Silicates (I)

Monday, October 12, 2020 7:27

Time on task: 3 hours (material posted on Nov 2nd, Student hour: Monday Nov 16th and Wednesday Nov 18th)

Goals:

Upon completion of lecture 13 you should be able to
- Describe the various rock classifications
- Describe the structures of the ortho-, soro-, cyclo- and inosilicates
- Be familiar with the chemical compositions of the minerals described in this section
- Be able to recognize these minerals in thin section

This lecture is complemented with your lab #9 and lab #10.

1. Introduction - Rock classifications

To classify the various types of silicates, we use a structural classification. Why?
1) Silicates have various forms (needles, flakes, cube,…) due to the arrangement of the SiO_4^{4-} tetrahedra
2) Tetrahedra link via cations:
- Nature of the cation depends on the arrangement of the tetrahedra
- Nature of the cation: controls some of the physical properties (Ex.: color, density)

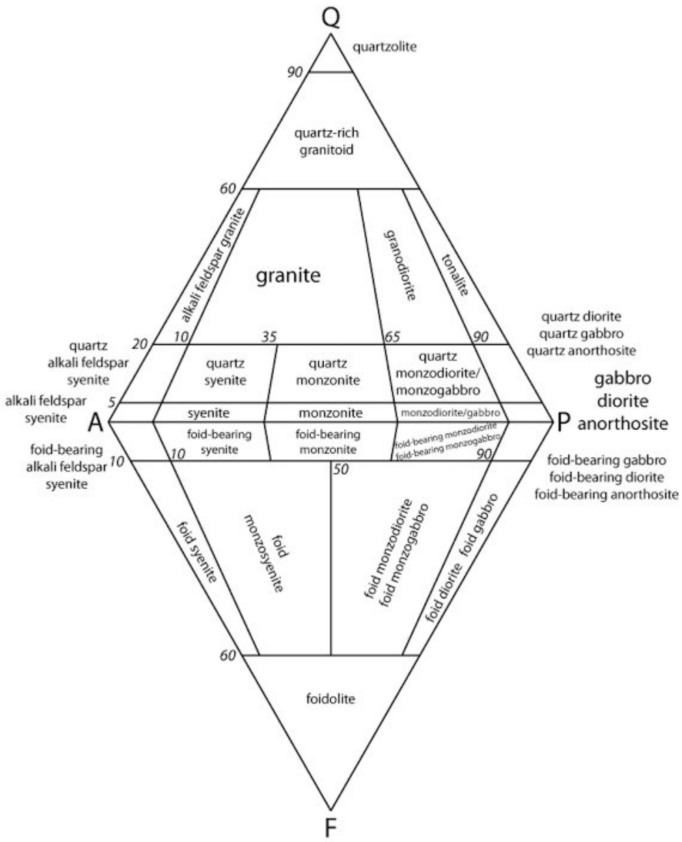
1.1. Igneous rocks.

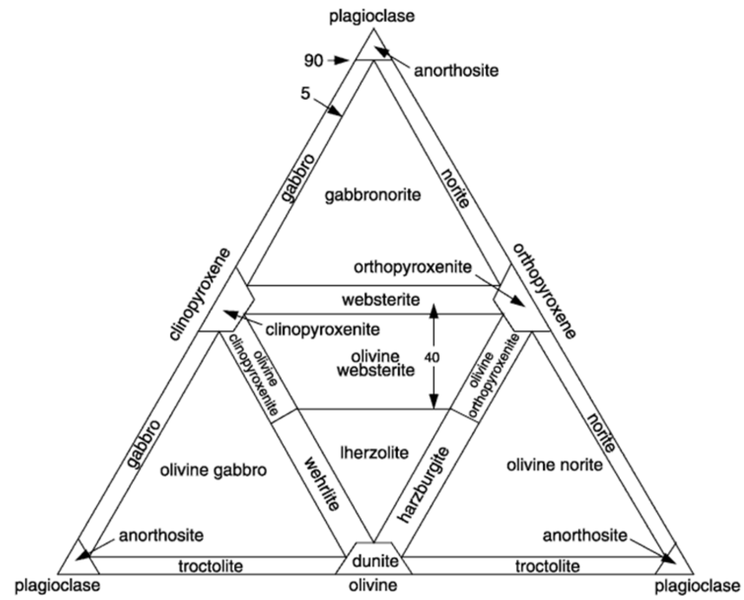
Igneous rocks = mostly silicates (O and Si are the most abudant elements in the Earth's crust)

Common silicate in igneous rocks: quartz, K-feldspar, plagioclase, muscovite, biotite, Ca-amphibole (e.g.: hornblende), Ca-pyroxene (e.g., augite), orthopyroxene and olivine, feldspathoids (e.g., leucite, nepheline)

Classifications:
- **Plutonic rocks** = **Streckeisen classification** = modal classification (volume of rock occupied by each mineral: obtained by "point counting").

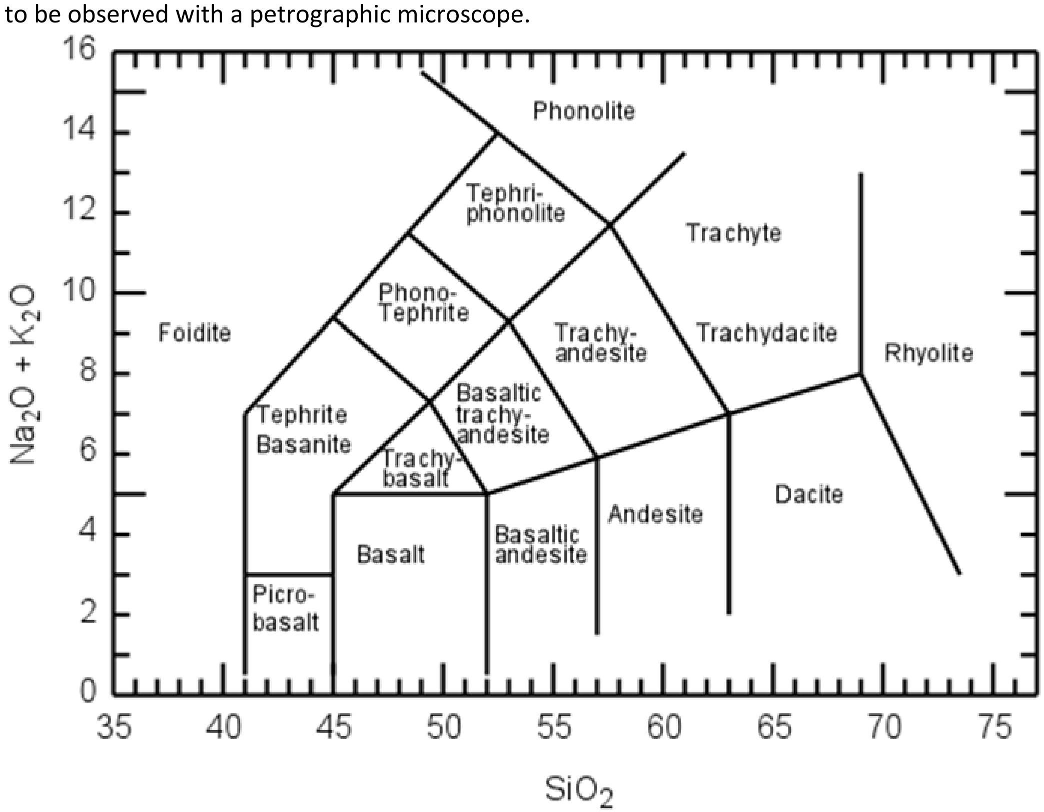
We distinguish between the Streickeisen classifications for





for fel**sic rocks: QAPF** and for **mafic and ultramafic rocks**

- **Volcanic rocks** = **TAS classification** = chemical classification ("total alkali as function of SiO2"). We usually can't use a modal classification for volcanic rock because of the presence of glass and/or of the size of the grains often too small to be observed with a petrographic microscope.



1.2. Terrigenous sedimentary rocks.

- Always stratified (layered)
- Mostly silicate minerals
- **Simple classification**: based on grain size
- **Most common silicates**: quartz, feldspar and clay + zircon, tourmaline > garnet, staurolite, biotite > epidote, kyanite, sillimanite, titanite, zoisite > amphibole, pyroxene, andalusite > olivine

Phi Units*	Size	Wentworth Size Class	Sediment/Rock Name
		Boulders	Sediment: GRAVEL Rcck RUDITES: (conglomerates, breccias)
-8	256 mm	Cobbles	
-6	64 mm	Pebbles	
-2	4 mm	Granules	
-1	2 mm	Very Coarse Sand	Sediment: SAND Rccks: SANDSTONES (arenites, wackes)
0	1 mm	Coarse Sanc	
1	1/2 mm	Medium Sand	
2	1/4 mm	Fine Sand	
3	1/8 mm	Very Fine Sand	
4	1/16 mm	Silt	Sediment: MUD Rccks: LUTITES (mudrocksi
8	1/256 mm	Clay	

* Udden-Wentworth Scale

1.3. Metamorphic rocks.

The classification is mostly based on texture (foliated versus non foliated) and grain size (that controls the luster of the rock: smaller the grain size is, more dull appears the rock).

