Silicates (II): Last lecture!

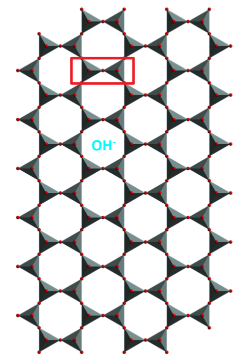
Monday, October 12, 2020 7:28

Time on task: 2 hours (material posted on Nov 9th, Student hour: Wednesday Nov 18th and Monday Nov 23th)

Goals:

Upon completion of lecture 14 you should be able to
- Describe the structures of the sheet and tectosilicates
- 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 #11



1. Sheet silicates = phyllosilicates

"Nesos" = leaf: silica tetrahedra are organized in layer

Large group of mineral including many common minerals: **muscovite, biotite, serpentine, chlorite, talc, clay minerals.**

1.1. General structure

- **Basic structural unit $Si_2O_5^{2-}$**

  Most phyllosilicates are hydrous: OH^- is located at the center of the rings. There is also the possibility of free water (H_2O) between the sheets.

  Structure organized into layers: Two kind of "layers" within one "sheet":

- **Layers:**

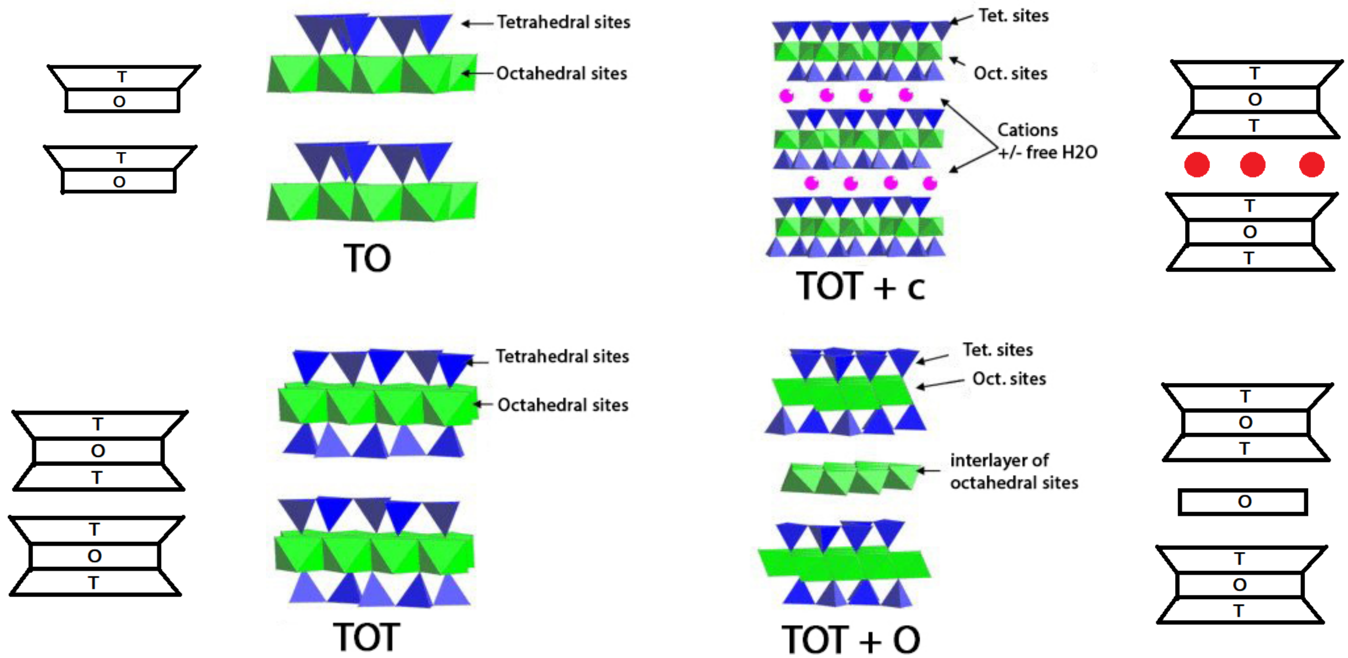
  T layers: tetrahedral sites: tetrahedral coordination of **Si and Al**
  O layers: octahedral sites: mostly Al and Mg, occasionally Fe

