Lecture 8: Silicates: Pyroxene and Amphibole

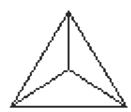
Silicates are an important class of minerals to study because they make up over 90% of the Earth's crust. Because most of the crust consists of oxygen and silicon, they may be regarded as arrangements of SiO_4 tetrahedra with metal ions occupying structural vacancies between the silicate framework.

Silicate Taxonomy

Silicates are organized into seven classes based on the arrangement of their SiO_4 tetrahedra. Silicates in a particular class share certain physical and chemical properties. Nearly all phyllosilicates, for example, have 180° cleavage. Silicates in a particular class also have constant silicon-to-oxygen ratios, so knowing a silicate's class helps you remember its formula.

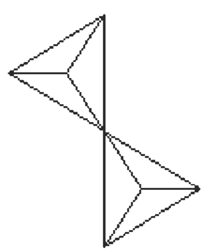
Nesosilicates

Nesosilicates take their name from the Greek nesos, meaning island. They are composed of independent SiO_4 tetrahedra. Their Si:O ratio is 1:4.



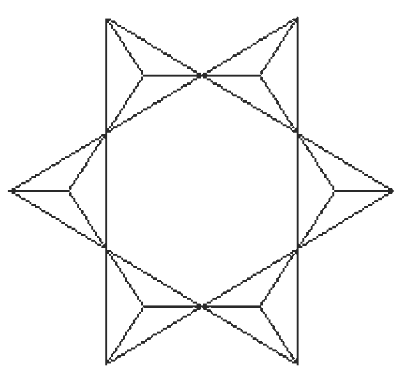
Sorosilicates

Sorosilicates take their name from the Greek soros, meaning heap. They are composed of two SiO_4 tetrahedra linked at a single apex. Their Si:O ratio is 2:7.



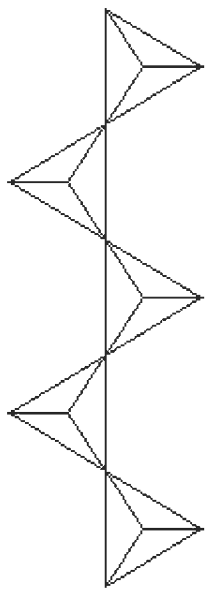
Cyclosilicates

Cyclosilicates take their name from the Greek kyklos, meaning circle. They are composed of six SiO_4 tetrahedra linked at a single oxygen apex in a ring. Their Si:O ratio is 1:3.



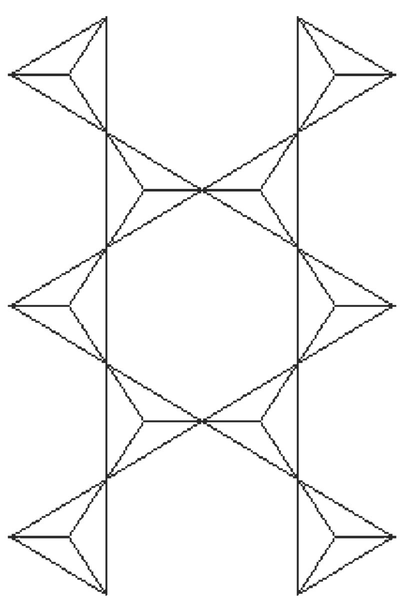
Inosilicates—Single Chain

Inosilicates take their name from the Greek inos, meaning thread. They are composed of SiO_4 tetrahedra linked in chains. The Si:O ratio of single-chain inosilicates is 1:3.