Rock Name		Texture	Grain Size	Comments	Parent Rock
Slate	Increasing Metamorphism	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite			Fine	Breaks along wavey surfaces, glossy sheen	Slate
Schist			Medium to Coarse	Micas dominate, scaly foliation	Phyllite
Gneiss			Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite, or volcanic rocks
Marble		Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite			Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Anthracite			Fine	Shiny black organic rock that may exhibit conchoidal fracture	Bituminous coal

Orthosilicates 1

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2. Orthosilicates = nesosilicates

"Nesos" = island: silica tetrahedra isolated by other cations
Important nesosilicates: Olivine, zircon, garnet and Alumino-silicates

2.1. Olivine

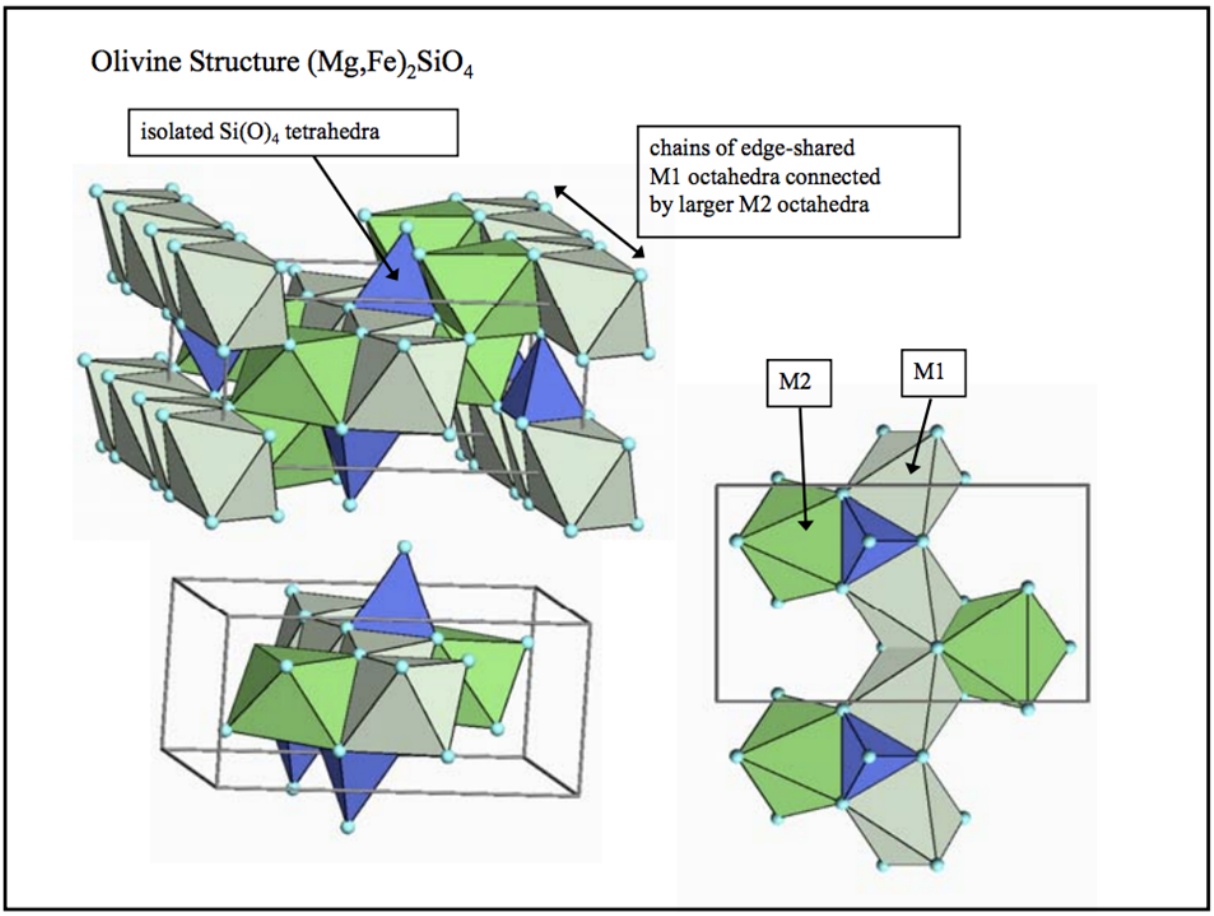
- **What?**

Cations between the tetrahedra: Mg^{2+} and/or Fe^{2+}
$(MgFe)_2SiO_4$: two end-members: $Mg_2SiO_4 \leftrightarrow Fe_2SiO_4$
forsterite ↔ fayalite

Olivines = solid solution between two end-members (ferrous and magnesium) : Substitution of Fe by Mg (or Mg by Fe) can be total (extensive substitution)
Notation: Fo_{85} = 85% of Mg_2SiO_4 (forsterite) in the solid solution = $(Mg_{.85}Fe_{.15})_2SiO_4$

- **Where?**
- Basic and ultrabasic rocks
- Major constituent of the upper mantle
- Almost pure forsterite (>Fo_{95}) in some magnesium marble
- Almost pure fayalite (<Fo_{10}): rare but exist in some granites

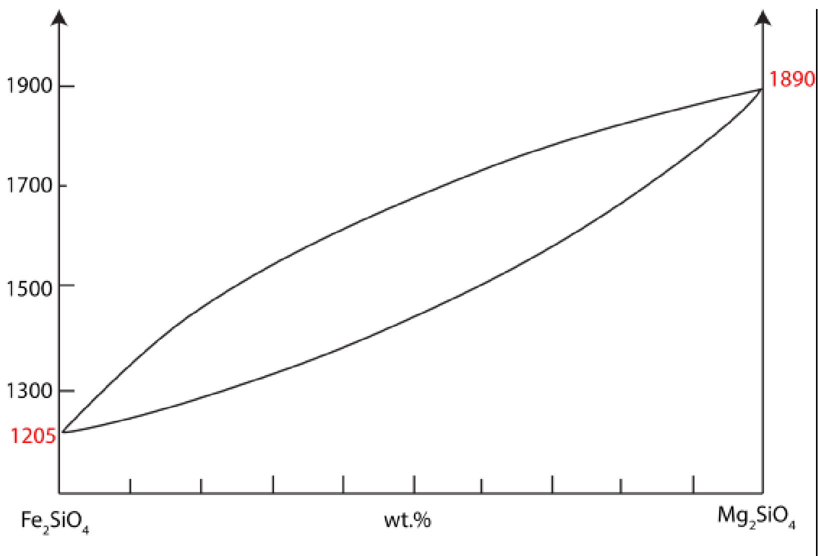
- **Structure**

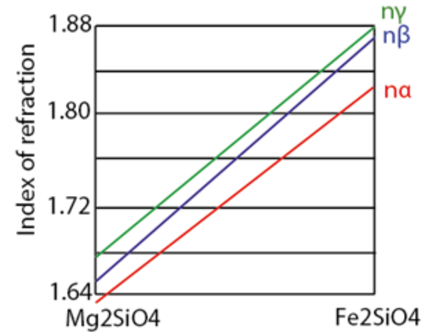


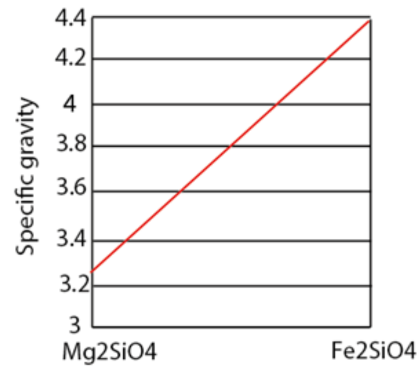
Credits: James J. Wray http://www.wray.eas.gatech.edu/

Chain of edge-shared octahedra (M1 sites) connected by larger (M2) octahedra (Fe and Mg occupy both sites with no preference). To visualize the forsterite structure in 3D, open forsterite.html

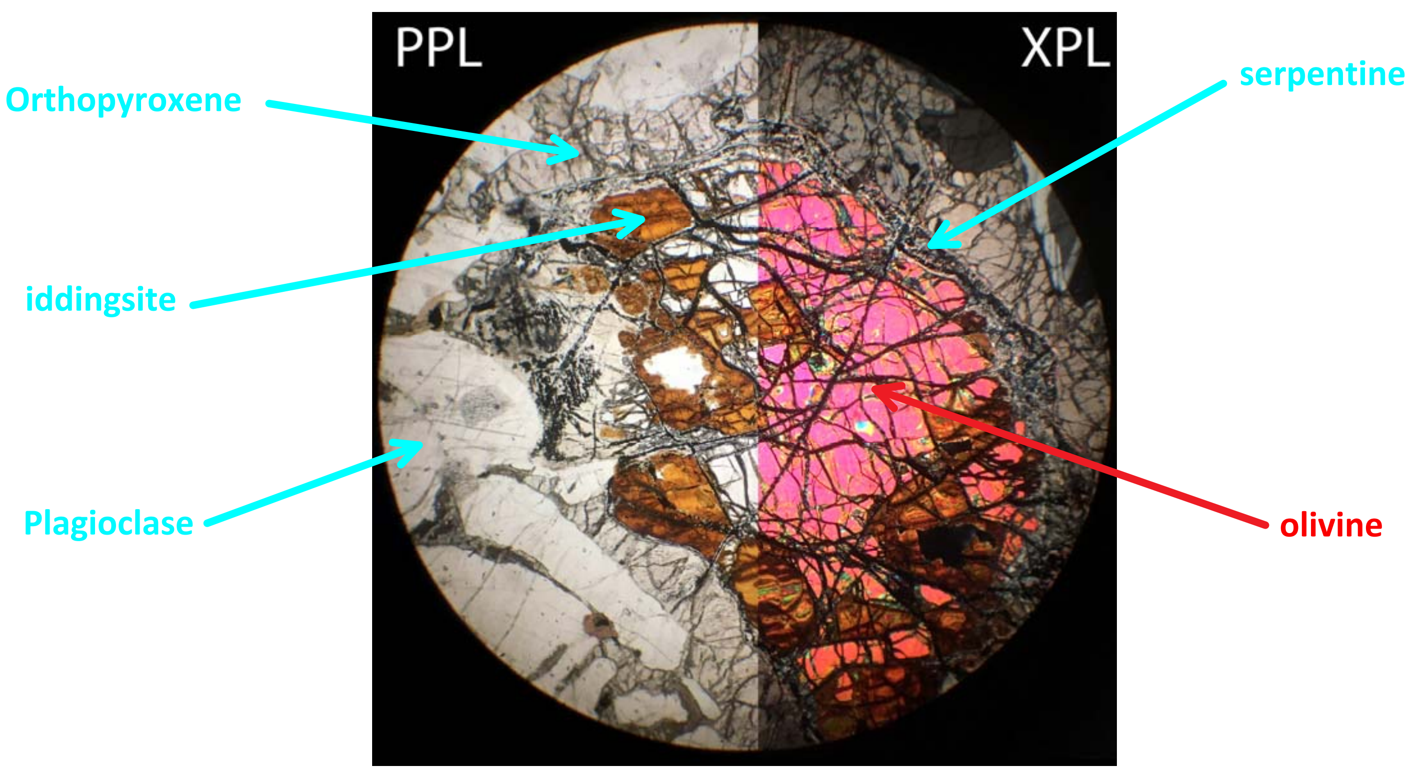
Olivine forms a complete a solid-solution. The physical, but also optical properties of olivine are affected by its composition.







