

## Mineral Tutorial

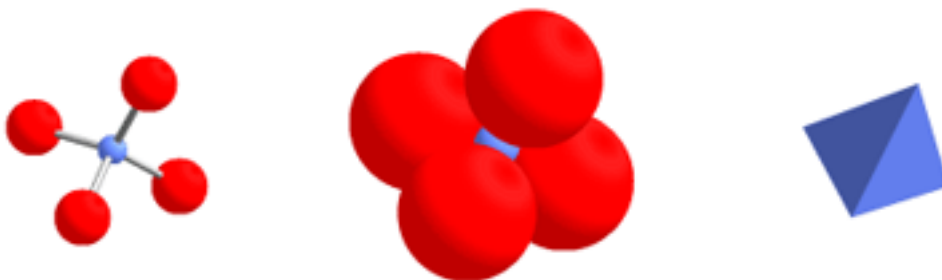
Definition of a mineral: A mineral substance is a naturally occurring solid that has been formed by geological processes, either on earth or in extraterrestrial bodies (Nickel 1995a). A mineral has a well-defined chemical composition and crystallographic properties, and which merits a unique name and therefore minerals are classified by their crystal chemistry and crystal structure.

The most common mineral species are those made up of the common elements. The Earth's crust is composed of 45.5% oxygen (O), 26.8% silicon (Si), 8.4% aluminum (Al), 7% iron (Fe), 5.3% calcium (Ca), 3.2% magnesium (Mg), 2.3% sodium (Na), 0.9% potassium (K) and 0.5% titanium (Ti). This is 99.9% of the crust so it stands to reason that silicate minerals composed of Si and O are the most abundant minerals in the crust - that portion that we live on. Although relatively scarce in nature the asbestos minerals are all silicates, classified as such by their chemistry.

The silicates are further divided into groups on the basis of their crystal structure that is defined by symmetry and the positions of the atoms in the structure. Silicates can have hundreds of atoms in their structure and in order to visualize the complexities of silicate crystal structures mineralogists break them up into smaller structural unit based on the metal atom sites.

### Structural building blocks

The fundamental unit of a silicate mineral is the Si-O tetrahedron with four apices and four sides. This is composed of a central Si atom surrounded by 4 O atoms. The  $\text{Si}^{4+}$  and  $\text{O}^{2-}$  are bonded by very strong covalent bonds. Silicon has a very small radius, only 0.26 Å and oxygen a large radius, 1.40 Å, so silicon fits nicely within the space provided by four bounding oxygen atoms. A cation when surrounded by four oxygens is called tetrahedrally coordinated, so named for the four sides of the tetrahedron. Other atoms commonly in tetrahedral coordination are  $\text{Al}^{3+}$  (0.53 Å), and  $\text{Fe}^{3+}$  (0.49 Å).



*Figure 1. Silicon (blue) and four oxygens (red) are shown here by "Ball and Stick", "Space Filling" and "Tetrahedral" representations. The bonds between the  $\text{Si}^{4+}$  and  $\text{O}^{2-}$  atoms are shown in gray in the Ball and Stick representation. The relative sizes of the atoms are shown in the Space Filling representation. The blue Tetrahedron represents the five atoms in more complex structures.*

### Structural building blocks (continued)

The second fundamental unit is the metal-oxygen octahedron with six apices and

eight sides. This geometry is required for larger cations such as  $\text{Ti}^{4+}$  (0.61 Å),  $\text{Fe}^{3+}$  (0.65 Å),  $\text{Al}^{3+}$  (0.675 Å),  $\text{Mg}^{2+}$  (0.72 Å),  $\text{Fe}^{2+}$  (0.77 Å). Metal cations surrounded by six oxygens are octahedrally coordinated, so named for the eight sides of the octahedron. The larger cations such as  $\text{Ca}^{2+}$  (1.00 Å),  $\text{Na}^{1+}$  (1.02 Å), and  $\text{K}^{1+}$  (1.38 Å) fit into larger and distorted sites distinct from tetrahedral and octahedral sites.