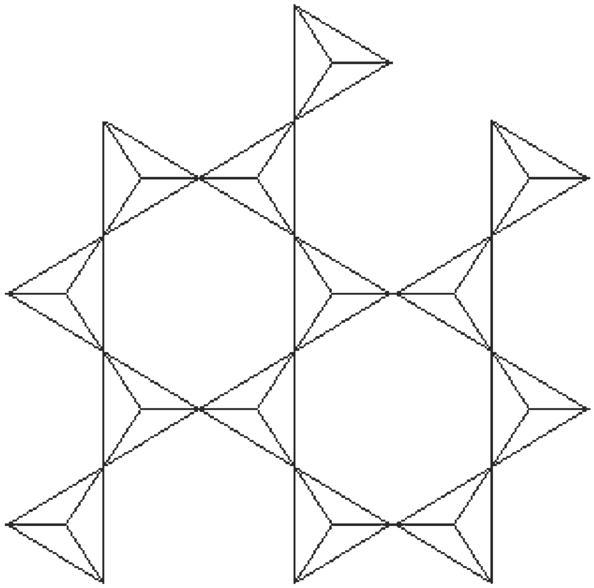
Inosilicates—Double Chain

Double-chain inosilicates consist of two chains of SiO_4 tetrahedra linked side by side. Their Si:O ratio is 4:11.



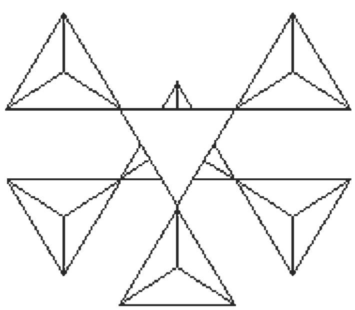
Phyllosilicates

Phyllosilicates take their name from the Greek phyllon, meaning leaf. They are composed of SiO_4 tetrahedral linked at three oxygen apices in a sheet. Their Si:O ratio is 2:5.



Tectosilicates

Tectosilicates take their name from the Greek tecton, meaning builder. They are composed of SiO_4 tetrahedra linked at all four oxygen apices in a three-dimensional network. Their Si:O ratio is 1:2.



Nesosilicates

Nesosilicates are typically hard and heavy because the ionic bonds between independent SiO_4 tetrahedra and interstitial cations result in dense atomic packing. They are also typically equidimensional and lack cleavage because the SiO_4 tetrahedra are not connected in sheets or chains.

Olivine, $(Mg, Fe)_2SiO_4$, is a very common member of the nesosilicate class. It consists of layers of octahedra occupied by Mg2+ and Fe2+ that are linked by SiO_4 tetrahedra.

Another common group of nesosilicate minerals is garnets, represented by the formula $A_3B_2(SiO_4)_3$. The A sites have 8-fold coordination and house relatively large divalent cations such as Ca^{2+}, Mg^{2+}, Fe^{2+}, and Mn^{2+}. The B sites have 6-fold coordination and house smaller trivalent cations such as Al^{3+}, Cr^{3+}, and Fe^{3+}. Which ions occupy these sites provides a basis for organizing garnets into two series.

Series	Mineral	Formula
Pyralspite	Pyrope	$Mg_3Al_2Si_3O_{12}$
	Almandine	$Fe_3Al_2Si_3O_{12}$
	Spessartine	$Mn_3Al_2Si_3O_{12}$
Ugrandite	Uvarovite	$Ca_3Cr_2Si_3O_{12}$
	Grossular	$Ca_3Al_2Si_3O_{12}$
	Andradite	$Ca_3Fe_2Si_3O_{12}$

The structure of garnets consists of a continuous network of SiO_4 tetrahedra bonded to BO_6 octahedra at the apices.

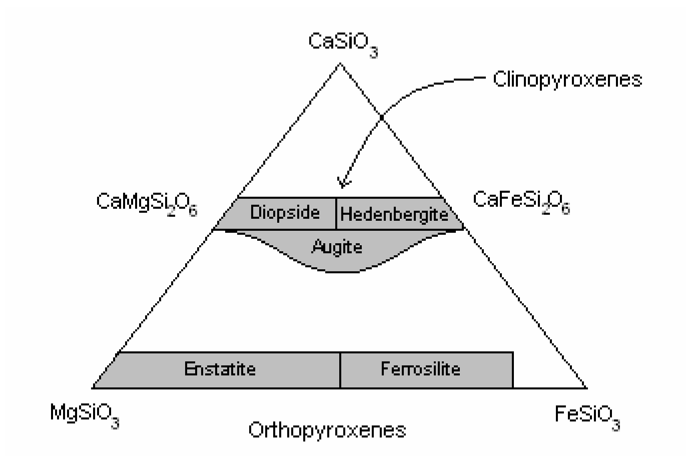
Sorosilicates

Sorosilicates are fairly rare. The most important group of minerals in this class is the epidote group.