- **In thin section**
- Strong relief
- Colorless
- No cleavage but irregular fracture are common
- Can be partly replaced by iddingsite (orange in PPL) or serpentine (often filling the fractures).
- Vivid second order interference colors



Plane (PPL) and crossed (XPL) polarized images of a thin section centered on a olivine grain- FoV = 4.5mm

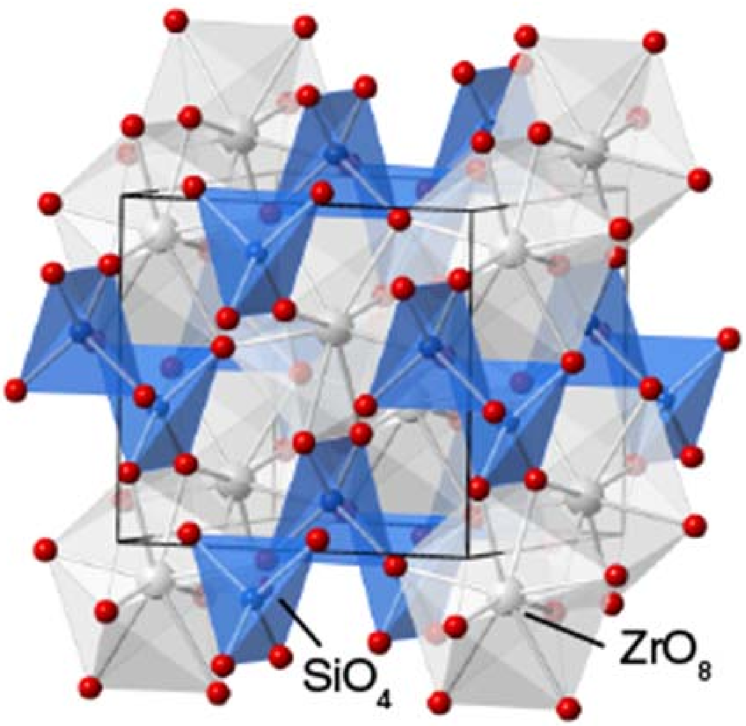
2.2. Zircon

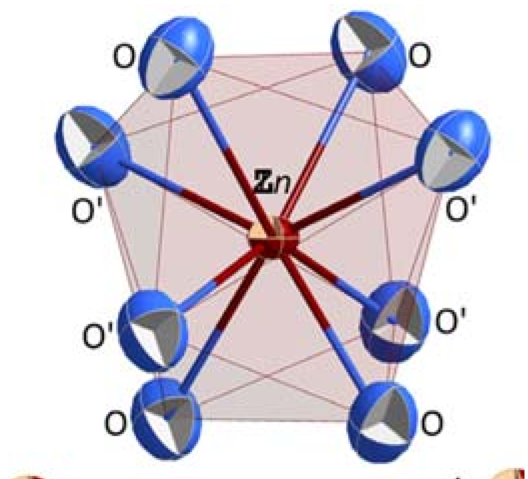
- **What? $ZrSiO_4$**
- Zr can be substituted by Hf, U or Th but complete substitutions are rare (simply because those elements are rare)
- U and Th are radioactive elements: allow the dating of rocks: T*he oldest zircon is 4.4 Gy (Australia; discovered in Feb. 2014) vs. oldest rock: 4.03 Gy vs. oldest fossil: 3.4 Gy vs oldest proof of life is 4.1Gy? (DNA preserved in fluid inclusion in halite– Sep. 2015)*

- **Where?**
- In granitoid (quartz + feldspar)
- Zircon: extremely resistant to alteration => in detritic sedimentary rocks
- As inclusion in biotite

- **Structure**

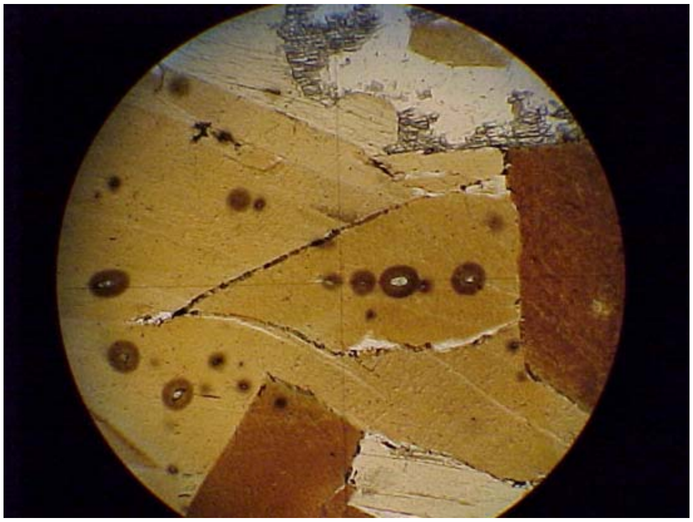
Zr is a large cation. It's coordination number is CN = 8. The crystallographic sites for Zr look like deformed cube. Zircon belongs to the tetragonal system.





- **In thin section**
- Extreme positive relief
- Colorless/ pale brown
- Often in inclusion in biotite
- Third order birefringence colors.

Plane (PPL) polarized image *of a grain of biotite with inclusion of zircon. The black circles around the inclusions are called "pleochroic hallo" and are due to the radioactive decay of the radioactive elements contained in zircon (U, Th, Hf). Before the development of the modern analytical techniques, the thickness of these hallo where used to estimate the age of the rock: thicker is the hallo, more time the radioactive elements had to decay. FoV = 0.4mm*



Orthosilicates 2

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2.3. Garnet

- **What? $X_3^{2+}Y_2^{3+}(SiO_4^{4-})_3$**
  - Aluminous garnet: Y = Al (= garnet with no calcium)
  - $Mg_3Al_2(SiO_4)_3$: **py**rope
  - $Fe_3Al_2(SiO_4)_3$: **al**mandine
  - $Mn_3Al_2(SiO_4)_3$: **sp**essartine

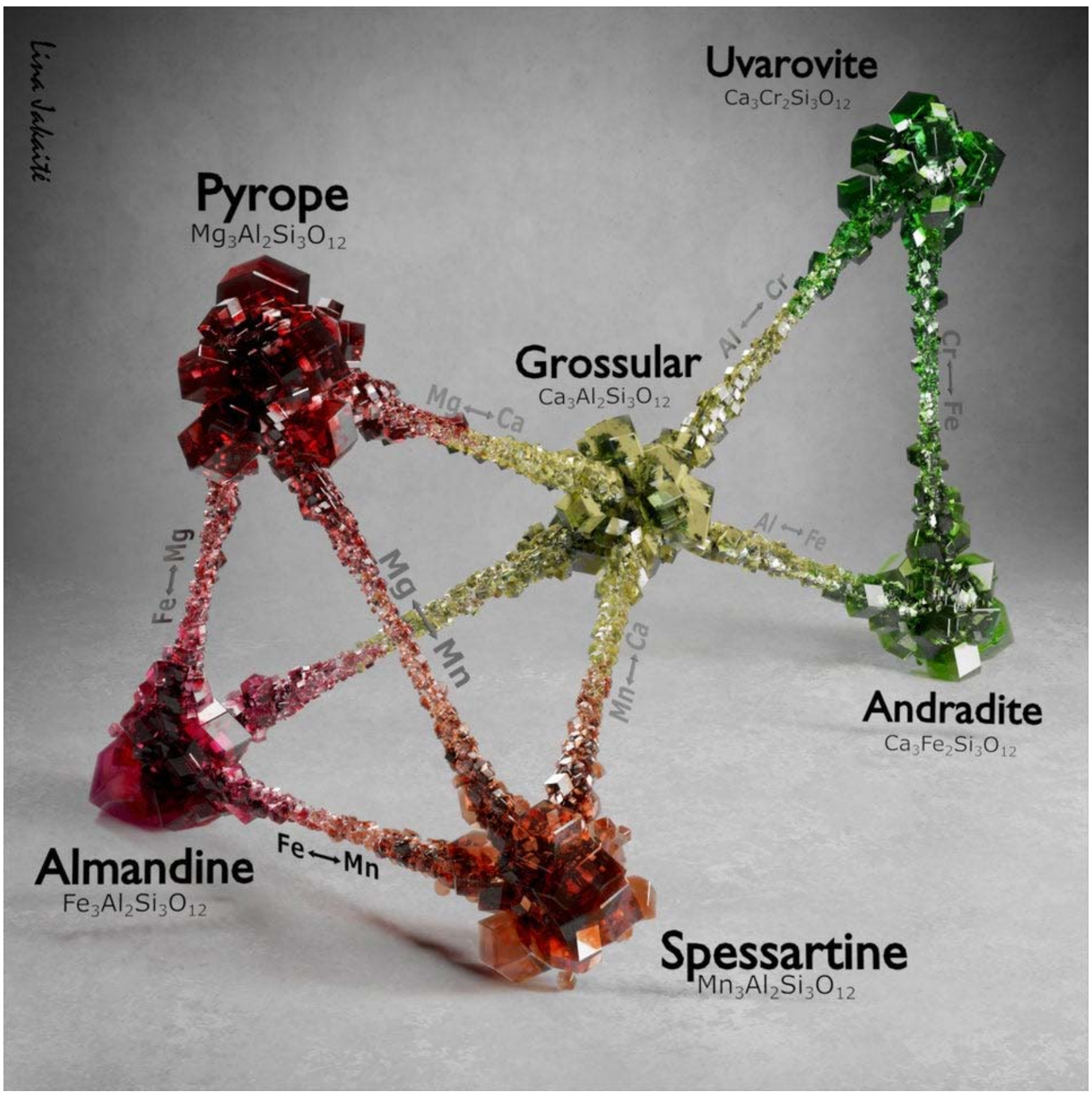
  → **Pyralsp**ite group

  Extensive substitution of Mg, Fe and Mn most common: ss Pyrope -Almandine or ss almandine-spessartine

  - Calcic garnet: X = Ca (= garnet with calcium)
  - $Ca_3Cr_2(SiO_4)_3$: **u**varovite
  - $Ca_3Al_2(SiO_4)_3$: **gr**ossular
  - $Ca_3Fe_2(SiO_4)_3$: **and**ratite

  → **Ugrand**ite group

  most common: ss grossular and andratite



Credits: Strike-dip.com

Pyraspite garnet and ugrandite garnet are extensive to complete solid-solution between their three end-embers. Limited solid-solution can exist between Pyralspite and ugrandite, usually with grossular.

