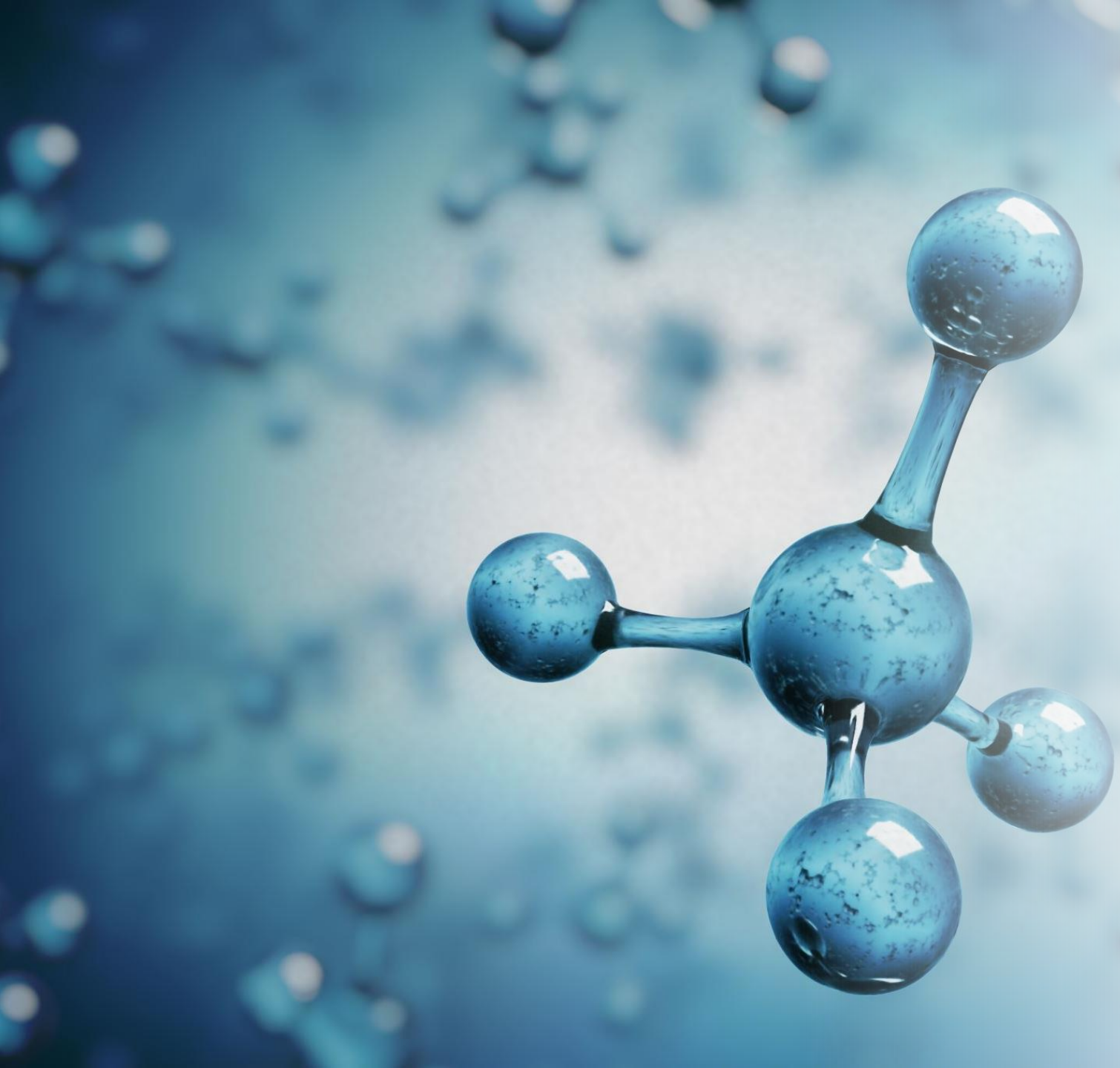


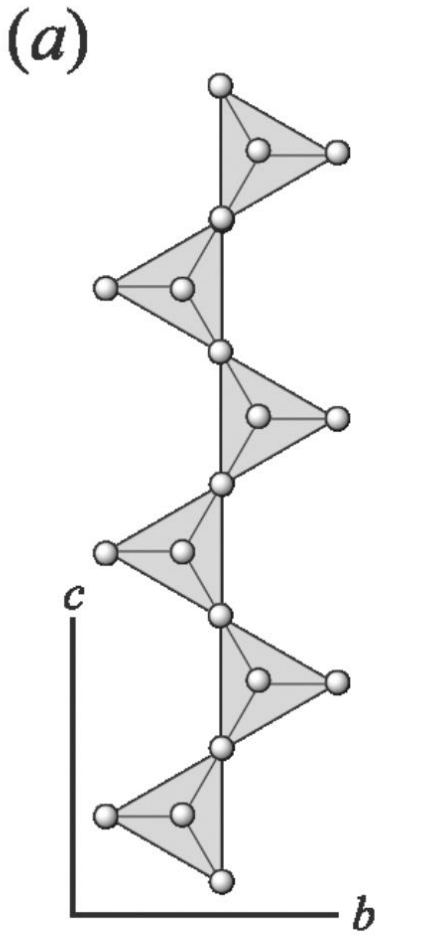
Chain Silicates

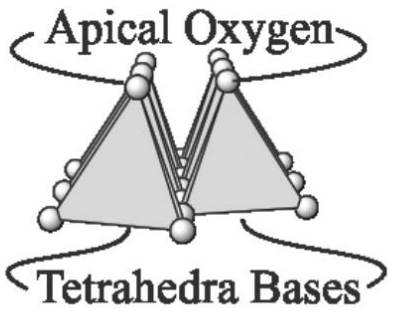
Dr. Tapabrato Sarkar

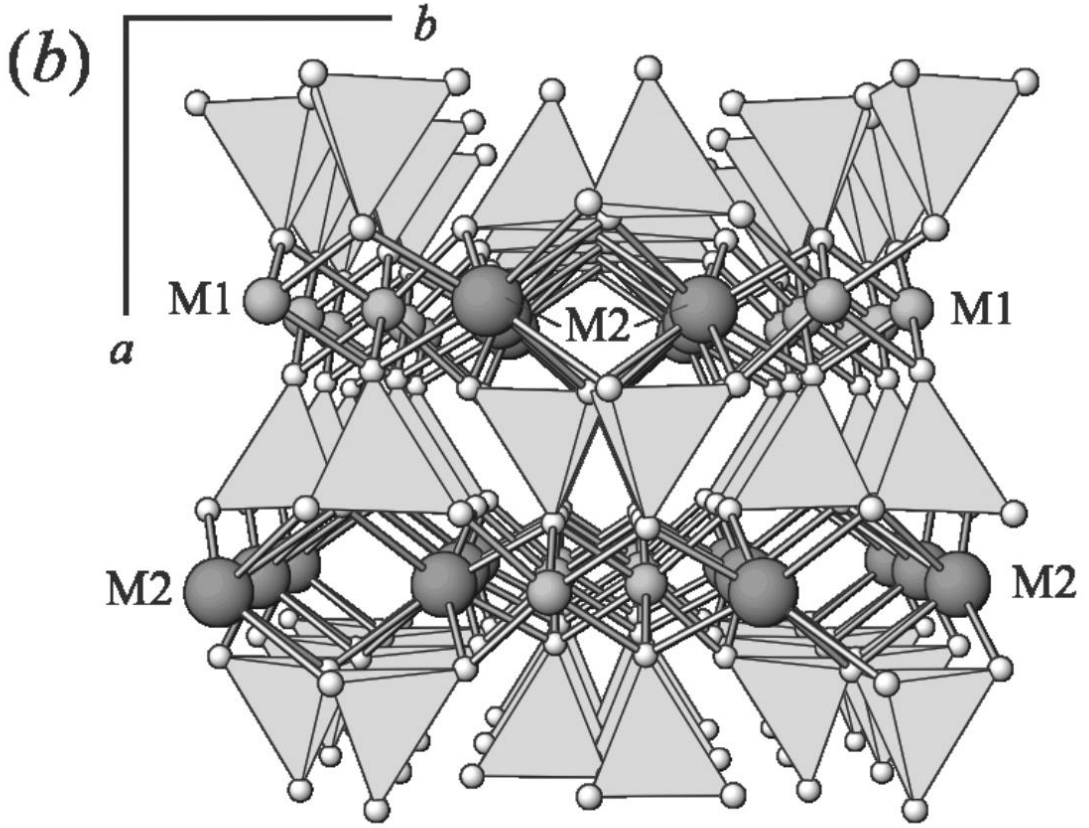
Chain Silicates (Inosilicates)

