decreases with charge  
Si<sup>4+</sup> (atomic number = 14) = 0.042  
Al<sup>3+</sup> (atomic number = 13) = 0.050
- Note that most cations smaller than anions

One important aspect of the size of ions is that this size (in conjunction with the charge) determines whether one ion may substitute for another in the crystal structure (*solid substitution*; common in many mineral groups as we will see below). Ions within 10-20% in size and with same charge can substitute.

Ionic radii also provide insight into crystal structure. In particular, relative sizes of cations and anions (and charge balance) determines geometric arrangement of *coordination polyhedra* (concept which we will need for discussing structure of silicate mineral groups). The principles of ionic sphere packing are:

1. ions like to surround themselves with max number of oppositely charged ions but remaining neutral
2. most stable situation is when cation fits snugly in interstices of anions

The number of nearest neighbors with opposite charge (*coordination number*) can be simply related to the geometrical constraints of packing together different sized spheres. The *radius ratio* (cation/anion, generally < 1 since cations are smaller) provides a range of sizes that are likely to be surrounded by a particular number of oppositely charged ions.

$\geq 1.0$	12
1.0 - 0.732	8
0.732-0.414	6
0.414-0.225	4
0.225-0.155	3
<0.155	2

### The silica tetrahedron

The concept of coordination number and ionic radii are particularly useful in understanding the structure of silicate minerals. Namely, the fundamental building block of silicate minerals is the silica tetrahedron, a single Si<sup>4+</sup> surrounded by 4 oxygens.

Si, Al, O are dominant ions in minerals

Si<sup>4+</sup> = 0.042 so RR = 0.042/.132 = 0.32 (CN = 4: silica tetrahedra)

Al<sup>3+</sup> = 0.050 so RR = 0.050/.132 = 0.38 (CN = 4 or 6; tetrahedra or octahedra)

silicate and aluminosilicate minerals most easily described in terms of arrangement of these basic structural units

Many transition metals in 6 fold coordination

Fe<sup>2+</sup> = 0.074/.132 = 0.56 (CN = 6)

Mg<sup>2+</sup> = 0.066/.132 = 0.50 (CN = 6)

Mn<sup>2+</sup> = ~0.078