- **Where?**

- Pyrope-rich garnet (Mg):
  In peridotite at depth > 90 km (upper mantle)
  In metabasite (high pressure grade – subduction zone)

- Almandine-rich garnet (Fe):
  in metamorphic clay (micashistes, metapelites – subducted sediments)
  In gneiss

- Spessartine-rich garnet (Mn): + rare
  In dikes from Al-rich granites

- Grossular-rich garnet (Ca): in metamorphosed carbonates
  around plutons (= skarns)

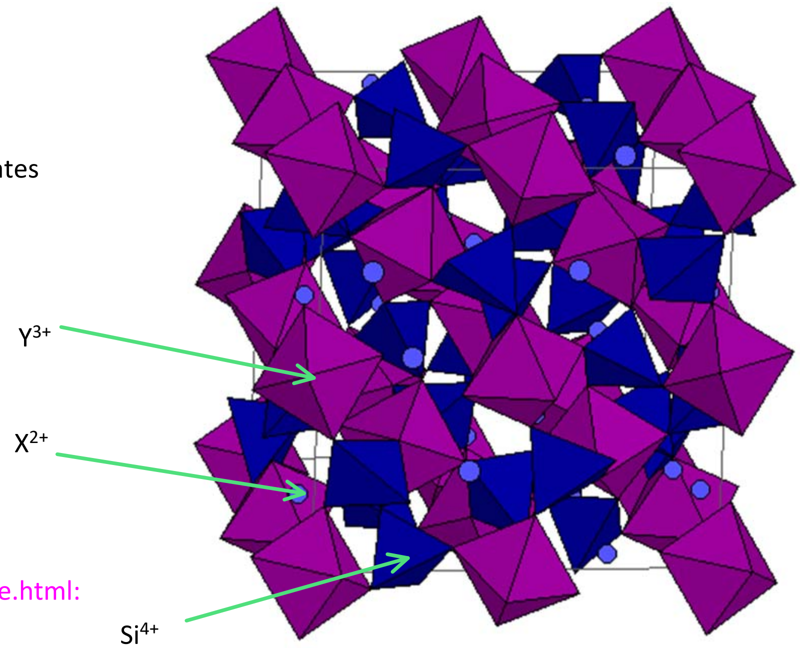
- Uvarovite & Andradite: anecdotal

- **Structure**

  System: isometric

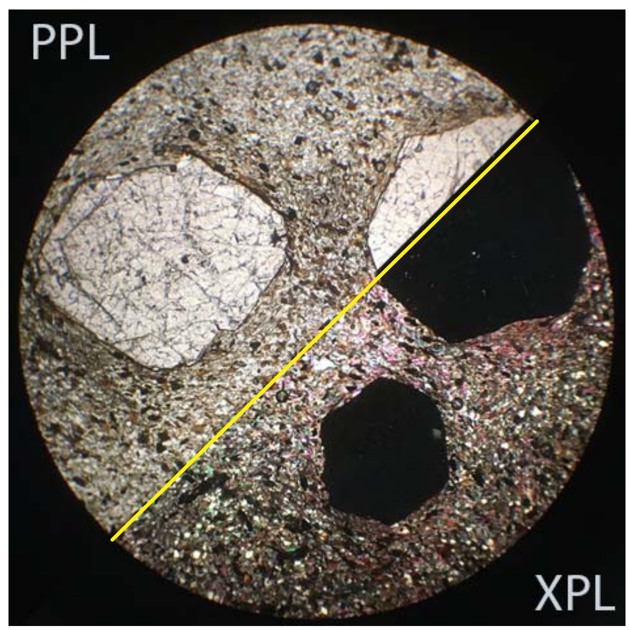
  Si^{4+}: tetrahedra (CN = 4)
  Y^{3+}: octahedra (CN = 6)
  X^{2+}: CN = 8 (not represented here)

  To visualize the garnet structure in 3D, open almandine.html:
  Si: dark blue, Al: light blue, Fe: brown.



- **In thin section**

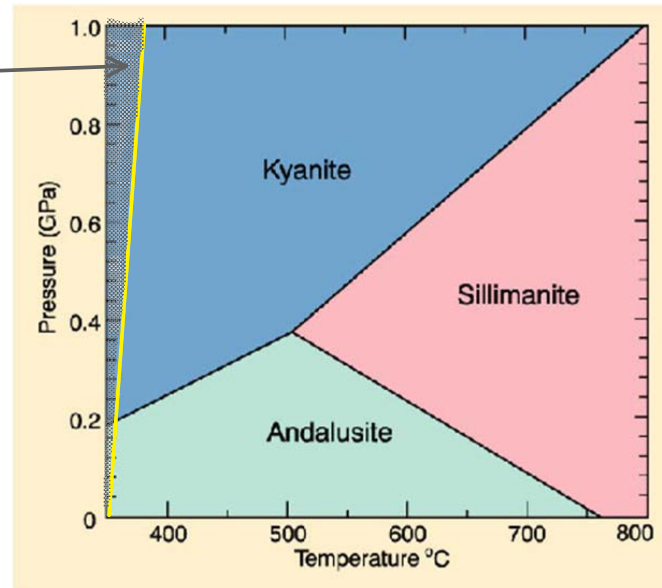
- Strong relief
- Colorless or pale colors (pink, brown, green, yellow)
- No cleavage - can contain inclusions
- Usually isometric
- Common euhedral habit (Equant)



Thin section picture of a micaschist with porphyroblasts of garnet (UUOP37 - FOV = 4.5 mm)

2.4. Alumino-silicates

Conditions do not exist on Earth



- **What? Al_2SiO_5**

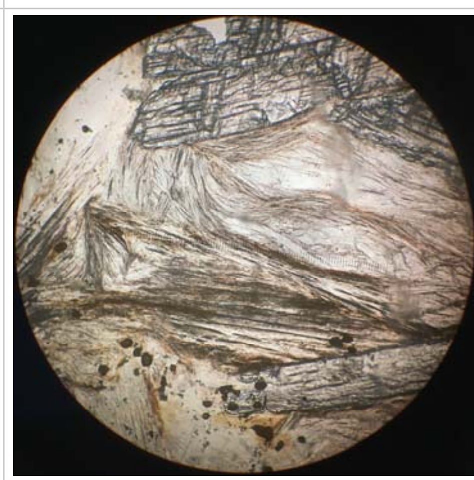
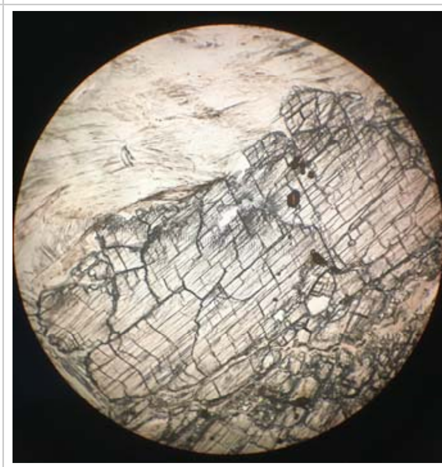
  3 polymorphs: Andalusite, sillimanite and kyanite.

- **Where?**
  - Exclusively in metamorphic rocks
  - The protolith must be rich in Al: mostly clays and pelites
  - Indicator of metamorphic conditions

- **Structure**

  $Al_2SiO_5 = Al_2OSiO_4$: they are oxygen outside of the silica tetrahedra: O's do the link between the tetrahedra

- **In thin section**

Andalusite	Sillimanite	Kyanite
Orthorhombic	**Orthorhombic**	**Triclinic**
- colorless - Moderate relief - 1st order birefringence colors - Potential presence of graphite in the core (Chiastolite) - Positive elongation - Prismatic habit	Very often **fibrous** = fibrolite -moderate relief -colorless - low second order colors - parallel extinction	- Strong relief - 1 Perfect cleavage and one very good cleavage - Second-order interference colors. - Inclined extinction - Prismatic habit
 PPL image of Chiastolite - *Credits: Tanis Coralee Leonhardis:*	 PPL image of fibrolite (the mineral with strong relief on the top is kyanite) FoV = 0.44mm	 PPL image of the same rock centered on kyanite FoV = 0.44mm

Sorosilicates & Cyclosilicates

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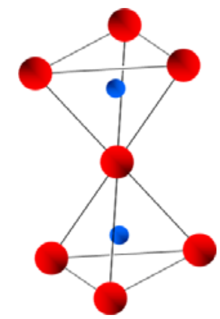
3. Double island silicates = sorosilicates



What?

Each tetrahedron shares one corner with another tetrahedron => basic structural unit: $Si_2O_7^{6-}$

- Some sorosilicate: combination of single and double island (ex.: **Epidote**)

Where?

Small group but widely distributed (common accessory minerals)

Structure :

Chains of edge sharing octahedra linked laterally through the double tetrahedral islands.

Important sorosilicates:

One important group: **epidote group** (zoizite, clinosoizite, epidote, allanite): they all have the same structure.

- **Epidote**: rich in Ca – LT/LP metamorphic rocks (Greenschist facies) ex.: hydrothermal alteration at mid-ocean ridges.
- **Allanite**: accessory mineral in granitoid, lanthanide-rich
- **Lawsonite**: LT/HP metamorphism in mafic rocks (=subduction metamorphism). Mineral often in association with the amphibole glaucophane. Both minerals are blue in hand samples and give the blue color to blueschists.

4. Ring silicates = cyclosilicates

Cyclosilicates sho ring of 3, 4 or more commonly **6 tetrahedra**

Important cyclosilicates: Beryl, tourmaline and cordierite (all 6-fold rings of Si and Al tetrahedra)

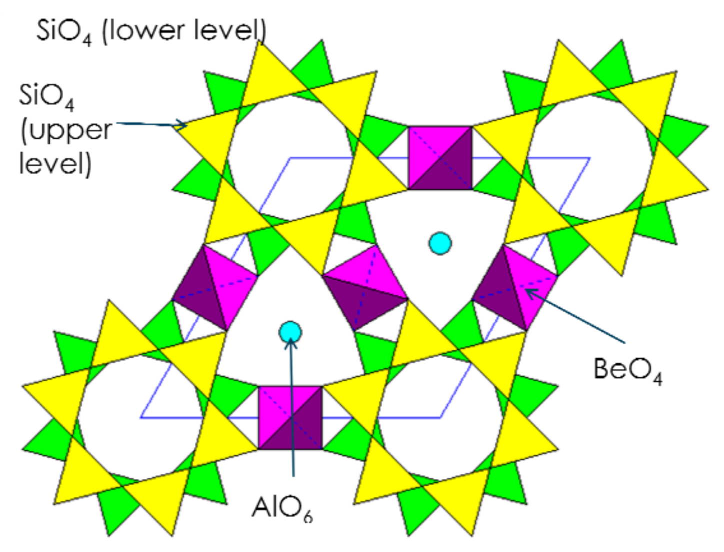
4.1. Beryls

Structure

$Al_2Be_3Si_6O_{18}$

- Si^{4+}: CN = 4
- Be: CN = 4
- Al^{3+}: CN = 6

Impurities: Potential cations (Na, K or Cs) or free water (H_2O) in the middle of the rings

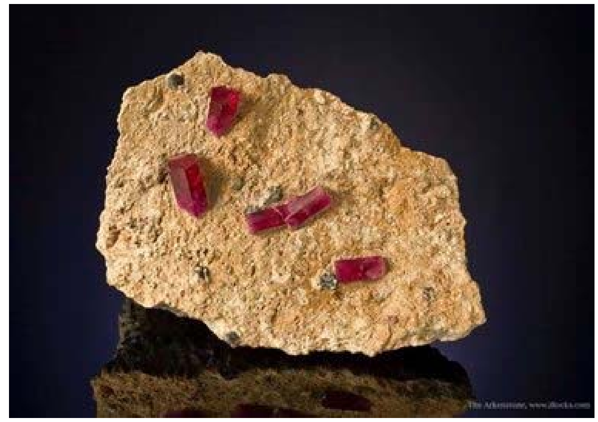


Where?