*Figure 2. A central iron (brown) atom and six oxygens (red) are shown here in "Ball and Stick", "Space Filling" and "Octahedral" representations. The bonds between the Si and O atoms are shown in gray in the Ball and Stick representation. The relative sizes of the atoms are shown in the Space Filling representation. Note that the size of the interstitial space in the octahedra is much larger than that in the tetrahedra shown above. The brown octahedra represents seven atoms in more complex structures.*

### **Silicate Group**

Silicates are grouped into structural types by the way the Si-O tetrahedra are interconnected. Simply put the scheme is based on the number of shared apical oxygens. The main groups are listed below

#### ***Nesosilicates -***

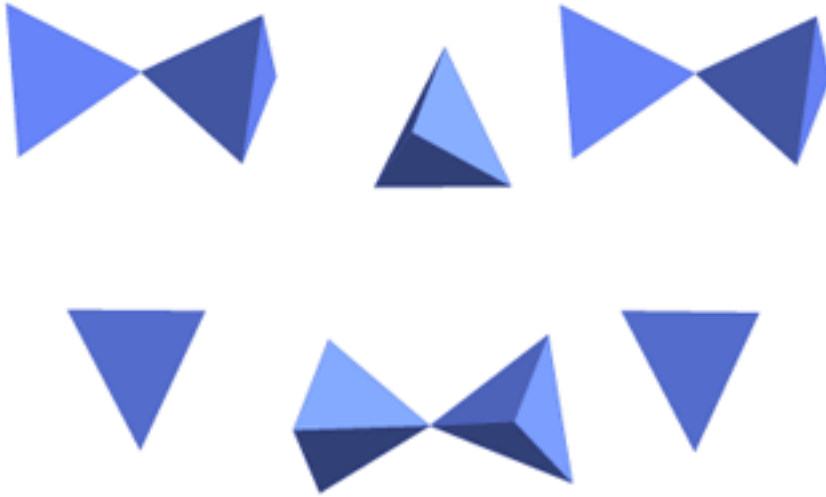
Silicates with isolated Si-O tetrahedra. There are no shared oxygens between adjacent tetrahedra. Olivine, garnet and zircon are examples of nesosilicates.



*Fig 3. Isolated Si-O tetrahedra in the olivine  $(\text{Mg,Fe})_2[\text{SiO}_4]$  structure*

### **Sorosilicates -**

Silicates with two Si-O tetrahedra connected. There is one shared oxygen. The epidote minerals such as Tanzanite are sorosilicates but with both  $\text{Si}_2\text{O}_7$  and  $\text{SiO}_4$  groups.



*Figure 4. Zoisite structure,  $\text{Ca}_2\text{Al Al}_2\text{O OH}[\text{Si}_2\text{O}_7][\text{SiO}_4]$  with two tetrahedra sharing an apical oxygen  $[\text{Si}_2\text{O}_7]$  and isolated tetrahedra  $[\text{SiO}_4]$ . Only Si-O tetrahedra are shown.*

### **Cyclosilicates -**

Silicates with 3, 4, 6, or 8 membered rings. Two oxygens are shared with adjacent tetrahedra. Beryl and tourmaline are ring silicates.



*Figure 5. Beryl  $\text{Be}_3\text{Al}_2[\text{Si}_6\text{O}_{18}]$  six-membered ring structure. Only two tetrahedral rings are shown.*

### **Inosilicates -**

Silicates with single and double chains of Si-O tetrahedra. Two or three oxygens are shared between adjacent tetrahedra. Pyroxenes are single chained and amphiboles are double chained silicates.

