

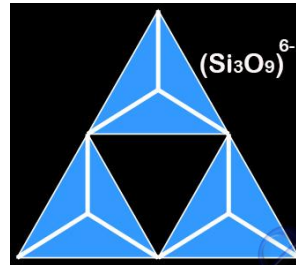
3) Cyclosilicates

The cyclosilicates contain rings of linked SiO_4 tetrahedra having a ratio $\text{Si}:\text{O} = 1:3$.

There are three cyclic configurations:

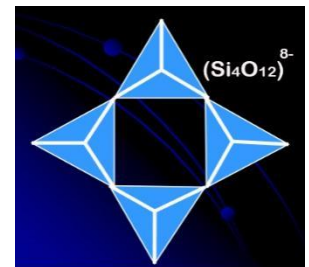
1- Si_3O_9 Ring (3 tetrahedra): $(\text{Si}_3\text{O}_9)^{6-}$

Example: Benitoite – $\text{BaTiSi}_3\text{O}_9$



2- Si_4O_{12} Ring (4 tetrahedra): $(\text{Si}_4\text{O}_{12})^{8-}$

Example: Axinite – $(\text{Ca}, \text{Fe}^{2+}, \text{Mn})_3\text{Al}_2(\text{BO}_3)(\text{Si}_4\text{O}_{12})(\text{OH})$



3- Si_6O_{18} Ring (6 tetrahedra): $(\text{Si}_6\text{O}_{18})^{12-}$

Examples:

A) Beryl – $\text{Be}_3\text{Al}_2(\text{Si}_6\text{O}_{18})$

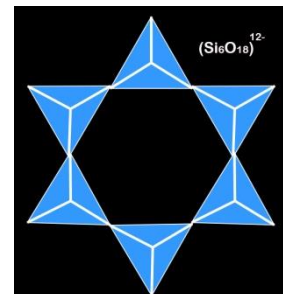
Crystallography: Hexagonal.

Color: Bluish-green, light-yellow, or colorless.

Diagnostic features: Hexagonal crystal and color.

Occurrence: Usually occurs in granite, pegmatite, and mica schist.

Uses: As a gemstone and it's the major source of beryllium.



B) Tourmaline – $(\text{Na}, \text{Ca})(\text{Li}, \text{Mg}, \text{Al})(\text{Al}, \text{Fe}, \text{Mn})_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4$

Crystallography: Hexagonal.

Color: Varied depending on the composition, but mostly black.

Hardness: 7-7.5.

Fracture: Conchoidal.

Diagnostic features Slender prismatic crystal and conchoidal fracture.

Occurrence: Found in granite and pegmatite, it's found also as an accessory mineral in igneous and metamorphic rocks.

Uses: Tourmaline forms one of the most beautiful gemstones.

C) Cordierite – $(\text{Mg, Fe})_2\text{Al}_4\text{Si}_5\text{O}_{18} \cdot n\text{H}_2\text{O}$

Crystallography: Orthorhombic.

Color: Blue to bluish-gray.

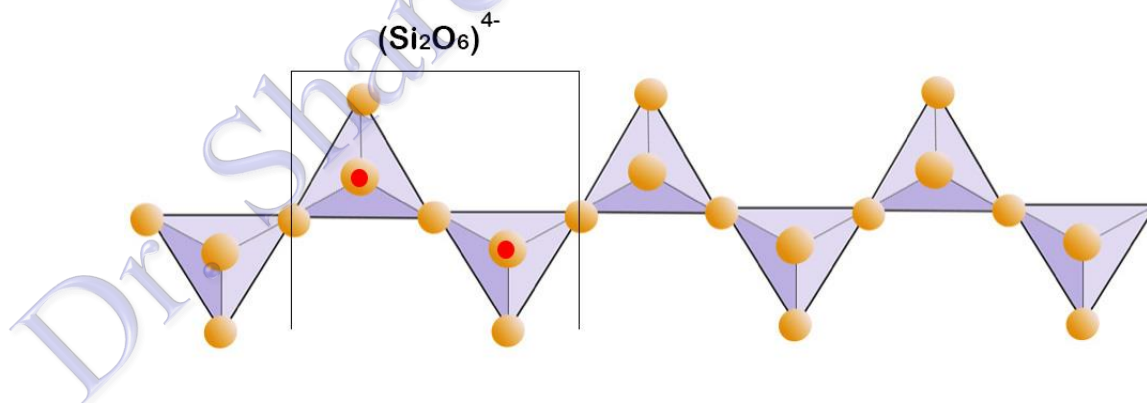
Occurrence: Found in metamorphic rocks (contact and regional).

4) Inosilicates (or chain silicates)

Inosilicates are divided into two groups:

A) Single chain – Pyroxene group:

In the single chain structure, two of the four oxygens in each SiO_4 tetrahedron are shared to build long chains of SiO_4 . The basic structural group is $(\text{Si}_2\text{O}_6)^{4-}$ with a ratio of $\text{Si}:\text{O} = 1:3$



Characteristics of Pyroxene:

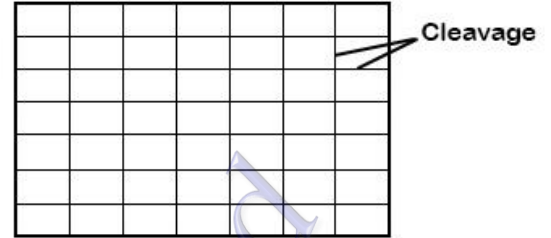
1- Pyroxene crystallizes at higher temperature than amphibole.

