

## HALIDES, SULFATES, AND BORATES

### Halides

Halide minerals contain the anions  $F^-$ ,  $Cl^-$ ,  $Br^-$ , or  $I^-$ . There are more than one hundred forty known halides but only a few are important. Because most of the halide ions are spherical in crystalline materials, the packing is of a highly symmetric nature. The bonding is almost purely ionic. If the cation is small and strongly polarizing the symmetry will be reduced. (Example: Cryolite  $Na_3AlF_6$  is monoclinic).

The halides are of low to moderate hardness. They occur as  $XZ$  or  $XZ_2$  structures in many cases, although other formulas are possible ( $X$  = metal cations,  $Z$  = halide anion). The halide minerals are often found in evaporite deposits.

#### XZ

#### Other forms

HALITE      $NaCl$   
SYLVITE     $KCl$

Cryolite  $Na_3AlF_6$

#### $XZ_2$

FLUORITE    $CaF_2$

### Sulfates

The  $SO_4^{2-}$  group characterizes the sulfates. In the sulfur group sulfur is  $6+$ , a small (0.03 nm) highly polarizing cation. The radius ratio with oxygen is 0.214, within the range for tetrahedral coordination. These groups are very strongly bonded and do not break up during most chemical reactions. Anaerobic bacteria can break the sulfur to oxygen bond, however.

The most important anhydrous sulfate group is the barite group. This group has large divalent cations in XII coordination to oxygen. Similar structures are found in manganates,  $MnO_4^{2-}$  and chromates,  $CrO_4^{2-}$ . In the anhydrite structure calcium ions are in eight coordination to oxygen.

The most important hydrous sulfate is gypsum. The structure consists of calcium ions strongly bonded to sulfate groups parallel to  $\{010\}$ . These layers are separated by sheets of water molecules. Bonds to the water molecules are weak, which explains the perfect cleavage along  $\{010\}$  in gypsum. Gypsum has secondary cleavage along  $\{100\}$ , and along  $\{011\}$ . These lead to a number of varieties.