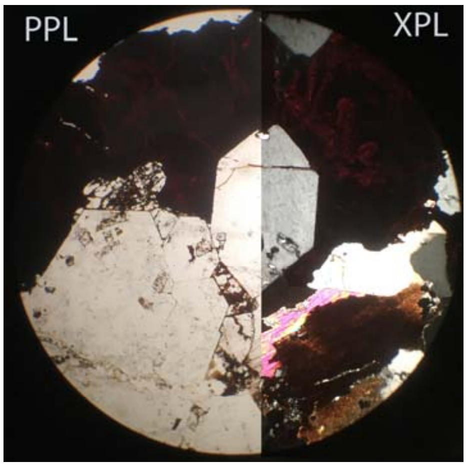
- Associated with Qz and Feldspar
- Common in pegmatite

Color (in hand sample)

- Be^{2+} replaced by Fe^{2+}: blue (aquamarine)
- Al^{3+} replaced by Fe^{3+}: yellow
- Substitution by Fe^{2+} and Fe^{3+}: dark blue (maxixe)
- Traces of Cr^{3+} or vanadium: green (emerald)
- **Be^{2+} replaced by Mn^{2+}: red** (the rarest variety of beryl = red beryl - **found in Utah**! Wah Wah Mountains)



Red beryls in rhyolite - Wah Wah Mountains.
Credits: Arkenstone / www.iRocks.com.



In thin section

- Mostly colorless
- Moderate relief
- 1st order interference color
- Often euhedral (hexagonal basal section and prismatic long sections)

4.2. Cordierite

Beryl and cordierite: isostructural but they do not form a solid solution (the size of the cations are too different).

Structure

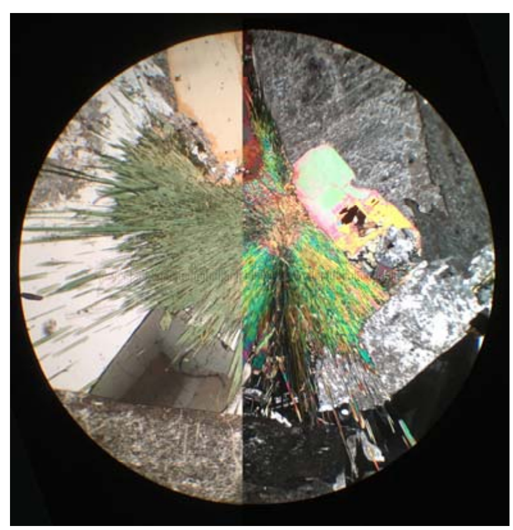
$Mg_2Al_4Si_5O_{18} = Mg_2Al_3AlSi_5O_{18}$: the ring of tetrahedral sites that form the ring are occupied by both Si and Al.

Where?

Cordierite is a common constituent of aluminous metamorphic rocks. It is common in contact metamorphic rocks where it is commonly associated with sillimanite or andalusite, feldspars and micas.

4.3. Tourmaline

Contains Fe, Mg, and a lot of Al



Where?

- In peraluminous [=(Na2O + K2O + CaO) < Al2O3 (mol%)] granites
- In metamorphic rocks (HT/LP: contact metamorphism): metapelites

In thin section

- Basal section are equant
- Elongated section can be acicular
- Strongly pleochroic (blue/green/yellow)
- High birefringence colors but extremely variable, so not a reliable optical property.

Inosilicates 1

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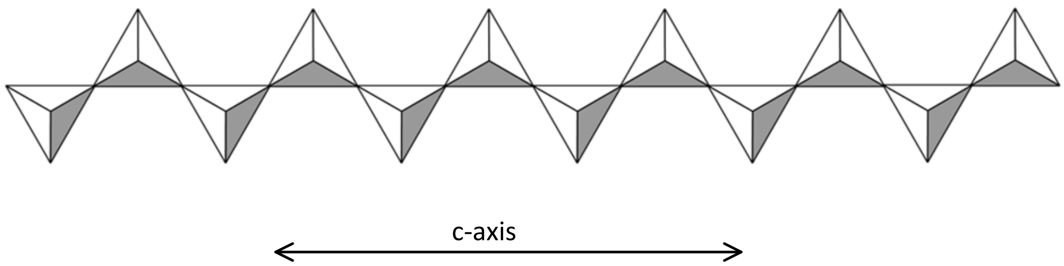
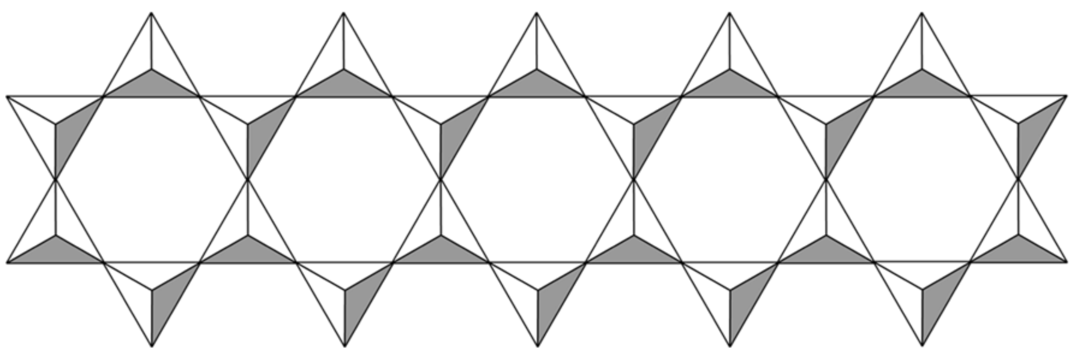
5. Chain silicates = inosilicates

"inos" = chains

Basic structural group: Si_2O_6 (each tetrahedra shared two corners)
Simple or double chains linked by cations

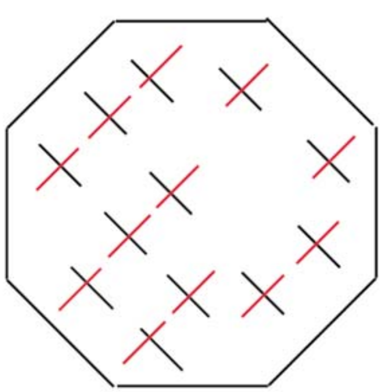




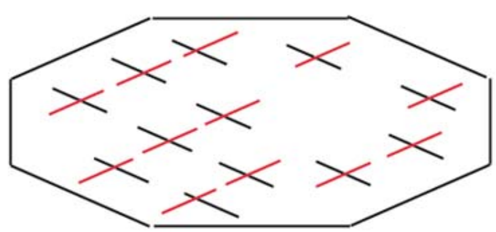
Important nesosilicates:

- Pyroxenes: simple chain - no water
- Amphibole: double chain - with water.

2 directions of cleavage in all inosilicates



Pyroxenes - single chain



Amphiboles- Double chain

5.1. Pyroxenes

a. **What? XYZ$_2$O$_6$**

- X = Na^+, Ca^{2+}, Mn^{2+}, Fe^{2+} or Mg^{2+} : octahedral sites M2
- Y = Mn^{2+}, Fe^{2+}, Mg^{2+}, Al^{3+}, Cr^{3+}, or Ti^{4+}: octahedral sites M1
- Z = Al^{3+} or Si^{4+}: Tetrahedral sites (mostly Si, Al when we have a couple substitution)

- **2 groups:**
  - **Orthorhombic: orthopyroxene (opx):**

(Mg,Fe)SiO3

Form a solid-solution between a Mg- and a Fe-end-member: I

- **Monoclinic: clinopyroxenes (cpx):**

(Ca,Na,Mg,Fe,Ti)$_2$(Si,Al)$_2$O$_6$

Form several solid-solutions:

- The diopside-hedenbergite series:

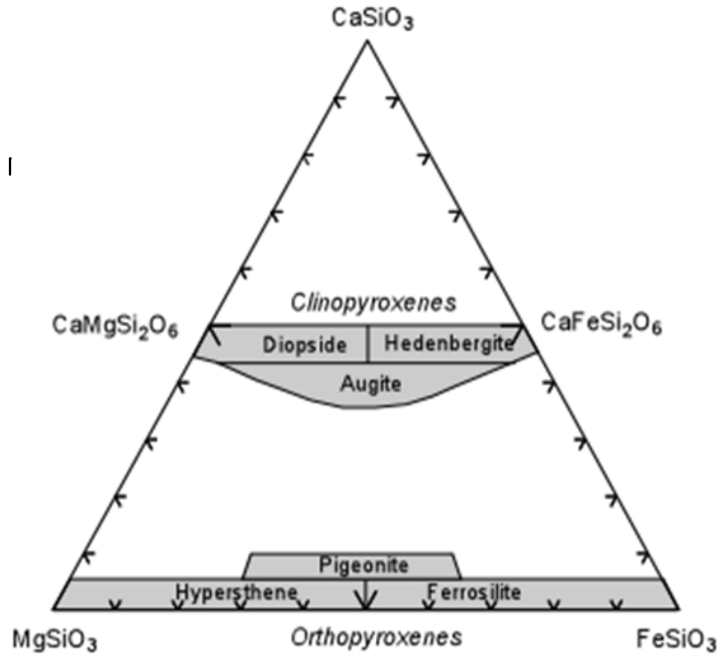
Diopside $CaMgSi_2O_6$ ↔ Ferrohedenbergite $CaFeSi_2O_6$

- **Augite**: (Na,Ca)(Mg,Fe,Al)Si_2O_6 (addition of Al and minor Na substitution to the diopside-hedenbergite series)
- **Pigeonite**: (Ca,Mg,Fe)(Mg,Fe)Si_2O_6 (equivalent to the Ca-poor the Diopside/Ferrohedenbergite series)