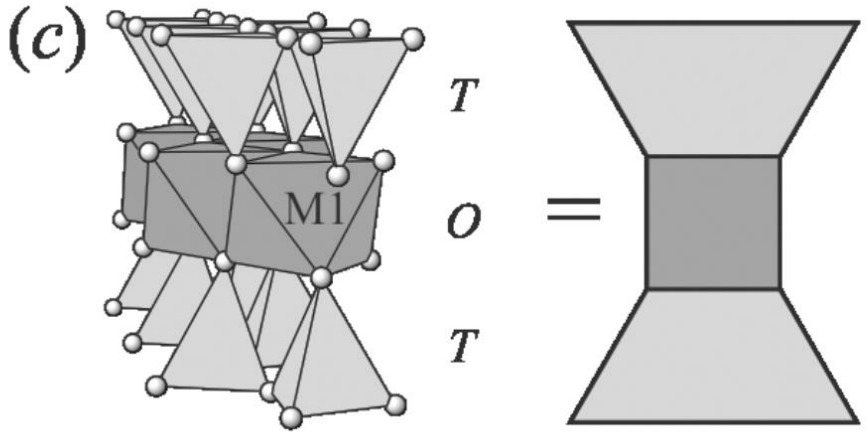
Most common mineral:
Pyroxene group

General Formula:
XYZ_2O_6









Pyroxene classification

Table 14.1 Pyroxene Classification[a]

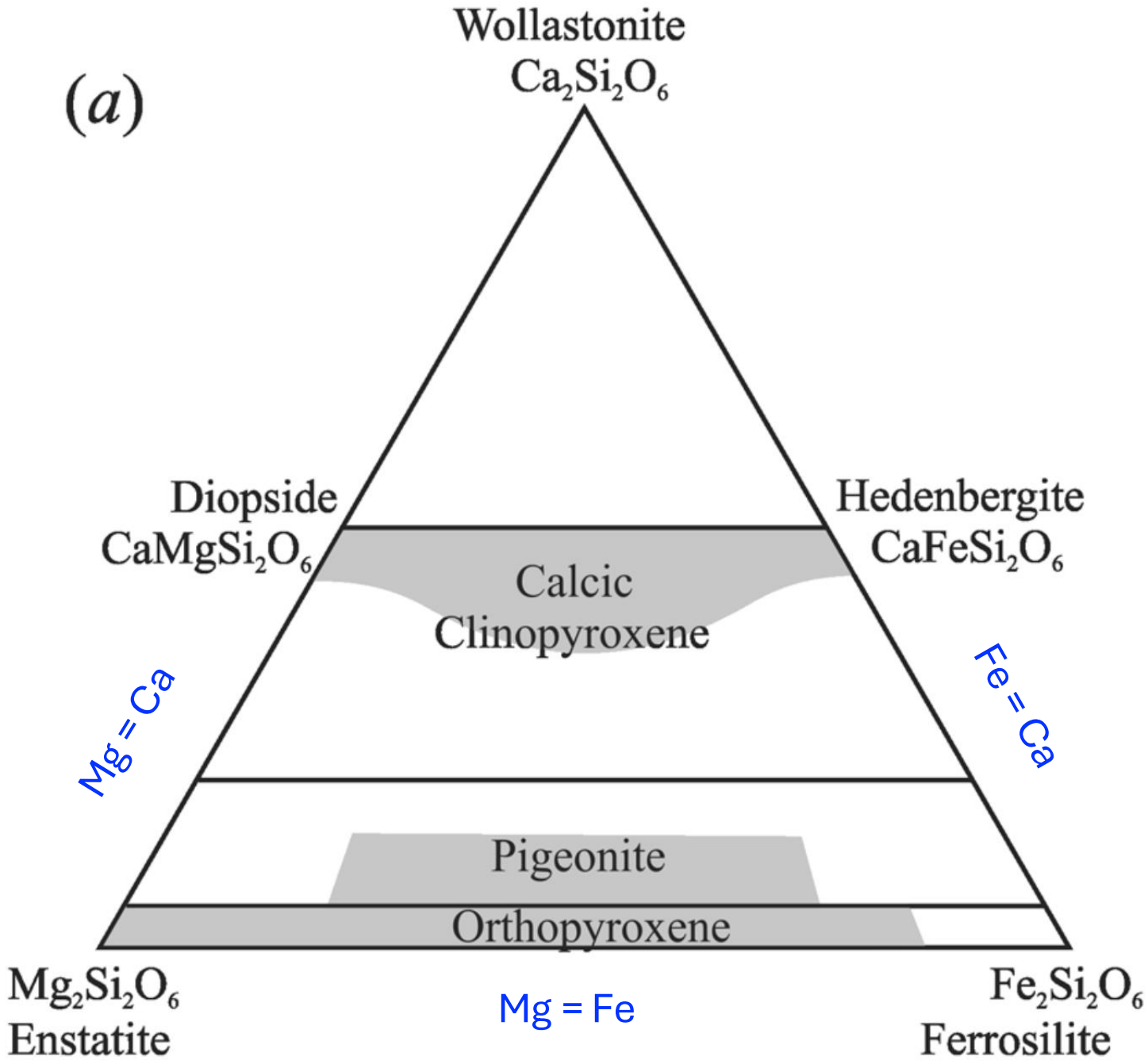
Group	X	Y	Z_2O_6	Mineral(s)	Symmetry	Comment
Magnesium–iron	Mg, Fe	Mg, Fe	Si_2O_6	Enstatite–Ferrosilite	Orthorhombic	Orthopyroxene (opx)
	Mg, Fe, Ca	Mg, Fe	Si_2O_6	Pigeonite	Monoclinic	Low-Ca clinopyroxene
Calcium	Ca	Mg, Fe	Si_2O_6	Diopside–Hedenbergite		Ca clinopyroxene (Ca-cpx or cpx)
		Mg, Fe, Al	$(Si,Al)_2O_6$	Augite		
Calcium–sodium	Ca, Na	Mg, Fe^{2+}, Al, Fe^{3+}	Si_2O_6	Omphacite		Sodic–Calcic clinopyroxene
		Mg, Fe^{2+}, Fe^{3+}	Si_2O_6	Aegirine–Augite		
Sodium	Na	Al	Si_2O_6	Jadeite		Sodic clinopyroxene
		Fe^{3+}	Si_2O_6	Aegirine		
Lithium	Li	Al	Si_2O_6	Spodumene		Lithium clinopyroxene

[a] Based on the general formula XYZ_2O_6 where X cations occupy M2 sites, Y cations occupy M1 sites, and Z cations occupy tetrahedral sites.

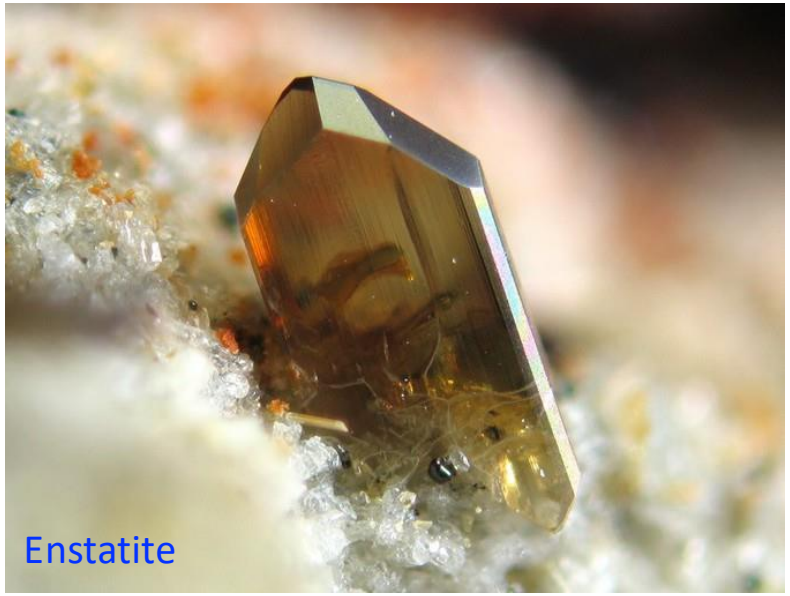
Pyroxene classification

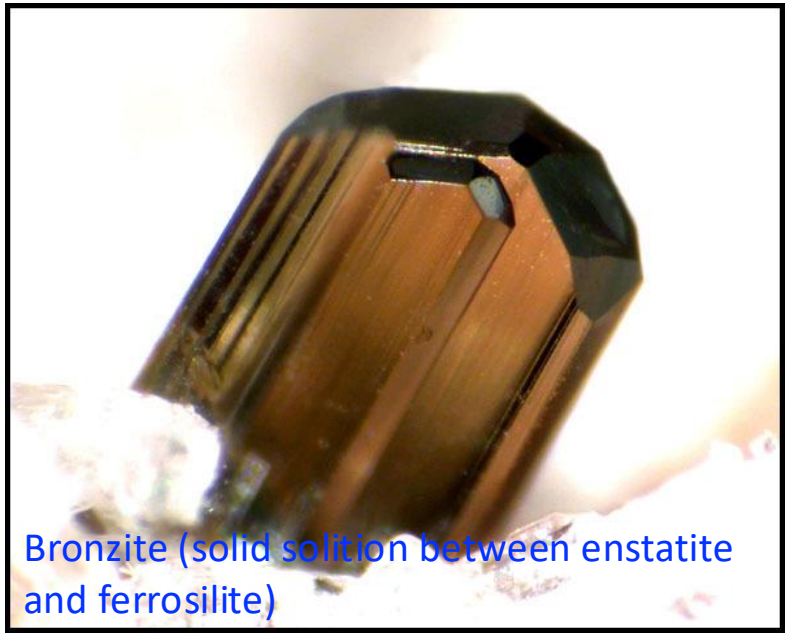
Two primary types of Pyroxene:

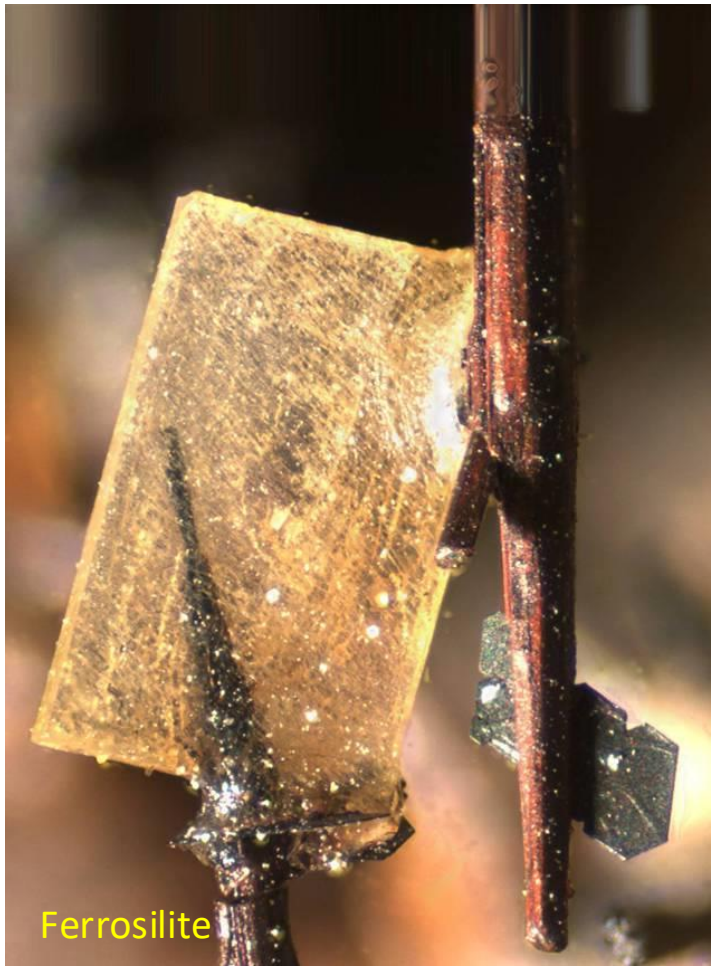
1. Orthopyroxene
2. Clinopyroxene



Orthopyroxene: Distinguishing features


Enstatite

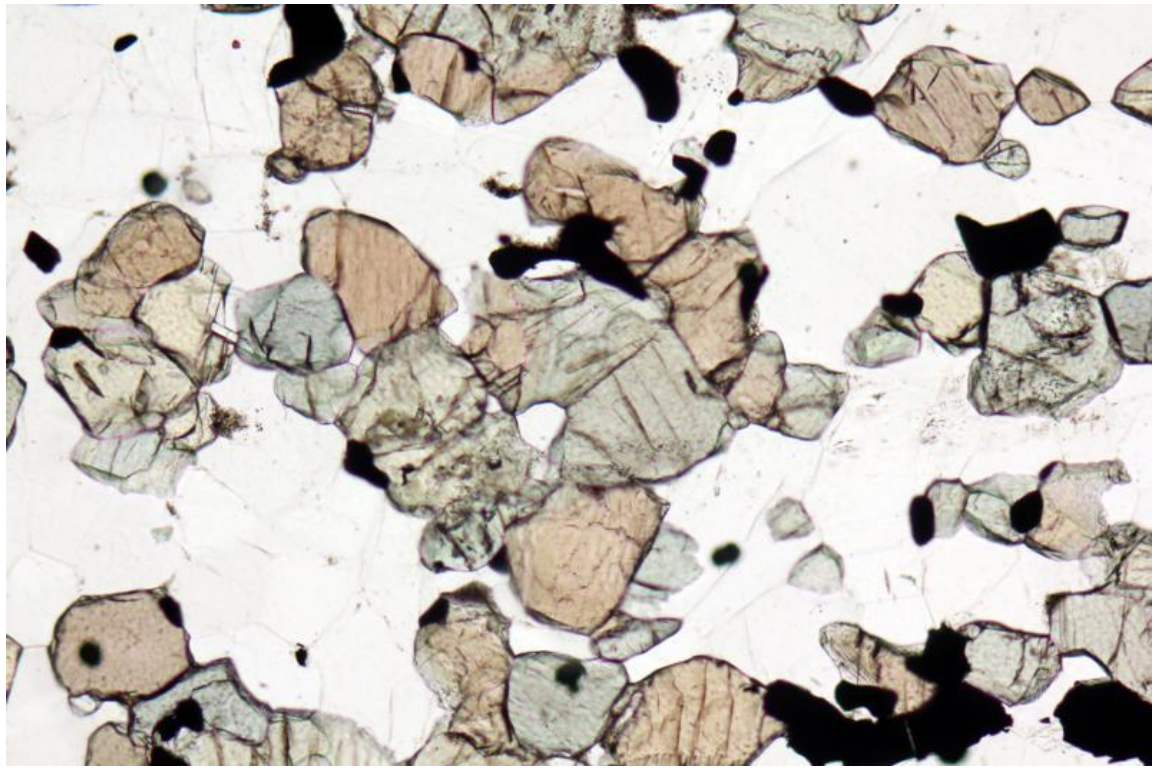

Bronzite (solid solition between enstatite and ferrosilite)

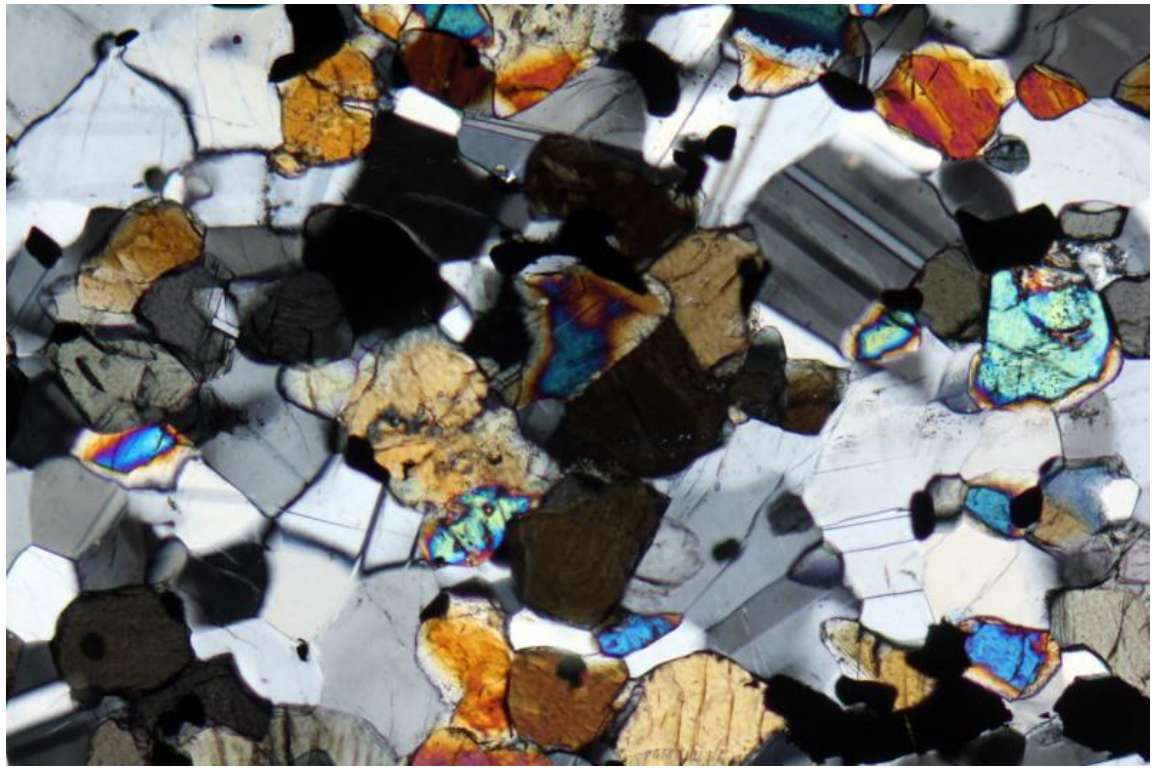

Ferrosilite

Distinguishing features in hand specimen:

- Color: Mg-rich varieties most often brown or greenish brown; also white, tan, or green. Fe-rich varieties are green, dark brown, or greenish black.
- Vitreous luster
- Streak: White to gray
- 2 sets good cleavage intersecting at right angles
- Euhedral crystals are stubby prisms

Orthopyroxene: Distinguishing features





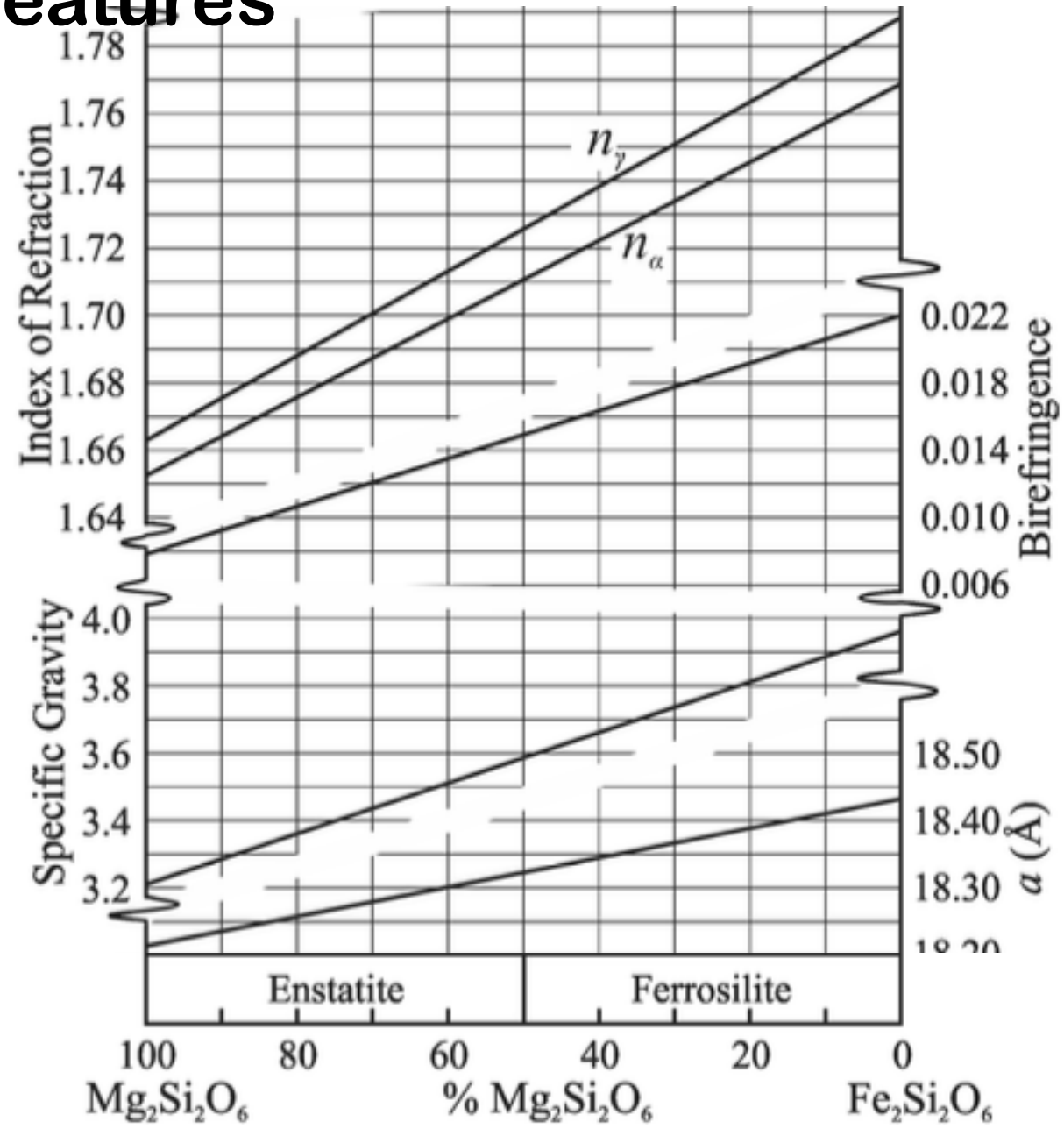
Optical properties

- ✓ Color: Varies with composition. Mg-rich enstatite is colorless or with very pale pinkish to greenish pleochroism; more Fe-rich varieties are darker colored with reddish to greenish pleochroism.
- ✓ Birefringence: Mędium; Vary systematically
- ✓ Interference colors: Vary with composition; 1st order gray to 1st order red-orange to red
- ✓ Cleavage: 2 sets, intersects at ~90°
- ✓ Distinctive features: Pleochroism and cleavage.

Orthopyroxene: Distinguishing features

Physical and optical properties vary systematically with composition

- Specific gravity
- Refractive index
- Birefringence



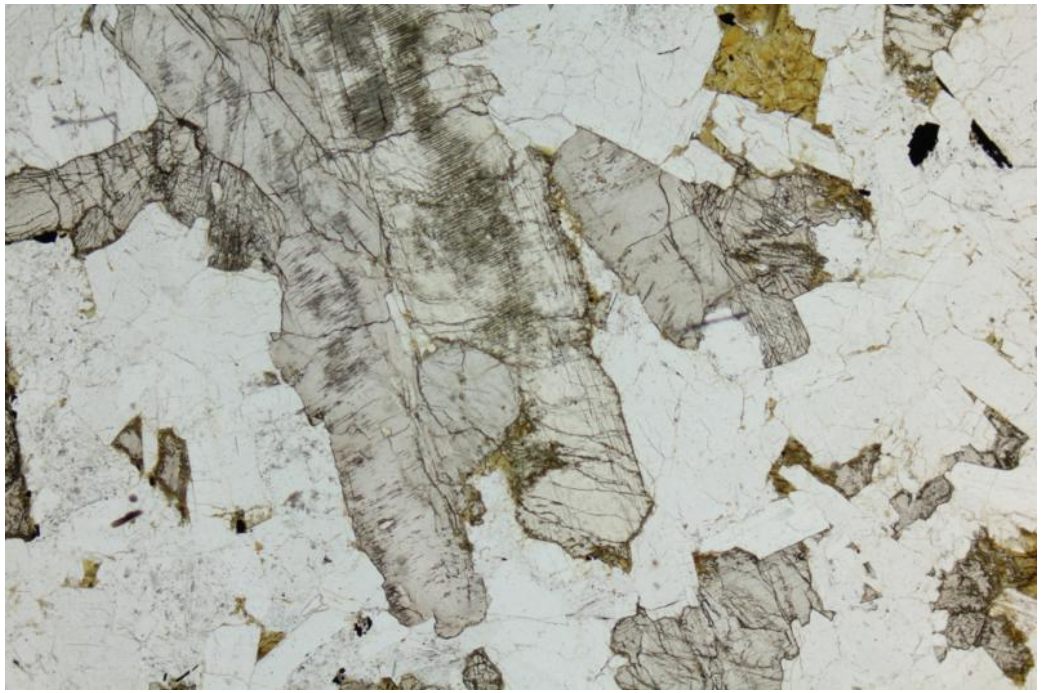
Clinopyroxene: Distinguishing features

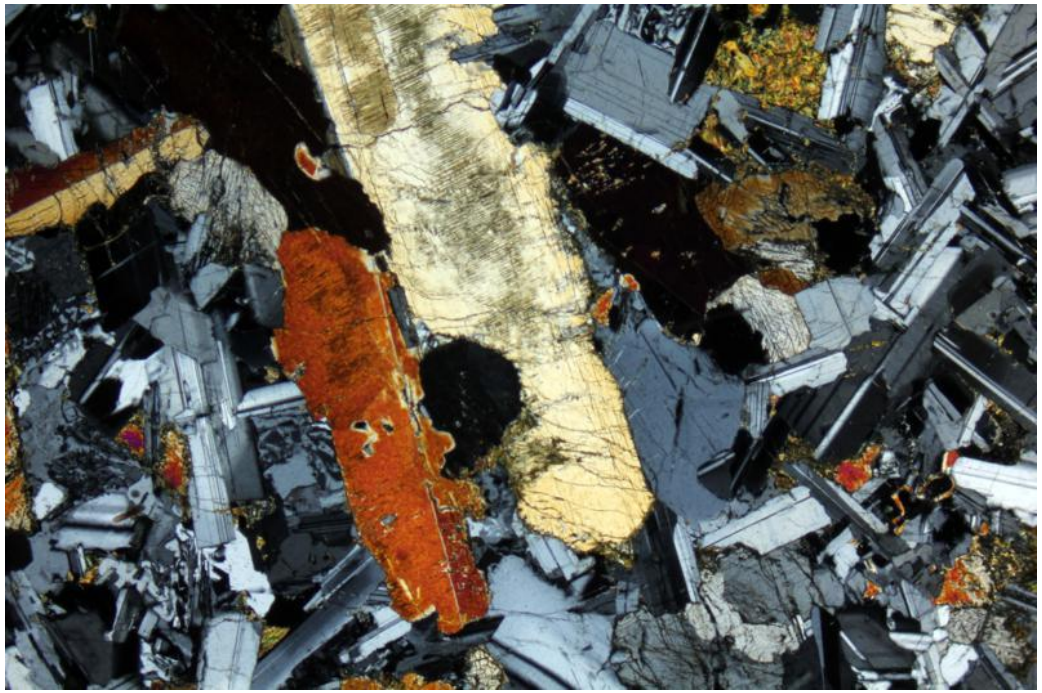
Dark → clinopyroxene

Distinguishing features in hand specimen:

- Color: Pale green (Mg rich) to black (Fe rich), usually dark
- green, **greenish black, or brownish black**.
- Vitreous luster
- Streak: White to gray
- 2 sets good cleavage intersecting at right angles
- Euhedral crystals; elongated in nature

Clinopyroxene: Distinguishing features





Optical properties

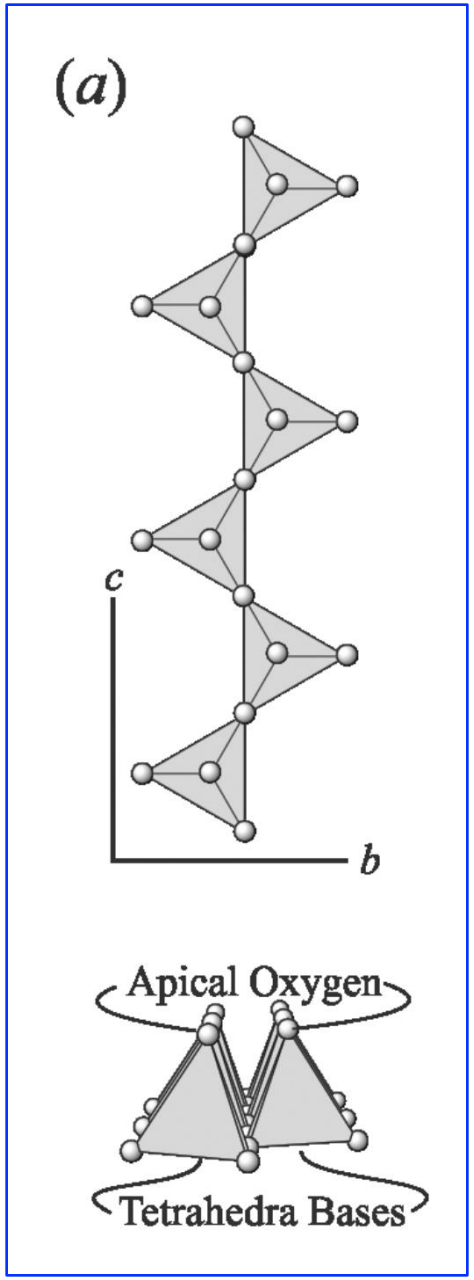
- ✓ Color: Colorless, gray, pale green, pale brown, or brownish green. **Most common in the shades of green.** ***Fe-rich samples may be weakly pleochroic in the shades of green.***
- ✓ Birefringence: Medium to high; Vary with composition. Birefringence generally increases
- ✓ with increasing Fe content. Not a distinctive feature.
- ✓ Interference colors: Vary with composition; 2nd order yellow-blue-green
- ✓ Cleavage: 2 sets, intersects at ~90°
- ✓ Distinctive features: Greenish color in PPL, 2nd order interference color, cleavage.

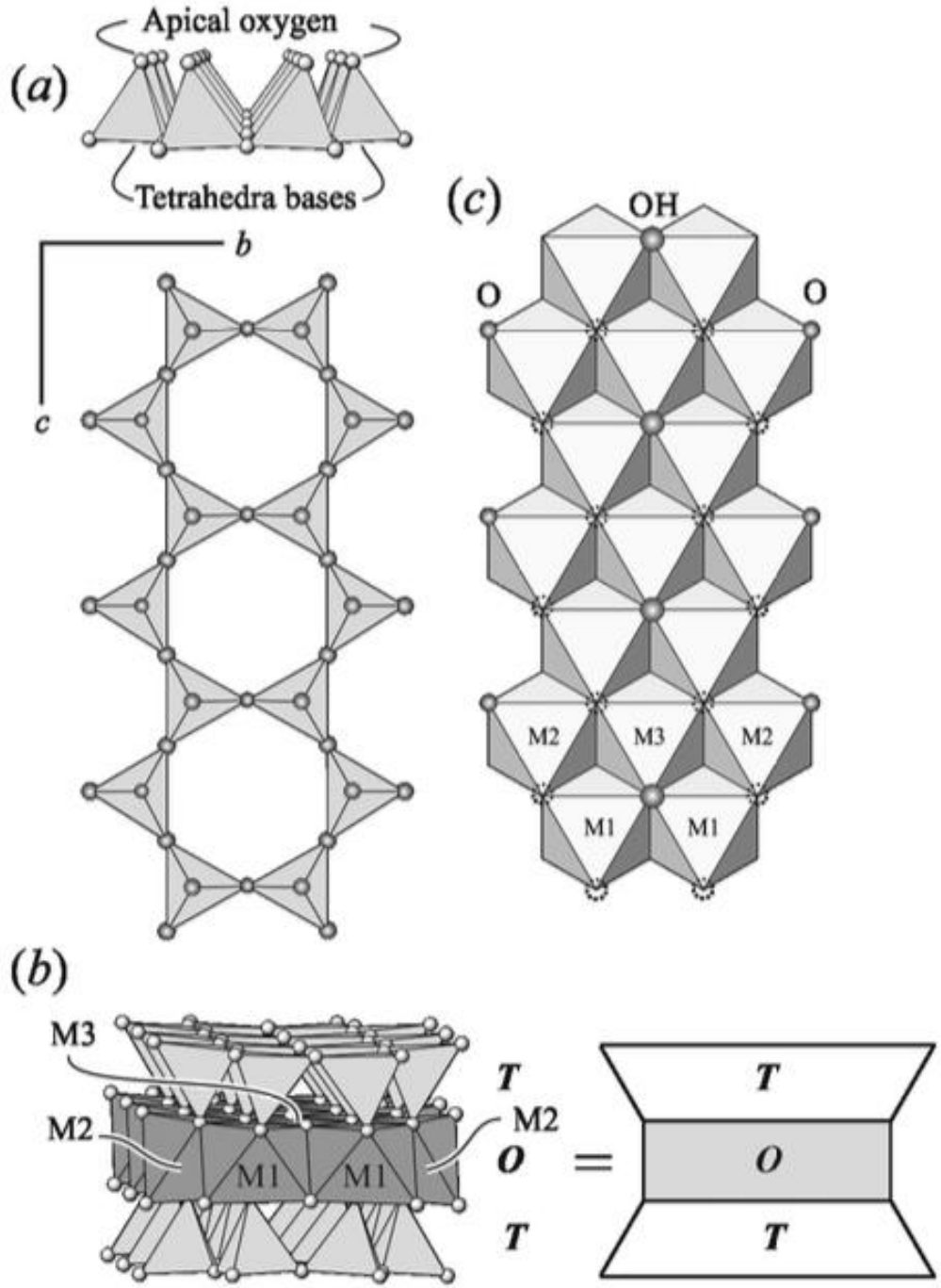
Double Chain Silicates (Inosilicates)