  T and O layers bounded to form sheet – The space between sheets can be:
  - Vacant
  - Filled with interlayer cations, water or other sheets

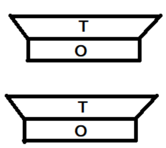
- **Two types of octahedral layers**:
  - **Trioctahedral**:
    - All cations sites are filles
    - Cations are divalent (Mg^{2+} or Fe^{2+})
    - OH^- or O^{2-} are bounded to 3 cations
  - **Dioctahedral**:
    - One every three sites is vacant
    - Cations are trivalent (Al^{3+}, Fe^{3+})
    - OH^- or O^{2-} are bounded to 2 cations

- **Stacking:** Different stacking arrangements of the tetrahedral and octahedral layers, along with the type of cation that occupies the octahedral sites, allow for the large variety of phyllosilicates that occur in nature.

There are four main type of stacking: **TO, TOT, TOT+c, TOT+O**

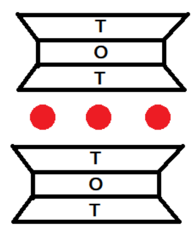


1.2. Common phyllosilicates:



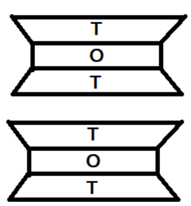
TO phyllosilicates:

- Trioctahedral:
  Serpentine [$(Mg,Fe)_3Si_2O_5(OH)_4$]
- Dioctahedral:
  Kaolinite [$Al_2Si_2O_5(OH)_4$]



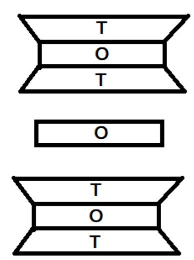
TOT+c phyllosilicates: micas

- Trioctahedral:
  Biotite [$K(Mg,Fe)_3Si_3Al_1O_{10}(OH)_2$]
- Dioctahedral:
  Muscovite [$KAl_2Si_3Al_1O_{10}(OH)_2$]



TOT phyllosilicates:

- Trioctahedral:
  Talc [$(Mg,Fe)_3Si_4O_{10}(OH)_2$]
- Dioctahedral:
  Pyrophyllite [$Al_2Si_4O_{10}(OH)_2$]



TOT+O phyllosilicates:
Chlorite

Common phyllosilicates

Sunday, November 1, 2020 9:00

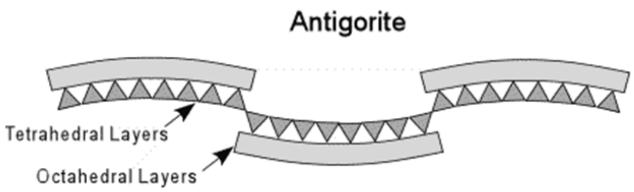
1.3. Serpentine group (TO structure)

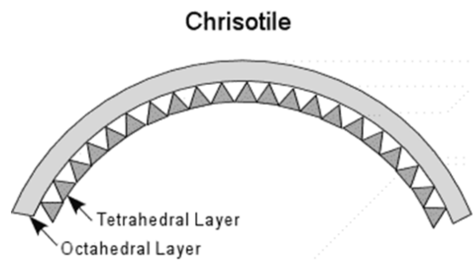
- **Structure Trioctahedral TO Phyllosilicates:** $(Mg,Fe)_3Si_2O_5(OH)_4$

  3 varieties: antigorite, lizardite and Chrysotile

  ◆

  Massive, fine grain fibrous (= asbestos variety)





- **Where?**

  Serpentine = hydration product of Mg-rich silicates (pyroxene, olivine)