- The sodic pyroxenes:

Jadeite $NaAlSi_2O_6$ ↔ Aegirine $NaFeSi_2O_6$ (Fe=Fe^{3+})

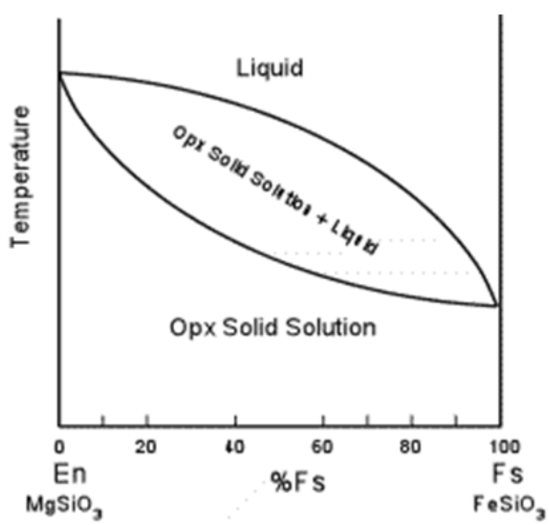
- **Omphacite**: (Na,Ca)(Mg,Fe^{2+},Fe^{3+},Al)Si_2O_6: intermediate between augite and jadeite

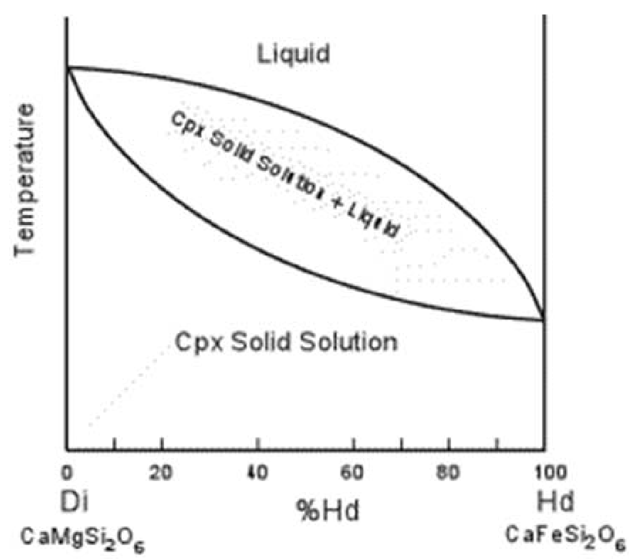


Classification of the Na-free pyroxenes

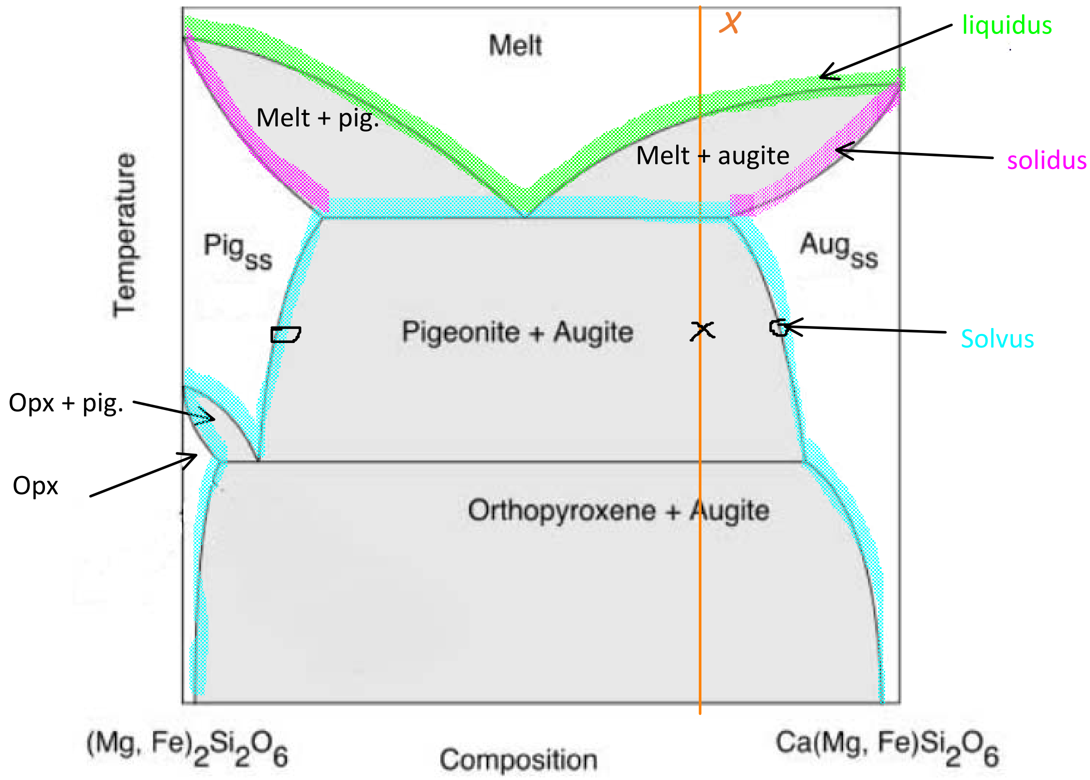
b. **Solid solution and immiscibility**

Both opx and cpx form complete solid-solutions. The Mg-end member melts at higher temperature (as with most Mg-Fe solid solutions).

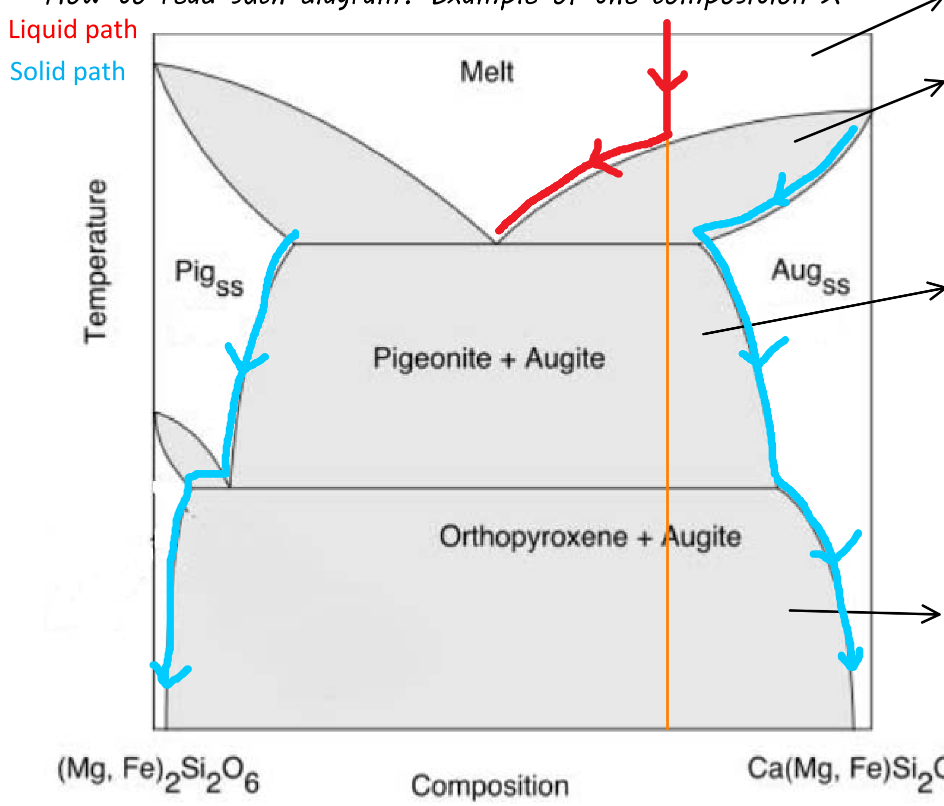




On the contrary, there is a solid immiscibility between diopside-hedenbergite series and opx series = presence of a solvus



How to read such diagram? Example of the composition X.



The system is all liquid

Liquid and augite are in equilibrium together (until now, this is similar to the solid-solution diagram you've seen in lecture 12.

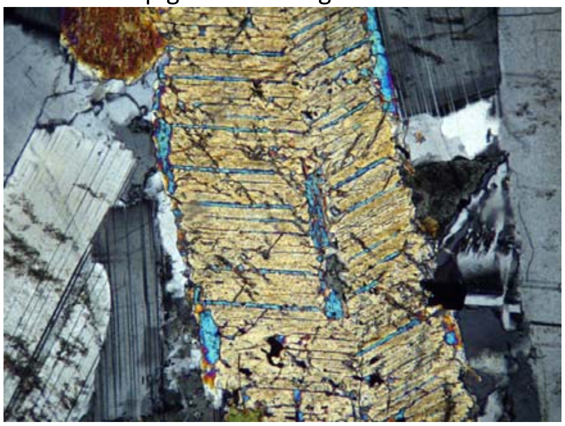
The immiscibility starts: the augite separated into two minerals: Ca-rich clinopyroxene (augite) and Ca-poor clinopyroxene (pigeonite). In thin section, we will observed **exsolution lamellae**. Because the bulk composition is closer to augite than to pigeonite (ie, the lever rule predicts much more augite than pigeonite), in thin section we will see exsolution lamellae of pigeonite in augite.

If the temperature continue to decreases slowly, we will reach the lower part of the diagram: piegonite is not stable anymore and is replaced by orthopyroxene.

Note that the if the magma cools fast (e.g., lava, dike), the exsolution lamella won't have time to develop and we only see augite. For intermediate cooling rate (e.g, gabbro/lower crust), you can stabilize pigeonite, and for slower cooling rates (e.g., mantle), pigeonite is replaced by orthopyroxene.