Most common mineral:
Amphibole group

General Formula:
$W_{0-1}X_2Y_5Z_8O_{22}(OH)_2$

Compare with the single chain silicates





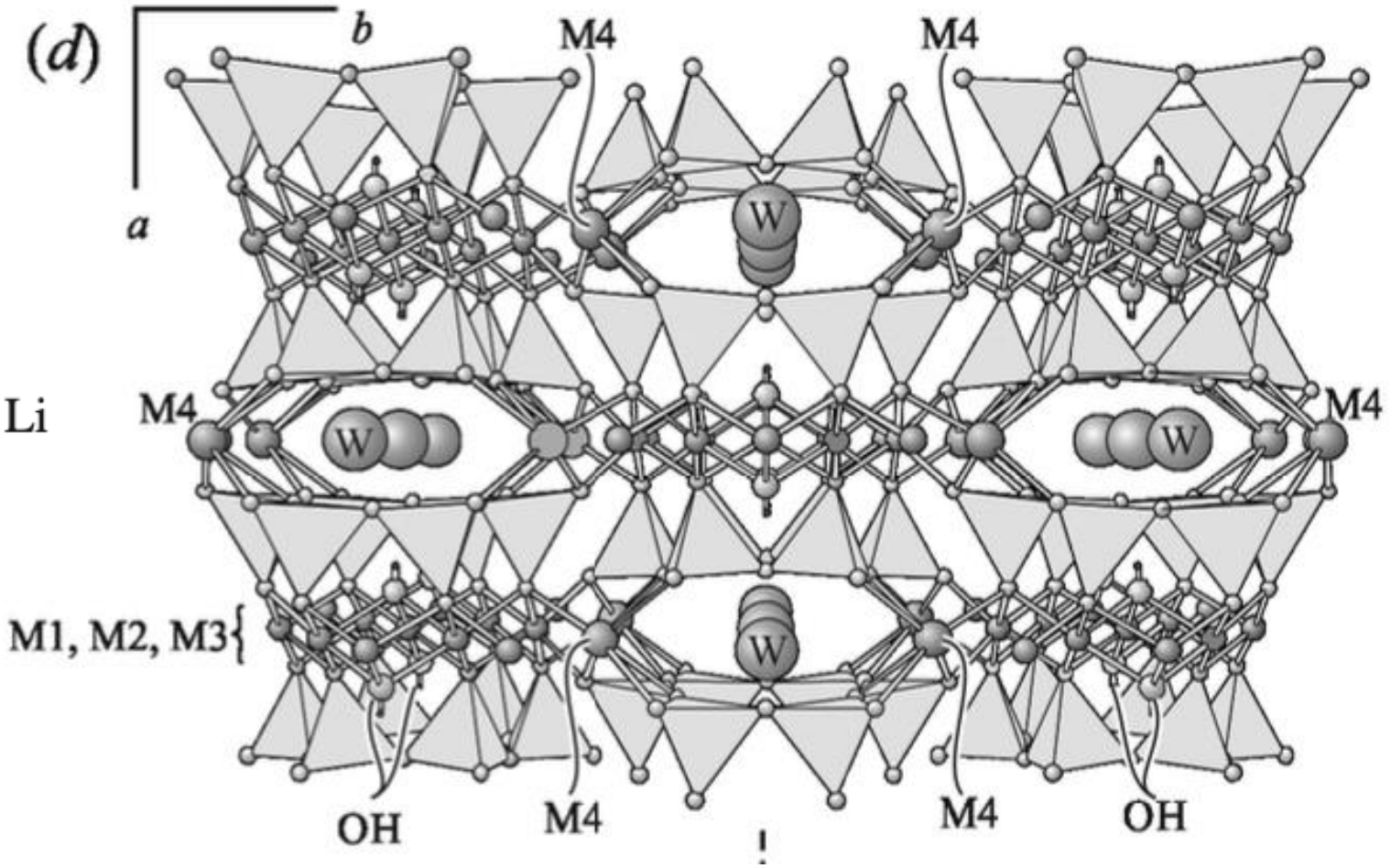
Double Chain Silicates (Inosilicates)

Most common mineral: **Amphibole group**

General Formula:

$W_{0-1}X_2Y_5Z_8O_{22}(OH)_2$

W = **Na**, □, K, Ca, Li
X = **Na**, **Ca**, **Fe^{2+}**, **Mg**, Mn^{2+}, Li
Y = **Mg**, **Fe^{2+}**, **Al**, **Fe^{3+}**, Mn^{2+}, Mn^{3+}, Ti^{4+}, Li
Z = **Si**, **Al**, Ti^{4+}
A = **$(OH)^-$**, **F^-**, **Cl^-**, **or O^{2-}**

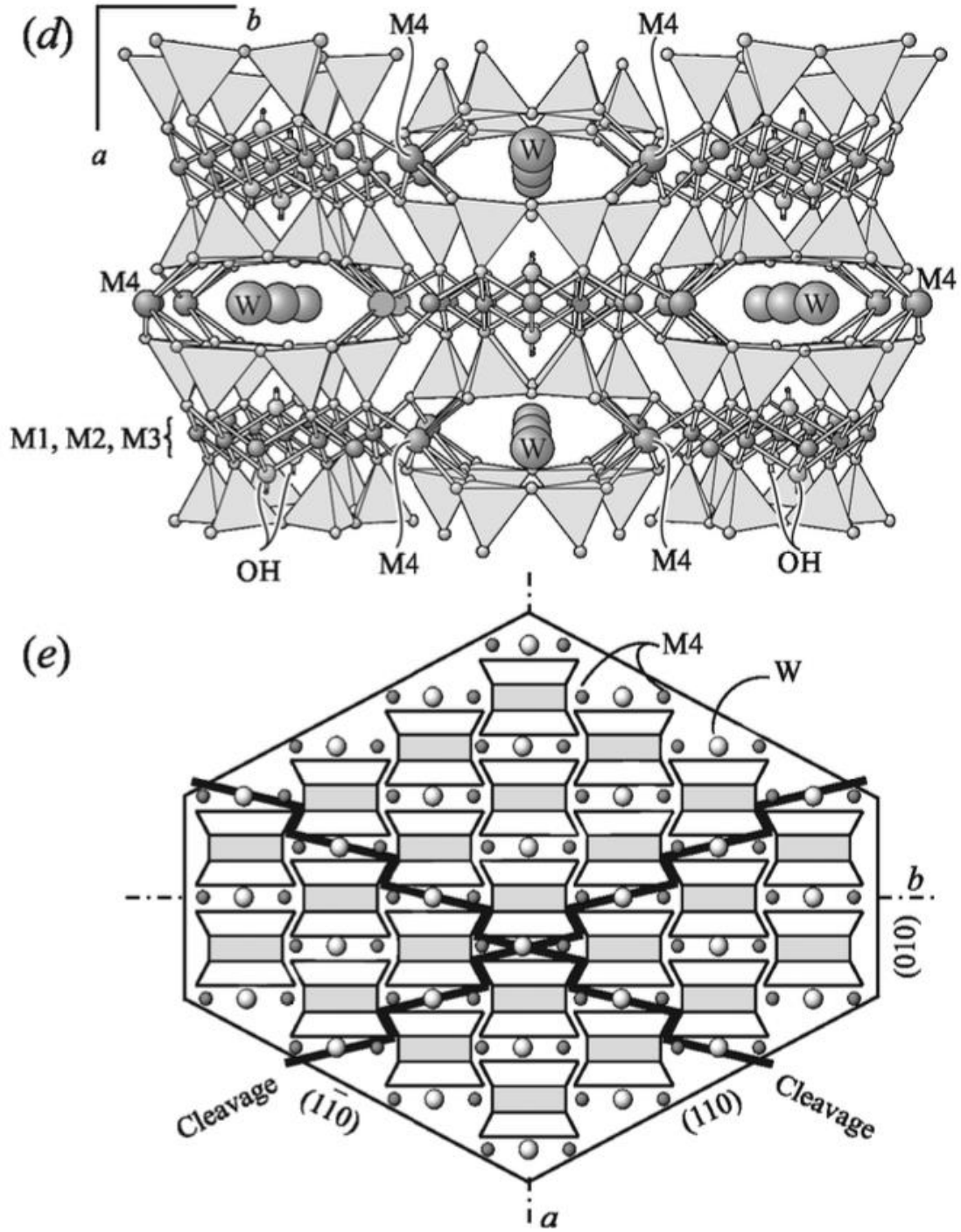


Double Chain Silicates (Inosilicates)

General Formula:

$W_{0-1}X_2Y_5Z_8O_{22}(OH)_2$

W = **Na**, □, K, Ca, Li
X = **Na**, **Ca**, **Fe^{2+}**, **Mg**, Mn^{2+}, Li
Y = **Mg**, **Fe^{2+}**, **Al**, **Fe^{3+}**, Mn^{2+}, Mn^{3+}, Ti^{4+}, Li
Z = **Si**, **Al**, Ti^{4+}
A = **$(OH)^-$**, **F^-**, **Cl^-**, **or O^{2-}**

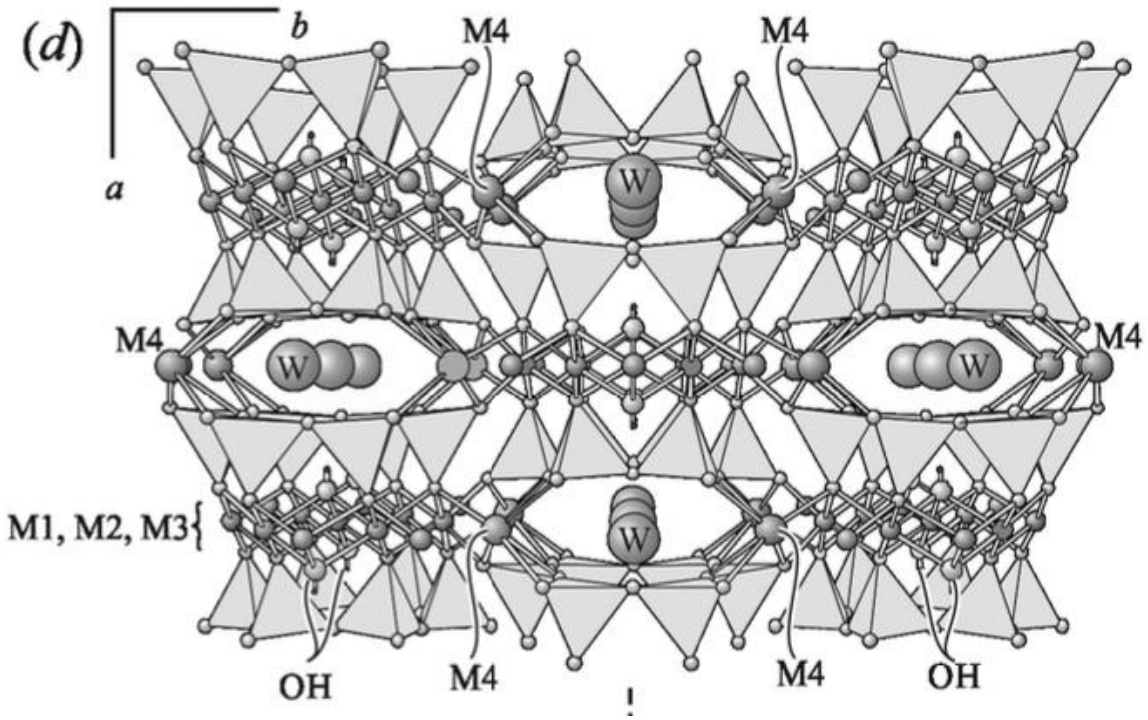


Double Chain Silicates (Inosilicates)