2- Pyroxene is anhydrous mineral.

3- Pyroxene commonly occurs in prism grains.

4- Characterized by two sets of cleavages ($87^\circ - 93^\circ$).

5- Under retrograde metamorphism, pyroxene commonly gives amphibole.



6- The chemical composition of pyroxene can be expressed by the general formula XYZ_2O_6 where:

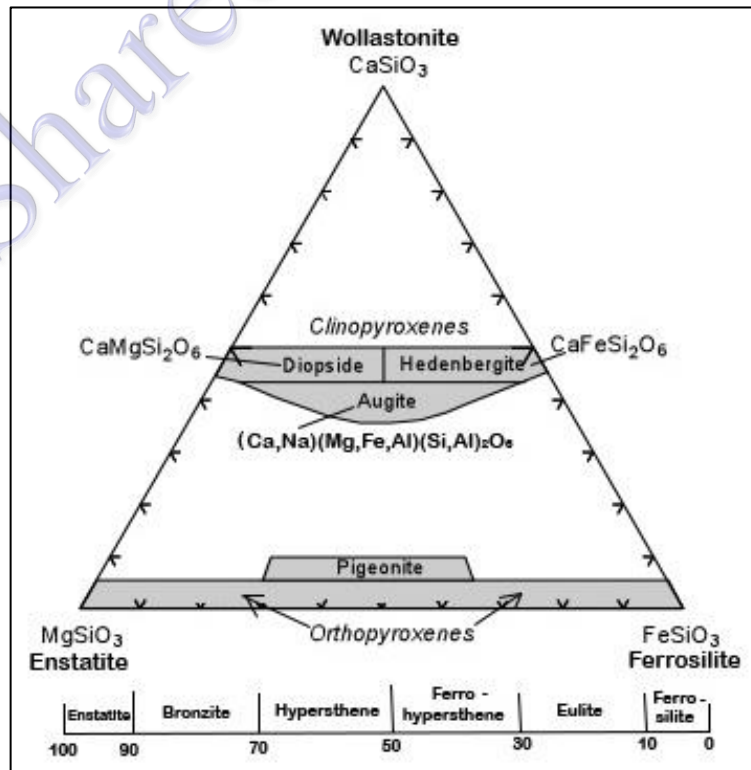
X site = Na^+ , Ca^{2+} , Mn^{2+} , Fe^{2+} , Mg^{2+} , Li^+ (one or more of these elements).

Y site = Mn^{2+} , Fe^{2+} , Mg^{2+} , Fe^{3+} , Al^{3+} , Cr^{3+} , Ti^{4+} (one or more of these elements).

Z site = Si^{4+} , Al^{3+} (or combination of both).

Classification of pyroxene

The pyroxenes can be divided into two subgroups based on chemistry and crystallography:



First: Orthopyroxene (Opx) (Orthorhombic Pyroxene)

Enstatite – Ferrosilite series:

- | | | |
|--------------------------------|-------------|--|
| a- Enstatite, MgSiO_3 | b- Bronzite | c- Hypersthene, $(\text{Mg, Fe}) \text{SiO}_3$ |
| d- Ferrohypersthene. | e- Eulite | f- Ferrosilite, FeSiO_3 |

Second: Clinopyroxene (Cpx)

A) Monoclinic Pyroxene

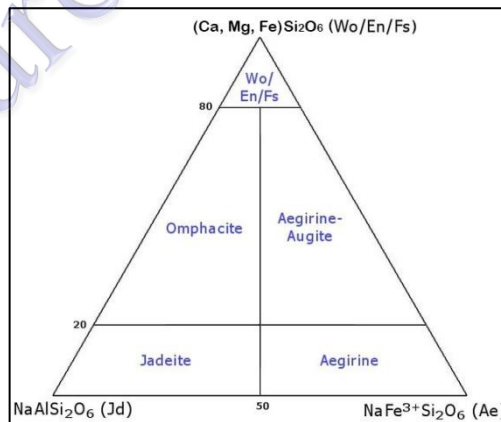
1– Diopside – Hedenbergite series:

- | | |
|--|--|
| a- Diopside, $\text{CaMgSi}_2\text{O}_6$ | b- Hedenbergite, $\text{CaFeSi}_2\text{O}_6$ |
| c- Augite, $(\text{Ca, Na})(\text{Mg, Fe, Al})(\text{Si, Al})_2\text{O}_6$ | |

2– Pigeonite, $(\text{Ca, Mg, Fe})(\text{Mg, Fe})\text{Si}_2\text{O}_6$

3– Sodic Pyroxene:

- | | |
|--|---|
| a- Aegirine, $\text{NaFe}^{3+}\text{Si}_2\text{O}_6$ | b- Aegirine-augite, $(\text{Na, Ca})(\text{Fe}^{3+}, \text{Fe}^{2+}, \text{Mg})\text{Si}_2\text{O}_6$ |
| c- Jadeite, $\text{NaAlSi}_2\text{O}_6$ | d- Omphacite, $(\text{Ca, Na})(\text{Mg, Fe}^{2+}, \text{Al})\text{Si}_2\text{O}_6$ |



4- Lithium pyroxene – Spodumene, $\text{LiAlSi}_2\text{O}_6$

B) Triclinic Pyroxene (Pyrxenoid group)

There are a number of silicate minerals that have, as do the pyroxenes, a ratio of Si:O =1:3, but with structures which are not identical to those of the pyroxenes. These minerals are called pyrxenoid and consist of:

1- Wollastonite, CaSiO_3 2- Rhodonite, MnSiO_3 3- Pectolite, $\text{Ca}_2\text{NaH}(\text{SiO}_3)_3$

Examples:

1) Enstatite – Ferrosilite series

Crystallography: Orthorhombic.

Color: Gray or yellow.

Cleavage: 2 sets ($87^\circ - 93^\circ$).

Diagnostic features: Color and cleavage.

Occurrence: Igneous rocks (peridotite, gabbro, norite, and basalt), also in metamorphic rocks (granulite).

2) Diopside – Hedenbergite – Augite

Crystallography: Monoclinic.

Color: White to light green.

Cleavage: 2 sets ($87^\circ - 93^\circ$).

Diagnostic features: Crystal form (prismatic form) and cleavage.

Occurrence: Igneous rocks (peridotite and gabbro), also in metamorphic rocks (marble).

3) Aegirine (acmite) – $\text{NaFe}^{3+}\text{Si}_2\text{O}_6$

Crystallography: Monoclinic.

Color: Brown or green.

Cleavage: 2 sets ($87^\circ - 93^\circ$).

Diagnostic features: Prismatic crystals and color.

Occurrence: Found in igneous rocks (nepheline syenite).

4) Jadeite – $\text{NaAlSi}_2\text{O}_6$

Crystallography: Monoclinic.

Color: Apple-green or white.

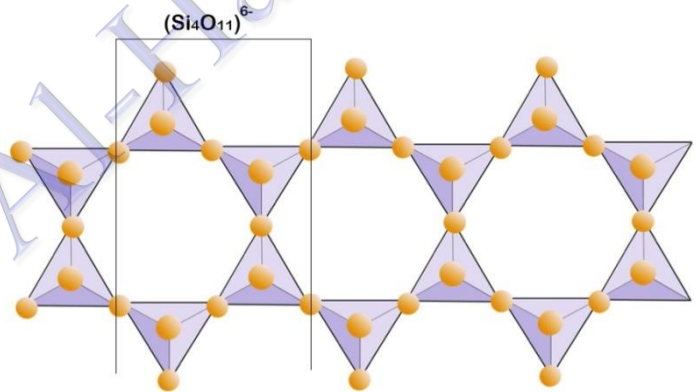
Cleavage: 2 sets ($87^\circ - 93^\circ$).

Diagnostic features: Color (green).

Occurrence: Found only in metamorphic rocks.

B) Double chain – Amphibole group:

If two chains are linked together, we can form double chains. The basic structural unit is $(\text{Si}_4\text{O}_{11})^{6-}$ with a ratio of Si:O = 4:11 = 8:22.



Characteristics of Amphibole:

- 1- Amphibole crystallizes at lower temperature than pyroxene.
- 2- Amphibole is hydrous mineral (contains OH^-).
- 3- Amphibole commonly occurs as prismatic-elongated crystals.
- 4- Characterized by two sets of cleavages ($56^\circ - 124^\circ$).
- 5- Amphibole has lower specific gravity compared with pyroxene.
- 6- The general formula of amphibole is: $\text{W}_{0-1}\text{X}_2\text{Y}_5\text{Z}_8\text{O}_{22}(\text{OH})_2$ where:
 $\text{W} = \text{Na}^+$ or K^+ (A site).
 $\text{X} = \text{Na}^+, \text{Ca}^{2+}, \text{Mn}^{2+}, \text{Fe}^{2+}, \text{Mg}^{2+}, \text{or Li}^+$ (M4 site).
 $\text{Y} = \text{Mn}^{2+}, \text{Fe}^{2+}, \text{Mg}^{2+}, \text{Fe}^{3+}, \text{Al}^{3+}, \text{or Ti}^{4+}$ (M1, M2, and M3 sites).
 $\text{Z} = \text{Si}^{4+}$ and Al^{3+} (tetrahedral site).
 $\text{OH}^-, \text{F}^-, \text{or O}^{2-}$ (hydroxyl sites).

Examples:

1) Hornblende – $(\text{Ca}, \text{Na})_2(\text{Mg}, \text{Fe}, \text{Al})_5(\text{Si}, \text{Al})_8\text{O}_{22}(\text{OH})_2$

Crystallography: Monoclinic.

Color: Dark green to black.