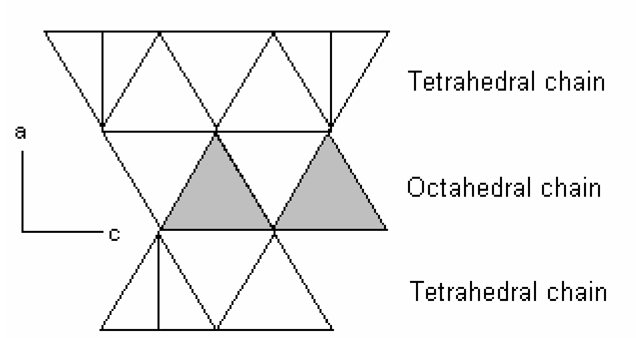
Group	Mineral	Formula
Epidote	Epidote	$Ca_2(Fe^{3+}, Al)Al_2O(SiO_4)(Si_2O_7)(OH)$
	Clinozoisite	$Ca_2Al_3O(SiO_4)(Si_2O_7)(OH)$
	Allanite	$X_2Y_3O(SiO_4)(Si_2O_7)(OH)$

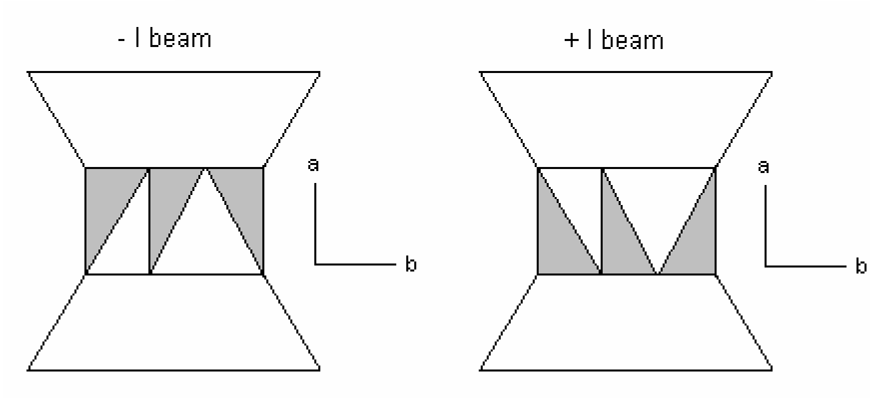
Single Chain Inosilicates

Pyroxenes are an important group of minerals in the single chain inosilicate class. They have the general formula XYZ_2O_6, where X and Y represent octahedral sites and Z represents the tetrahedral sites occupied by Si^{4+} or Al^{3+}. The most common pyroxenes can be represented as part of the ternary system whose endmembers are wollastonite ($CaSiO_3$), enstatite ($MgSiO_3$), and ferrosilite ($FeSiO_3$).



The structure of pyroxenes consists of chains of tetrahedra and octahedra that run parallel to the c axis. One chain of octahedra is sandwiched between two chains of tetrahedra. This arrangement of chains can be visualized as I-beams.