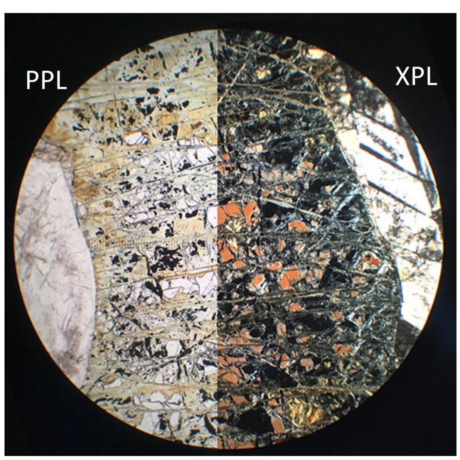
  $$2Mg_2SiO_4 + 3H_2O \Leftrightarrow Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$

  Olivine water Serpentine Brucite

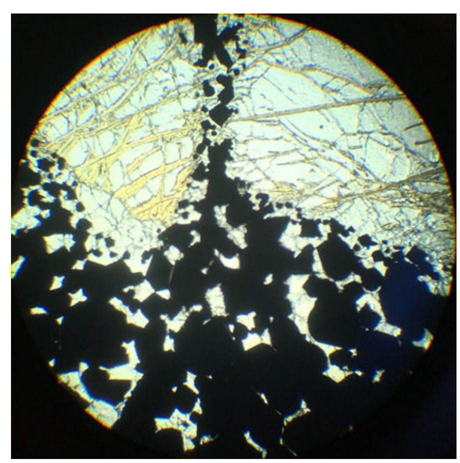
  Pseudomorph after olivine and pyroxene in altered basic and ultrabasic igneous rocks (peridotite, dunite, basalt, gabbro) - often associated with minerals magnesite (MgCO3), chromite, and magnetite.

  Rock made up almost entirely of serpentine, it is called a **serpentinite**

- **In thin section**
  - green to pale brown in PPL
  - Relief slightly negative to slightly positive
  - Very low interference color (δ=0.001-0.01)
  - Often located in fractures of olivine and pyroxene (product of alteration)



Serpentinized grain of pyroxene in a anorthosite.



PPL view of a serpentine in fracture of an olivine grain in a chromite (UUOP 15.5)

1.4. Talc (TOT structure)

- **Structure: Trioctahedral TOT Phyllosilicates:** $(Mg,Fe)_3Si_4O_{10}(OH)_2$

  Known for its low hardness.

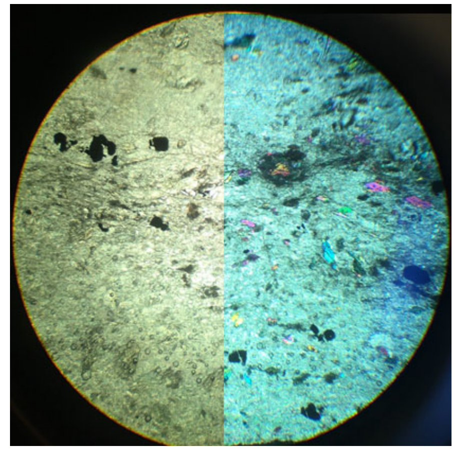
- **Where?**

  Low grade metamorphic rocks that originated as ultrabasic to basic igneous rocks.

  Rock made up almost entirely of talc is called a **soapstone**.

  E.g., Hydrothermal solutions concentrated during final stages of magma crystallization in batholiths or hot seawater solutions drawn down into subduction zones

- **In thin section**
  - Colorless
  - Relief slightly positive
  - Second order birefringence colors (δ=0.05)



UUOP 3.2: mostly talc with inclusions of augite and iron oxide

1.5. Micas group (TOT+c structure)

White micas (dioctahedral) versus Black micas (trioctahedral)

Muscovite, Paragonite, Margarite, Lepidolite

Biotite, Clintonite

- **What?**
  - White micas: **Muscovite** $[KAl_2Si_3Al_1O_{10}(OH)_2]$ and paragonite $[NaAl_2Si_3Al_1O_{10}(OH)_2]$ are the **end-members of the solid solution** involving **K** and **Na** but with a large immiscibility gap (incomplete solid solution).