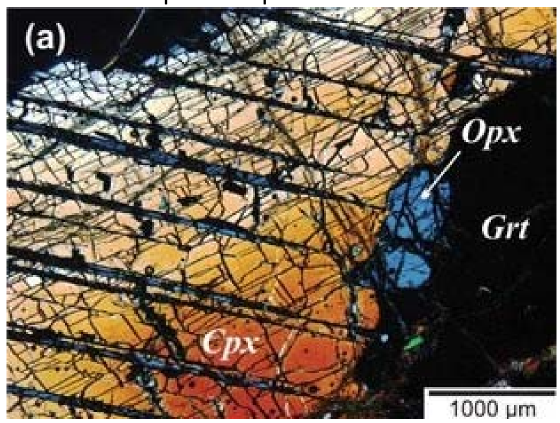
c. **In thin section:**
Examples of exsolution

Lamellae of pigeonite in augite



FOV = 2 mm. *Credits : Alex Strekeisen*

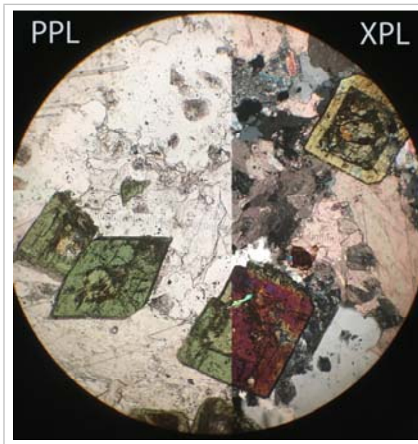
Lamellae of opx in diopside



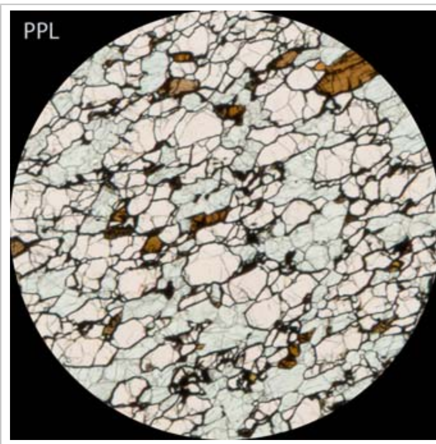
Source: DOI: 10.1080/00206814.2011.623011

What optical criteria would you use to determine if the lamellae are composed of pigeonite or opx?
Can you broadly locate the composition of the bulk mineral on the phase diagram above?

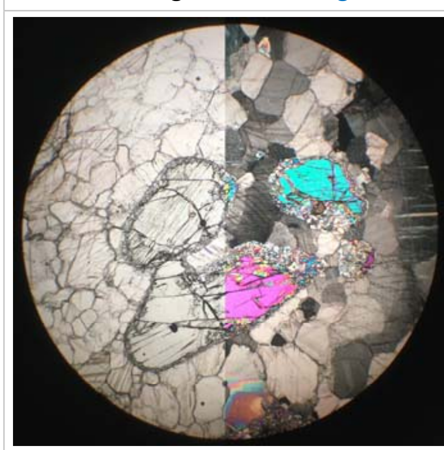
All clinopyroxenes: strong relief, often show twinning, 2 good to very good cleavages, 2nd & 3rd order interference colors (sometimes hidden by the true color of the mineral, only on prismatic sections), **inclined extinction**



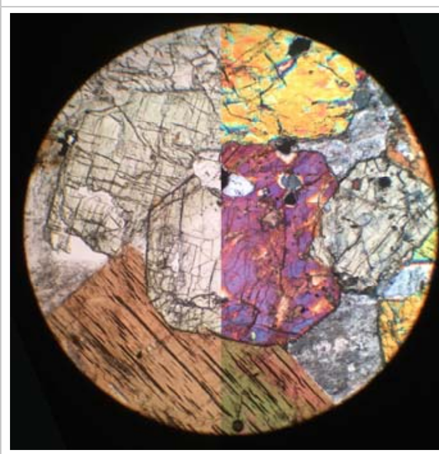
Aegirine : Green, pleochroic, often show twinning - in alkaline ig. rock



Omphacite: Pale green (very weekly pleochroic) - in eclogite with garent

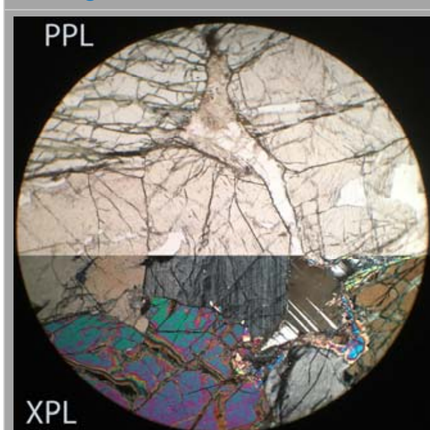


Diopside: shows at least one very good cleavage. Colorless to very pale green In upper mantle and marble



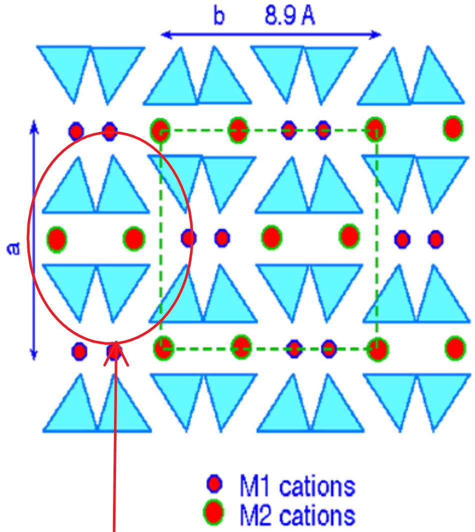
Augite: Colorless, pale pink/green. Not pleochroic. Often shows twinning and/or zoning - mostly igneous rocks

Orthopyroxene:
strong relief, 2 good to very good cleavages, 1st order interference colors, pleochroism: light pink to light green, **parallel extinction**
Igneous and mantle rocks

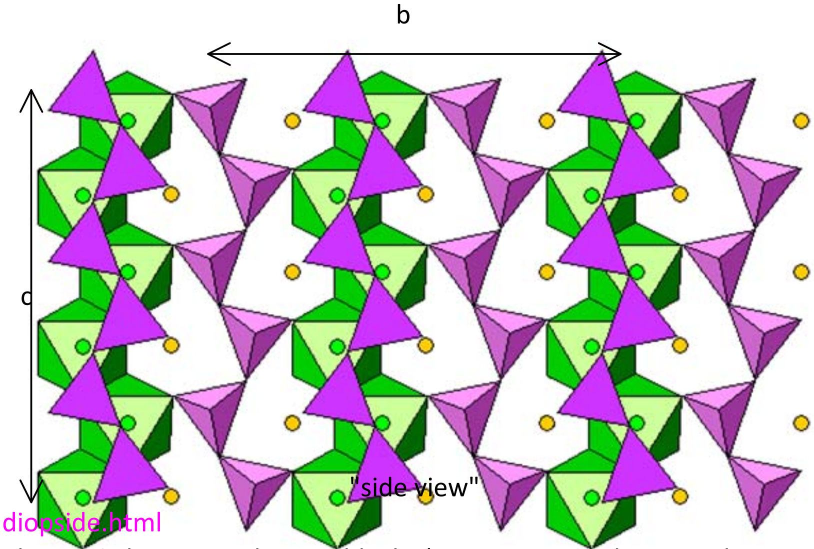


green In upper mantle and marble	and/or zoning - mostly igneous rocks

d. Structure



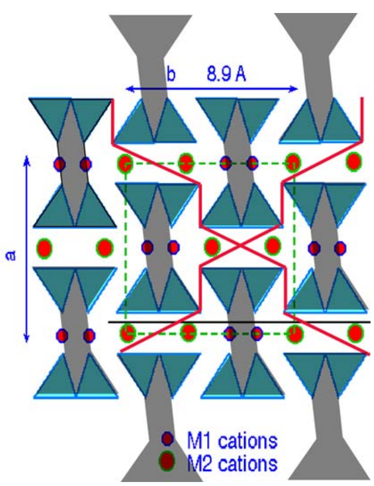
"top view"



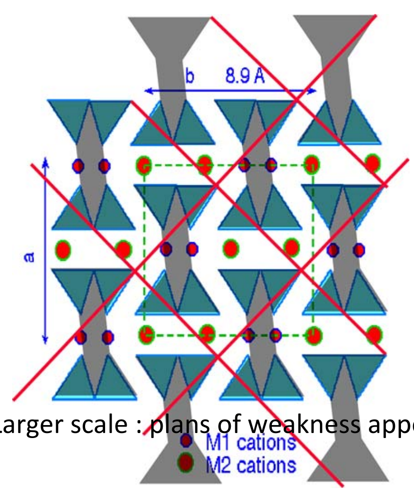
"side view"

To visualize the pyroxene structure in 3D, open diopside.html

The structure of the pyroxene is responsible for the ~90° cleavages. The TOT blocks (TOT =tetragonal-octaonal-tetragonal) form the strongest part of the crystal. Hence, the space between these TOT blocks are weaker and the mineral can break more easily between these TOT blocks).



Atomic scale



Larger scale : plans of weakness appears at ~90°

Inosilicates 2

Monday, October 12, 2020 23:02

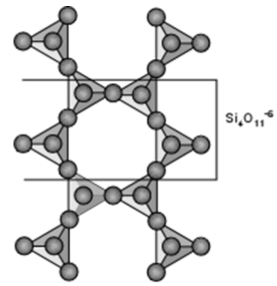
5.2. Amphiboles

a. What?

- Basic structural unit: **$(Si_4O_{11})^{6-}$**

$W_{0-1}X_2Y_5Z_8O_{22}(OH,F)_2$: **HYDROUS MINERAL**

  - W = Na^+, K^+: "sites A" – CN = 10 or 12
  - X= Ca^{2+}, Na^+, Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}: "Sites M4" – CN = 6 or 8
  - Y = Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+} or Ti^{4+}: "octahedral sites M1"
  - Z = Al^{3+} or Si^{4+}: Tetrahedral sites

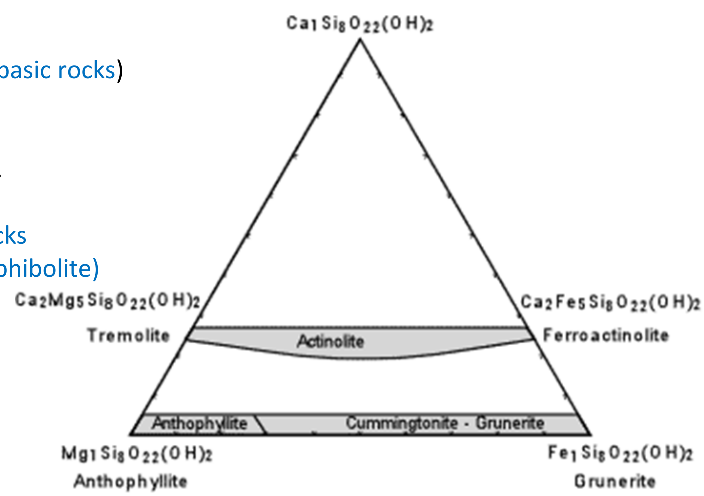


- **Solid-solutions:**
  - Complete substitution of Na and Ca and of Mg and Fe end-members
  - Partial substitution of Si by Al or OH by F