General Formula:

$W_{0-1}X_2Y_5Z_8O_{22}(OH)_2$

W = **Na**, □, K, Ca, Li
X = **Na**, **Ca**, **Fe^{2+}**, **Mg**, Mn^{2+}, Li
Y = **Mg**, **Fe^{2+}**, **Al**, **Fe^{3+}**, Mn^{2+}, Mn^{3+}, Ti^{4+}, Li
Z = **Si**, **Al**, Ti^{4+}
A = **$(OH)^-$**, **F^-**, **Cl^-**, **or O^{2-}**



- The W cations occupy the W structural sites.
- In some amphiboles, the W site is filled, in others it is partially or entirely vacant.
- The two **X cations** are located in the **M4 sites**. May have either 8- or 6-fold coordination, depending on the cation. If 8-fold, the X cations are usually Ca^{2+} or Na^+, and if 6-fold, the X cations are Mg^{2+} or Fe^{2+}.
- The five **Y cations** occupy the octahedral **M1, M2, and M3 sites**, which are the octahedral sites in the middle of the TOT strips.
- The eight **Z sites** are tetrahedral and usually contain Si and some Al.
- The **A in the formula** signifies additional anions, most commonly (OH)−. Because amphiboles contain hydroxyl, they are considered hydrous minerals.

Amphibole classification

Table 14.2 Abbreviated Amphibole Classification Based on the General Formula $W_{0-1}X_2Y_5Z_8O_{22}A_2$[a]

Group	W	X_2	Y_5	$Z_8O_{22}(OH)_2$	Mineral	Symmetry	Comment
Iron–magnesium		$(Mg,Fe)_2$	$(Mg,Fe)_5$	$Si_8O_{22}(OH)_2$	Anthophyllite	Orthorhombic	Orthoamphibole
		$(Mg,Fe)_2$	$(Mg,Fe)_3Al_2$	$Al_2Si_6O_{22}(OH)_2$	Gedrite		
		$(Mg,Fe)_2$	$(Mg,Fe,Ca)_5$	$Si_8O_{22}(OH)_2$	Cummingtonite–Grunerite	Monoclinic	Low-Ca clinoamphibole
Calcic		Ca_2	$(Mg,Fe)_5$	$Si_8O_{22}(OH)_2$	Tremolite–Actinolite		Ca clinoamphibole
	$(Na,K)_{0-1}$	Ca_2	$(Mg,Fe^{2+},Fe^{3+},Al)_5$	$(Si,Al)_8O_{22}(OH)_2$	Hornblende		
	Na	Ca_2	$(Mg,Fe)_4Ti$	$Si_6Al_2O_{22}(OH)_2$	Kaersutite		
Sodic–calcic	Na	CaNa	$(Mg,Fe)_5$	$Si_8O_{22}(OH)_2$	Richterite		Na–Ca clinoamphibole
	Na	CaNa	$(Mg,Fe)_4Fe^{3+}$	$Si_7AlO_{22}(OH)_2$	Katophorite		
Sodic		Na_2	$(Mg,Fe^{2+})_3(Al,Fe^{3+})_2$	$Si_8O_{22}(OH)_2$	Glaucophane–Riebeckite		Na clinoamphhibole
	Na	Na_2	$(Mg,Fe^{2+})_4(Al,Fe^{3+})$	$Si_8O_{22}(OH)_2$	Eckermannite–Arfvedsonite		

[a]The W cations occupy the W sites, X cations the M4 sites, Y cations the M1, M2, and M3 sites (Figure 14.12); A is assumed to be (OH).

Source: Adapted from Hawthorne and others (2012)

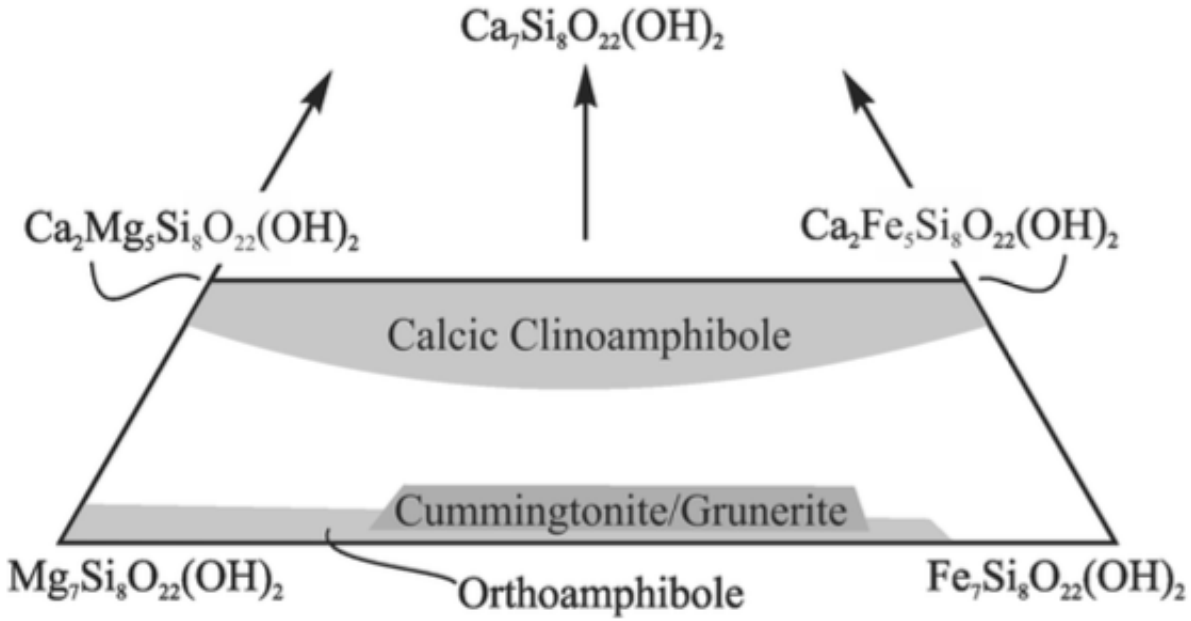
Amphibole classification

Table 14.3 Simple Substitutions in the Amphiboles

Formula	Structural Site	Cations
W	W	Na^{+}, K^{+}
X	M4	Ca^{2+}, Mg^{2+}, Fe^{2+}
Y	M1, M2, M3	Mg^{2+}, Fe^{2+}
Y	M1, M2, M3	Al^{3+}, Fe^{3+}
Z	Tetrahedral	Si^{4+}, Ti^{4+}

Table 14.4 Selected Coupled Substitution Schemes in Clinoamphiboles

W	X	Y	Z	=	W	X	Y	Z
□			Si^{4+}	=	Na^{+}			Al^{3+}
		(Fe^{2+},Mg^{2+})	Si^{4+}	=			(Al^{3+},Fe^{3+})	Al^{3+}
			Si^{4+}	=	Na^{+}			Al^{3+}
	Ca^{2+}			=	Na^{+}	Na^{+}		
	Ca_2^{2+}	(Fe^{2+},Mg^{2+})		=	Na^{+}	Na_2^{+}	Al^{3+}	