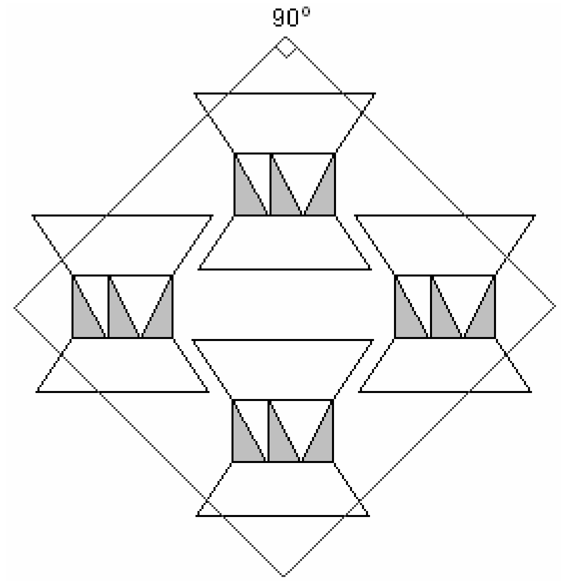


Pyroxenes differ in the direction of their I-beams. When the I-beams all have the same direction, the pyroxene is a clinopyroxene. When the I-beams alternate directions, the pyroxene is a protopyroxene. When two I-beams pointing in the same direction are followed by another two I beams pointing in the opposite direction—and so on—the pyroxene is an orthopyroxene.

Direction of I beams

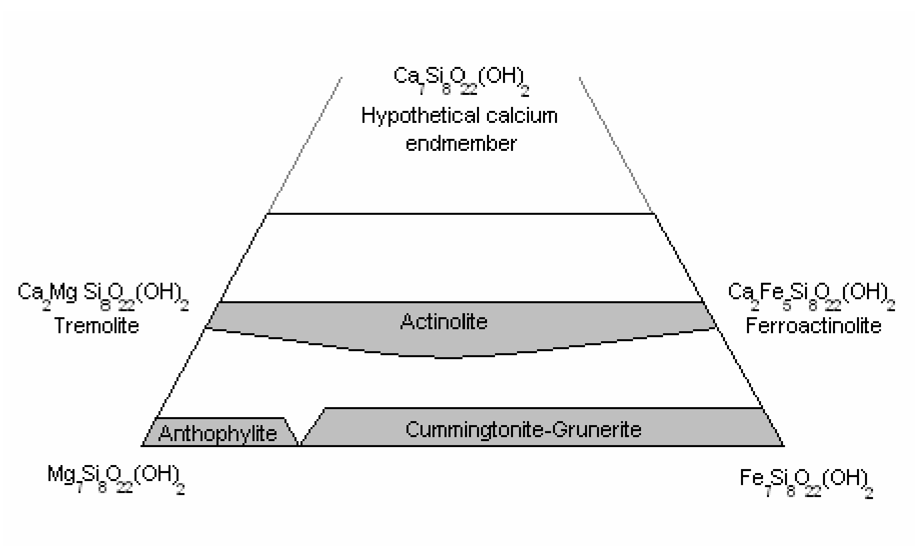
+	+	+
+	-	+
+	+	-
+	-	-
+	+	+
+	-	+
clino-	proto-	ortho-

The arrangement of I-beams in pyroxene accounts for the 90° cleavage.



Double Chain Inosilicates

Amphiboles are an important group of minerals in the double-chain inosilicate class. They have the general formula $W_{0\text{-}1}X_2Y_5Z_8O_{22}(OH, F)_2$. W represents 10- to 12-coordinated sites occupied by Na^+ or K^+; X represents 6- to 8-coordinated sites occupied by Ca^{2+}, Fe^{2+}, Mg^{2+}, Mn^{2+}, Na^+, or Li^+; Y represents 6-coordinated sites occupied by Fe^{2+}, Fe^{3+}, Mg^{2+}, Mn^{2+}, Al^{3+}, or Ti^{4+}; and Z represents tetrahedral sites occupied by Al^{3+} or Si^{4+}. The most common amphiboles can be represented as part of the quaternary system whose endmembers are anthophylite ($Mg_7Si_8O_{22}(OH)_2$), tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$), ferroactinolite ($Ca_2Fe_5Si_8O_{22}(OH)_2$), and grunerite ($Fe_7Si_8O_{22}(OH)_2$).



The structure of amphibole is very similar to the structure of pyroxene. It is based on chains of tetrahedra and octahedra that run parallel to the c-axis and can be visualized as I-beams. Just as in the structure of pyroxene, the directionality of the I-beams distinguishes different types of amphibole. Their arrangement accounts for cleavage.