- **2 groups:**

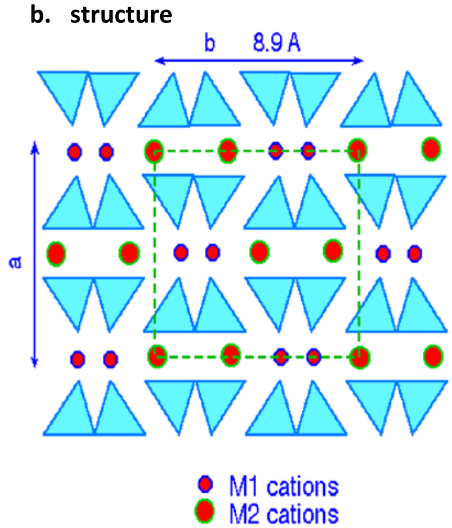
Orthorhombic: Anthophyllite (from hydrothermal alteration of ultrabasic rocks)
Monoclinic:

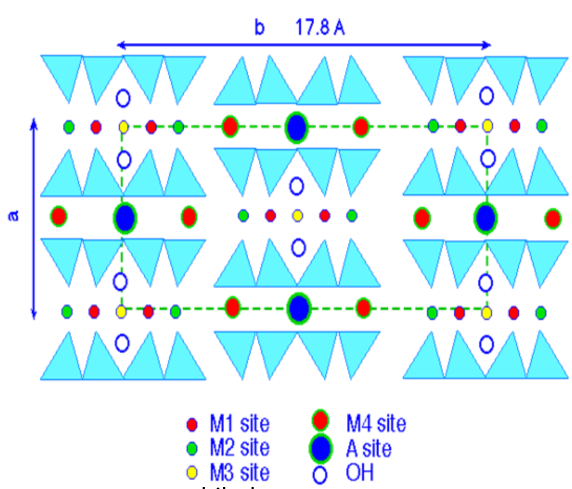
- Tremolite-Ferroactinoline series
  - **Hornblendes** = addition of Al and minor Na to actinolite.
    Most common amphibole
  - Ca-rich: green hornblende – in intermediate plutonic rocks (diorite, granodiorite) and mafic metamorphic rock (amphibolite)
  - Fe,Mg-rich: brown hornblende
    (also called oxyhornblende) – in intermediate lavas



- **Sodic amphiboles**: in alkaline rocks
  - **Glaucophane** - HP-LT metamorphism (blueschist)

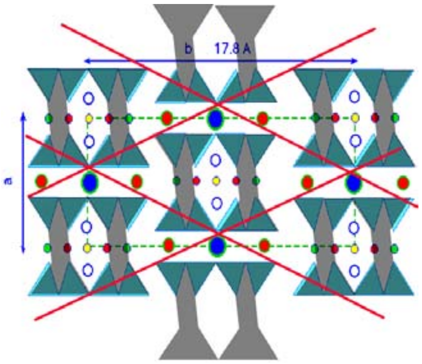
b. structure

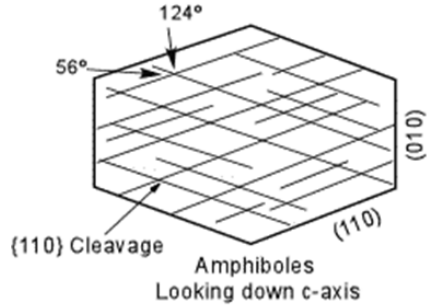




Pyroxene vs amphibole

To visualize the amphibole structure in 3D, open hornblende.html





c. **Hydrous mineral:**

- Not stable at very high temperature: dehydration of amphiboles give pyroxenes
- Si:O ratio: higher in amphiboles (4:11) than pyroxenes or olivine: Si-richer rocks

=>

Mafic and ultramafic rock = not abundant: Si-poor, crystallized at high T and little dissolved water (if present: crystallize late in the magmatic history)

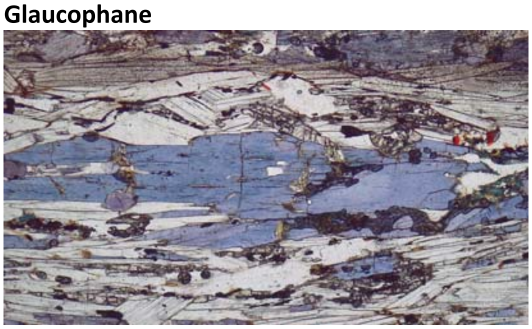
Intermediate igneous rock = common: in particular calcic and sodic-calcic varieties: diorite, graodiorite, andesite, dacite

Rq: amphibole: Na&Ca-rich rocks vs biotite: K-rich rocks

c. **In thin section:**

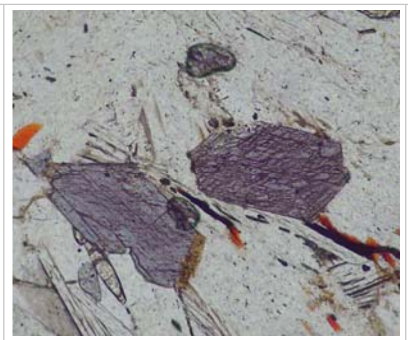
All amphiboles show 120°/60° cleavages on their basal sections and a symmetrical extinction and one perfect cleavage on prismatic section. Most amphiboles are also pleochroic (tremolite is colorless).

Glaucophane

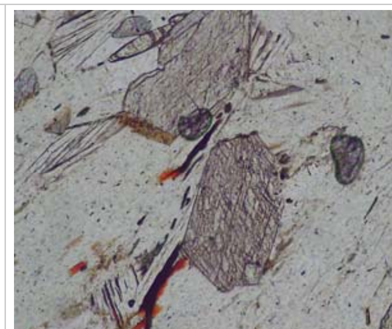


Prismatic section in PPL

Credits: Etienne Medard

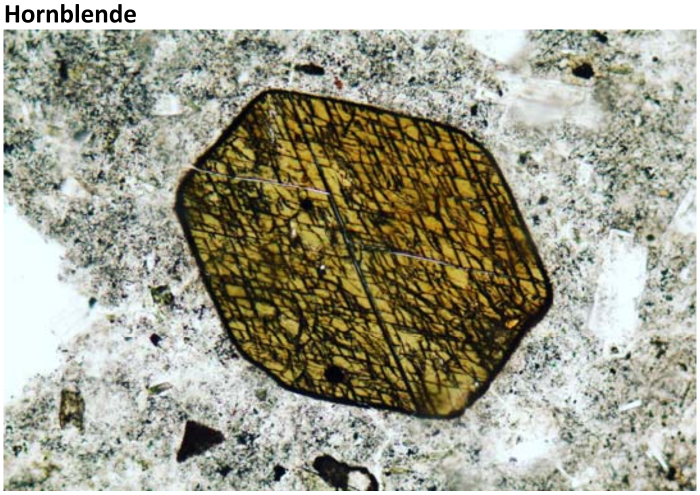


Basal section: in PPL



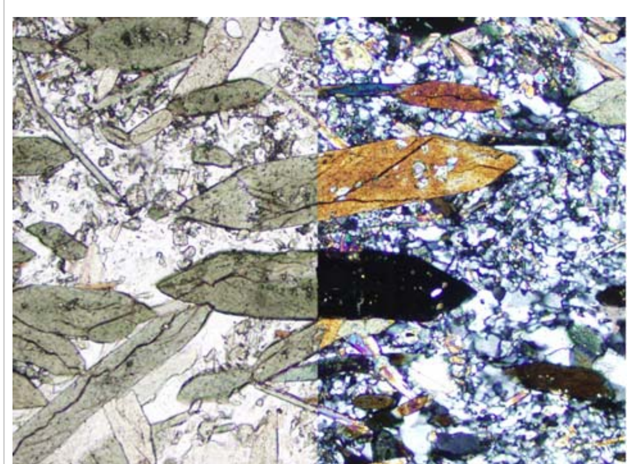
Basal section rotated at 90° in PPL

Hornblende



Basal section of oxy-hornblende in andesite in PPL

Credits: @alexstrekeisen



Prismatic sections of hornblende in PPL and XPL

Credits: Smith College

Personal assessment

Monday, October 12, 2020 7:36

After reviewing the lecture, you should be able to answer these questions:

1) **Which statement(s) is/are correct?**

A – A silicate is a mineral group that is defined by its dominant anionic group
B – A silicate is a mineral group that is defined by its structure.
C – The morphology of a silicate is mainly controlled by its composition .
D – The morphology of a silicate is mainly controlled by its structure .

2) **Which statement(s) is/are correct?**

A – olivine and zircon belongs to the same mineral group
B – olivine and zircon have the same structure
C – olivine and zircon are nesosilicates

3) **Which statement(s) is/are correct?**

A – olivine show two types of crystallographic sites.
B – fayalite and forsterite form a complete solid-solution
C – The octahedral sites M1 in olivines are connected by edges and corners
D – Mg^{2+} preferentially sit in M1 octahedral sites rather than M2 octahedral sites.

4) **Which statement(s) is/are correct?**

A – grossular and pyrope form a complete solid-solution
B – the color of the garnet reflects its composition
C – Spessartine garnet are rare because it is hard to substitute Mg or Fe for Mn.
D – garnet are always extinct in PPL

5) **Which statement(s) is/are correct?**

A – Epidote and beryl belongs in the same structural group.
B – Beryl and cordierite both have ring**Augite**s of silica tetrahedra
C – Ring silicates can accommodate large cations and/or free water in the center of the rings
D – Andalusite and Kyanite are isomorphs.

6) **Which statement(s) is/are correct?**

A – The main structural difference between pyroxenes and amphiboles is the presence of water in amphibole
B – The main structural difference between pyroxenes and amphiboles is that pyroxene are single chain silicates and amphiboles are double chain silicate
C – The main structural difference between pyroxenes and amphiboles is the cleavage angle
D – Mafic lavas preferentially crystallize pyroxene over amphiboles.
E- Intermediate lavas preferentially crystallize pyroxene over amphiboles.
F- All pyroxenes belong to the same crystal system.

7) **Which statement(s) is/are correct?**

A – In thin section, augite can be easily distinguished from opx as augite always show 2nd-3rd order interfernce colors and opx only show 1st order interference color.
B – In thin section, augite can be easily distinguished from opx as augite always show inclined extinction and opx always show parallel extinction.
C – In a lava, it is common to observe exsolution lamellae in pyroxenes.
D – All pyroxenes show 90° angles on their basal section.