Amphibole classification: Hornblende

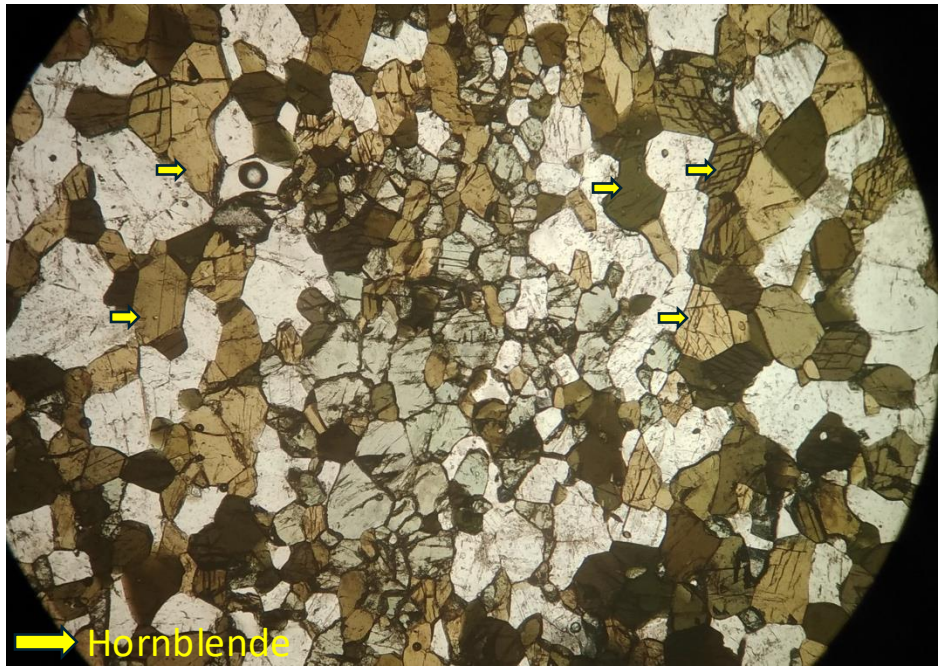
Hornblende Formula: $(Na,K)_{0-1}Ca_2(Mg, Fe^{2+}, Al)_5(Si,Al)_8O_{22}(OH)_2$

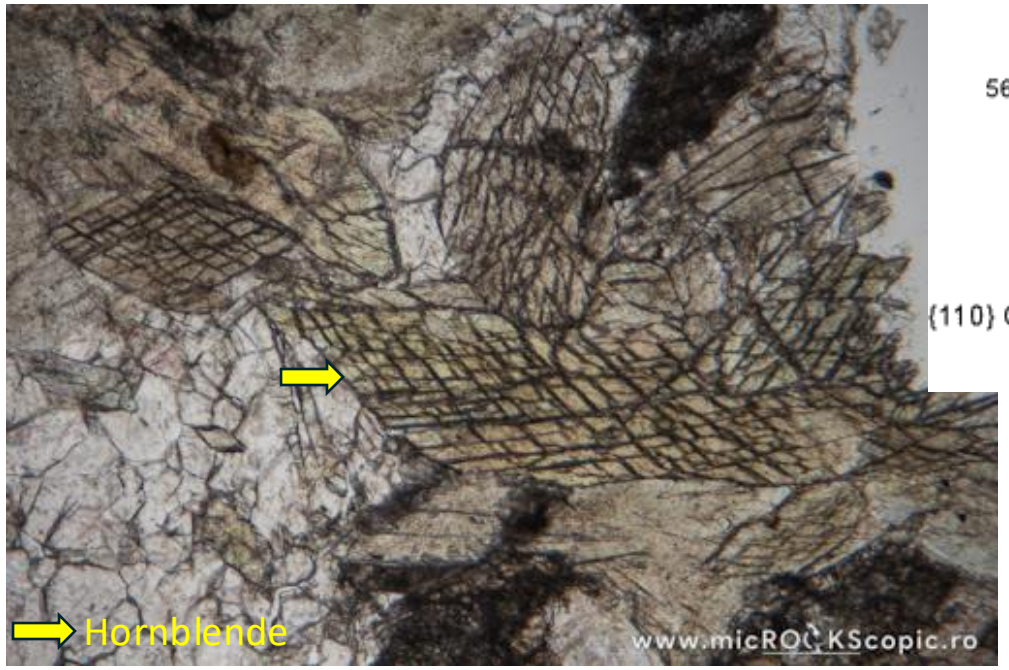
Hornblende (Black grains)

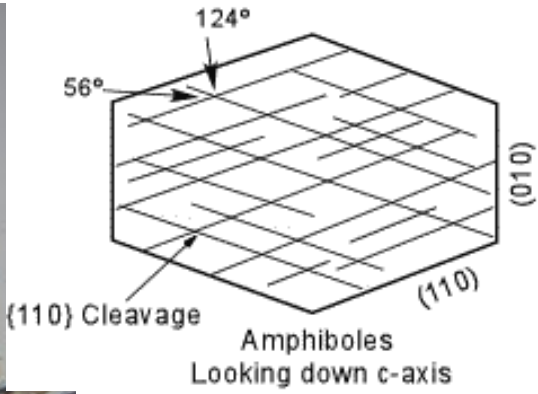
Distinguishing features in hand specimen:

- Color: Most commonly **green, dark green, black**, also
- brown.
- Vitreous luster
- Streak: Gray to greenish gray
- 2 sets good cleavage intersecting at 124° and 56°
- Fragments are usually elongated
- Irregular fracture; Brittle

Hornblende: Distinguishing features



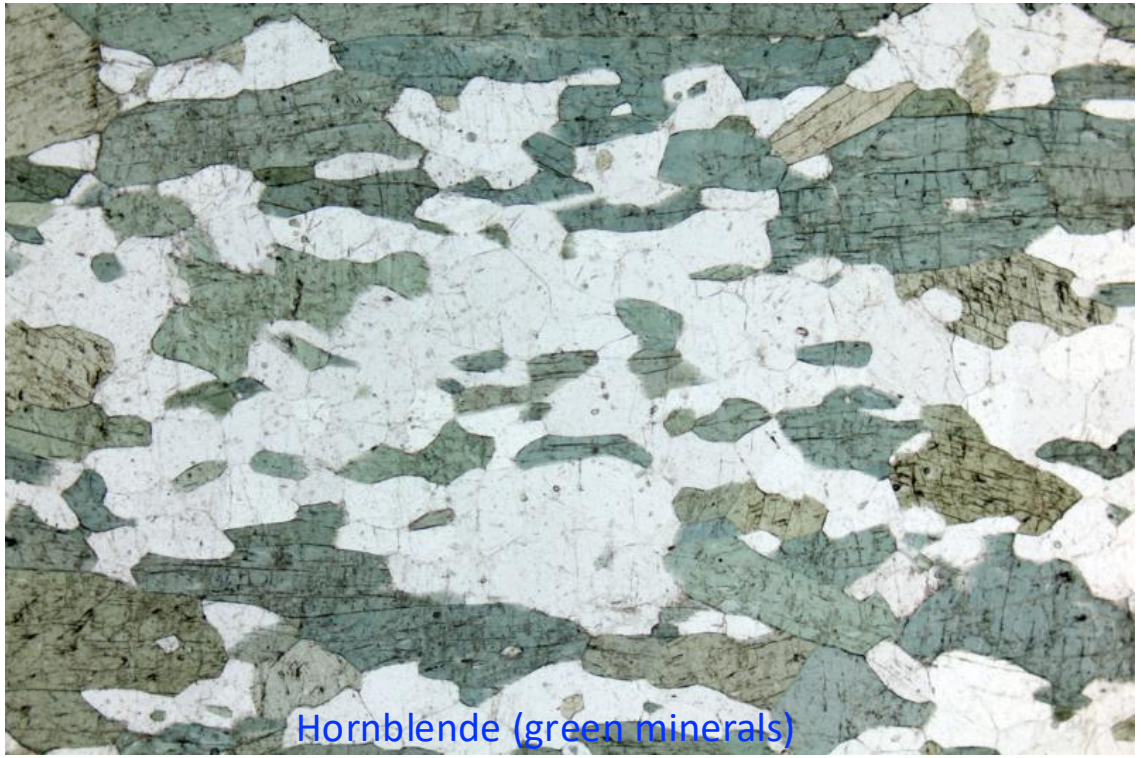




Optical properties

- ✓ Color: Distinctly colored, **usually in shades of green, bluish green**, or brown.
- ✓ Pleochroism: Distinctly pleochroic in the shades of green and brown.
- ✓ Birefringence: Medium to high; Vary with composition. Birefringence generally increases with increasing Fe content.
- ✓ Interference colors: 2nd order green-brown. Mineral color may mask interference color.
- ✓ Cleavage: 2 sets, intersects at ~124° and 56°.
- ✓ Distinctive features: Pleochroism, Intersecting cleavage at ~124° and 56°.

Hornblende: Distinguishing features



Optical properties

- ✓ Color: Distinctly colored, **usually in shades of green, bluish green**, or brown.
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- ✓ Interference colors: 2nd order green-brown. Mineral color may mask interference color.
- ✓ Cleavage: 2 sets, intersects at ~124° and 56°.
- ✓ Distinctive features: Pleochroism, Intersecting cleavage at ~124° and 56°.

Amphibole: Occurrence and uses

Amphiboles occur in a very wide variety of igneous and metamorphic rocks

As understood so far, amphiboles can have a varied range of chemical compositions

The chemical composition of amphiboles can be directly linked with the physico-chemical compositions in which the amphibole formed

Amphibole is an important mineral for petrologists as the chemical composition of the mineral can reveal the formation and evolution of the rock

References

✓ Introduction to Mineralogy, W. Nesse, Oxford University Press

Chapter 14 (Chain silicates)

(Read the related portions that have been discussed in the class)