

Chapter 1

Ore Minerals

1.1. Types of Ore Mineral

In a hydrometallurgical process leaching of a metal from an ore is carried out at a relatively low temperature, below about 200°C. The rate of reaction may be slow and will depend on the nature of the phase containing the metal. For example under acidic oxidizing conditions copper is dissolved very much more rapidly from chalcocite, Cu_2S , than it is from chalcopyrite, CuFeS_2 . Therefore in a hydrometallurgical process, the nature of the minerals present is important whereas when a copper sulphide concentrate is fed into a smelter this is not the case.

The type of process used to recover a metal from an ore depends on the chemical nature of the mineral containing it. Many minerals are treated in hydrometallurgical processes but there are few classes of such minerals. They are shown, with some examples, in Table 1.1.

1.2. Types of Crystal Lattice

1.2.1. *Introduction*

Textbooks on physical chemistry give accounts of crystal chemistry and specialist texts are available such as that of Wells.¹ These should be consulted for information concerning the arrangements of atoms or ions in the different

Table 1.1. Some ore minerals of different types.

Silicates	Sulphides	Oxides	Others
Bertrandite (Be)	Cinnabar (Hg)	Anatase (Ti)	Bastnasite (rare earths)
Beryl (Be)	Copper minerals	Baddeleyite (Zr)	Fluorapatite (P)
Lateritic ores (Ni, Co)	Galena (Pb)	Bauxite (Al)	Gold metal
Lepidolite (Li)	Molybdenite (Mo)	Cassiterite (Sn)	Gold tellurides
Magnesite (Mg)	Nickel minerals	Chromite (Cr)	Monazite (rare earths)
Olivine (Mg)	Silver minerals	Columbite- tantalite (Nb, Ta)	Phosphate rock (P)
Petalite (Li)	Sphalerite (Zn)	Ilmenite (Ti)	Platinum group metals and alloys
Spodumene (Li)		Oxidized products of sulphides (Cu, Pb)	
Thorite (Th)		Pyrochlore (Nb)	Silver halides
Zircon (Zr)		Pyrolusite (Mn)	Silver metal
		Rutile (Ti)	Xenotime (rare earths)
		Scheelite (W)	
		Thorianite (Th)	
		Uraninite (U)	
		Wolframite (W)	

types of crystal structure. This chapter deals with some general matters of importance in understanding the behaviour of minerals of different kinds during chemical processing.

Almost all minerals are crystalline. The fundamental fact about the crystalline state is that the atoms are arranged in an ordered three dimensional pattern known as the “space lattice”. This is formed by repetition of a unit cell which is a group of atoms characteristic of a particular kind of crystal which, when extended in three dimensions leads to the macroscopic crystal. A group of atoms smaller than the unit cell does not contain all the information necessary to produce the structure of the macroscopic crystal.

The shape of the unit cell and hence the constants needed to define it depends on the symmetry of the crystal. The maximum number of constants required is six, three lengths of sides of the unit cell, written a , b and c to correspond to the crystal axes with those symbols, and the angles between the axes, taken in pairs. These angles are written as α , β and γ , between bc , ca and ab respectively. The choice of axes in the triclinic system is arbitrary but in the other systems is determined by the symmetry elements, which are of no concern here.

Unit cells are figures of simple geometrical shape, bounded by plane faces. Usually they contain only a few atoms and so are small with sides only a few Ångstroms long. However sometimes there is a degree of order which is repeated only at relatively great distances; this leads to a superlattice structure which may have a hundred or more atoms in the unit cell.

The atoms in a unit cell are packed together in a manner to minimise the energy of the group. This means that there will be preferred distances of closest approach between them. Since in many minerals the atoms are best regarded as being ions, these distances are described as ionic radii. In the case of an element which can have several valencies, each kind of ion has a different ionic radius. The outer regions of ions are volumes of electronic charge and heavier elements tend to be larger than lighter; however for elements of similar atomic number, anions are larger than cations.

In some solids, an oxide of a light metal such as MgO for example, the size of O^{2-} is so much greater than that of Mg^{2+} that the interionic distances in the lattice are determined by the distance of closest approach of the oxide ions, the magnesium ions being small enough to go into the spaces between the spherical O^{2-} ions. This is known as close packing and in general such lattices are made up of layers of spherical anions, arranged so that each occupies as little space as possible, packed one on top of another. There are two ways in which this packing can occur, one leading to the hexagonal close packed and the other to the cubic close packed structure. The ratio of the radii of the anions and cations determines whether or not close packing is possible.

It is often convenient to consider a mineral lattice as an array of anions with cations occupying holes between them. Some holes will be between four anions, usually arranged tetrahedrally around the centre point of the hole, the so-called tetrahedral holes. Others will be between six anions arranged octahedrally around the centre point, the octahedral holes. In general the arrangement of anions around a cation will be the most symmetrical in three dimensions, that is 3, 4, 6 or 8 ions will be arranged at the apices of a triangle, tetrahedron, octahedron or cube around the central ion.

In oxides such as MgO the bond between cation and anion can be regarded as ionic in character although physical properties indicate not entirely so. The lattice structure is determined by electrostatic interactions between oppositely charged spheres and MgO has the rock salt (NaCl) structure in which each ion is surrounded octahedrally by six of the other kind. In the cases of many other solids the bonds between cations and anions have a degree of covalent character

and the arrangement of one kind of atom around another is determined by the orientations of the covalent bonds in space. This is the case in some metal sulphides, many of which are semiconductors. The properties of the solids are then best considered in terms of electron energy levels rather than individual bonds between atoms.

1.2.2. *Silicate Structures*

The earth's crust is made up almost entirely of silicates and silica, the rock forming minerals and the breakdown products of them which result from the weathering of rocks. The basis of the structure of silicates is the SiO_4^{4-} group in which four oxygen atoms are arranged tetrahedrally around the silicon atoms, the Si–O distance being about 1.6 Å and the distance between centres of oxygen atoms about 2.6 Å. There are some minerals which are orthosilicates, with lattices built up from simple SiO_4^{4-} ions and cations. Most silicates however are based on polymeric silicate groups, the simplest of which is $\text{Si}_2\text{O}_7^{6-}$, and which proceed to rings, chains, doubled chains (bands) and sheets, some of which are illustrated in Fig. 1.1. In addition there are the three dimensional frameworks, in the various forms of silica. The tetrahedral group AlO_4 has very nearly the same size as the SiO_4 group and so aluminium can replace silicon in the silicate anion structure, giving rise to the aluminosilicates.

Silicate and aluminosilicate lattices can be looked upon as being tetrahedra of oxide ions containing silicon or aluminium ions in the tetrahedral holes, packed together so as to form polyhedra which contain holes of different coordination numbers and sizes. These latter contain cations having appropriate ionic radii, in sufficient number to neutralise the ionic charge of the anionic silicate structure. Clearly as aluminium replaces some silicon more cationic charge is necessary. There are a number of ions of similar size which can occupy octahedral holes in silicate structures. Many metals were present in the magma from which silicate minerals crystallised so that isomorphous substitution is common in silicate minerals. This is the reason why many of them do not have the “ideal” composition of a chemical compound. Aluminium cannot only replace silicon in tetrahedral holes but also occupy octahedral holes and it is this dual role which makes the compositions of some aluminosilicates appear to be exceedingly confusing.

If aluminium replaces some silicon in a three dimensional framework silica structure, the composition remaining $(\text{Si}, \text{Al})\text{O}_2$, the solid becomes negatively