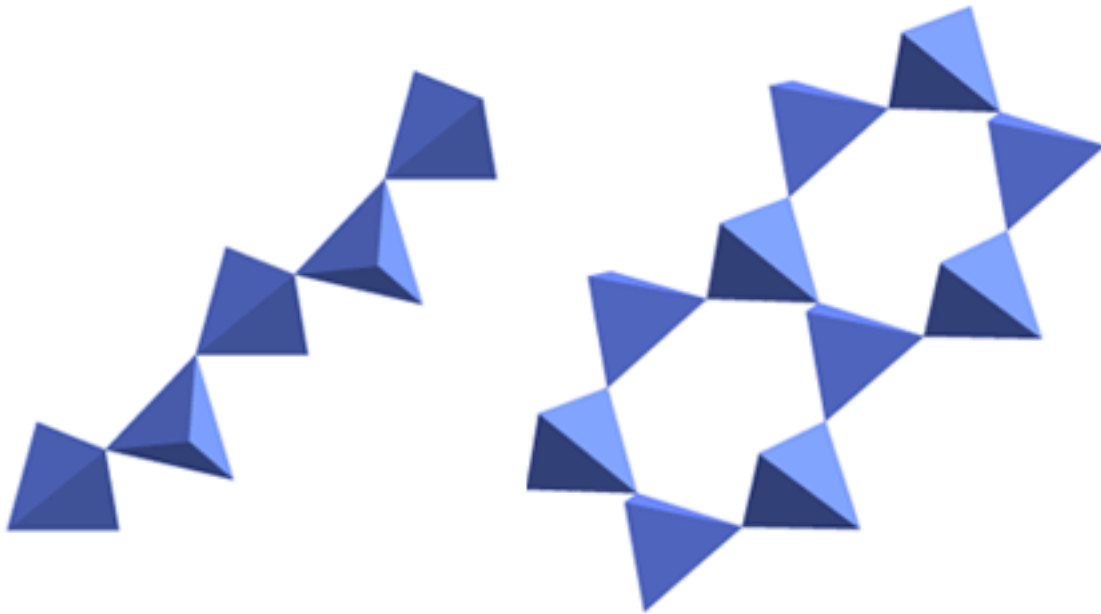


Figure 6. Diopside,  $\text{CaMg}[\text{SiO}_3]$  - single chain pyroxene and tremolite,  $\text{CaMg}_7\text{Si}_8\text{O}_{22}(\text{OH})_2$  - double chain amphibole. Only the Si-O tetrahedra are shown.

***Phyllosilicates*** -

Silicates arranged with a sheet of Si-O tetrahedra. Three oxygens are shared between adjacent tetrahedra. The micas, talc and serpentines are sheet silicates.

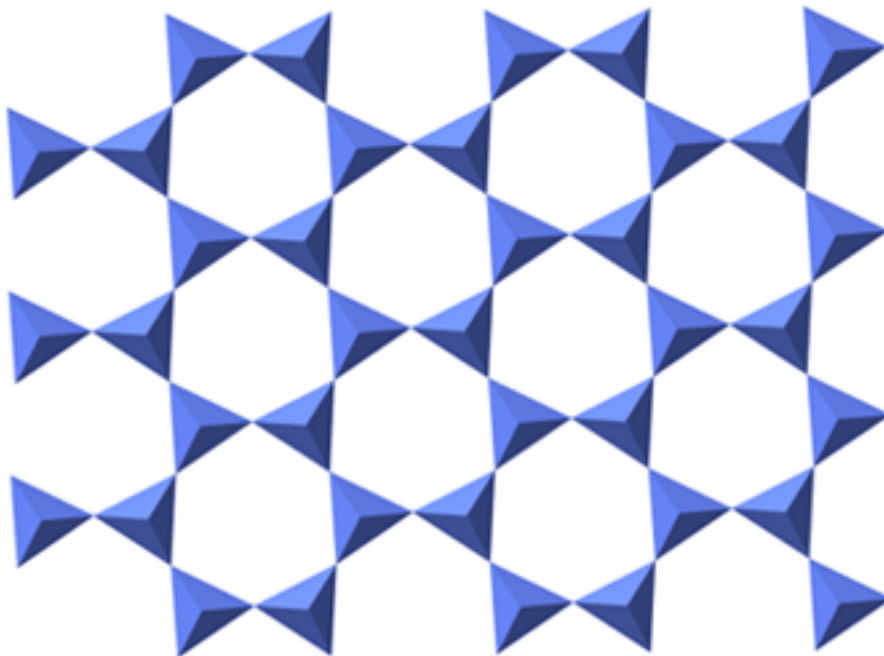


Figure 7. Talc,  $\text{Mg}_6[\text{Si}_8\text{O}_{20}](\text{OH})_4$ , Si-O sheet structure. Mg is not shown.

***Tectosilicates*** -

Silicates with Si-O tetrahedra arranged into a three-dimensional framework. Each Si-O tetrahedra shares four oxygens with adjacent tetrahedral linking all four

apices into a framework. Quartz, feldspars and zeolites are framework silicates.



*Figure 8. Quartz, SiO<sub>2</sub>. This is a small portion of the quartz structure showing the sharing of all apical oxygens with adjacent Si-O tetrahedra to form a framework.*