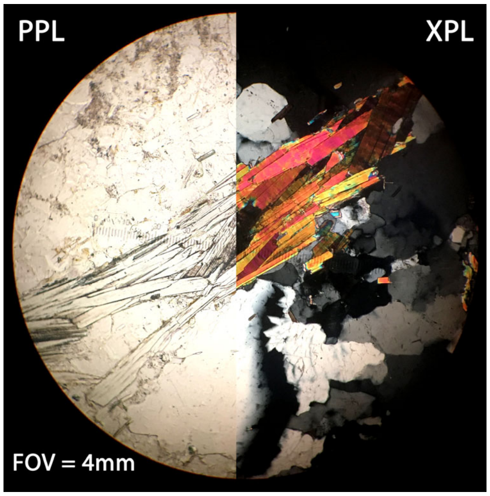
  We call muscovite, minerals with 65 to 100% K and paragonite, minerals with 80 to 100% Na. The intermediate compositions does not exist as mineral.

  - Black micas: **Biotite is a solid solution** between the **end members Phlogopite** $KMg_3AlSi_3O_{10}(OH)_2$ and Annite $KFe_3AlSi_3O_{10}(OH)_2$,

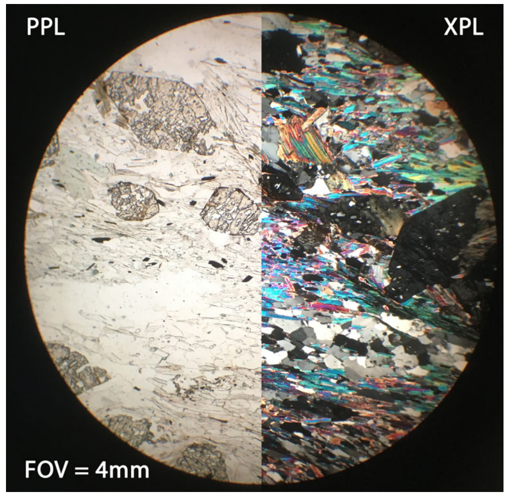
  but pure Annite does not occur in nature.

- **Where?**
  - White micas are present in Al-rich medium grade metamorphic rocks (Al-rich schist) - often marks the foliation, in Si- and Al-rich plutonic igneous rocks (but not in volcanic rock) - in association with alkali feldspar, quartz, and sometimes biotite, garnet, andalusite, sillimanite, or kyanite.
    Substitution of Al by Li: Lepidolite – pink mica found in **pegmatite**
  - **Biotite** is found in intermediate felsic volcanic rocks, granitic plutonic rocks and a wide variety of metamorphic rock. We also find phlogopite in kimberlite.

- **In thin section**
  Muscovite: Colorless, prismatic habit, strong positif relief, one perfect cleavage, 3rd order interferences color, parallel extinction

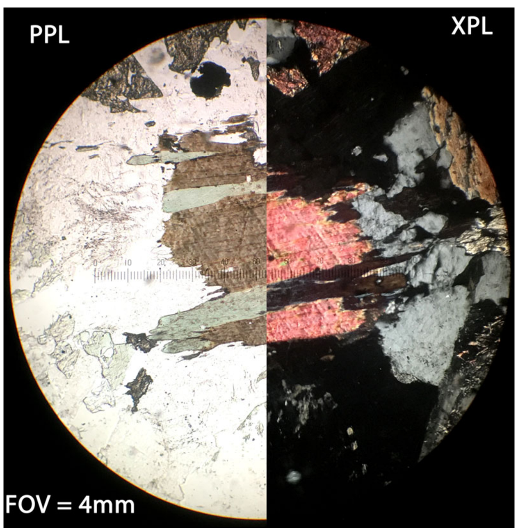


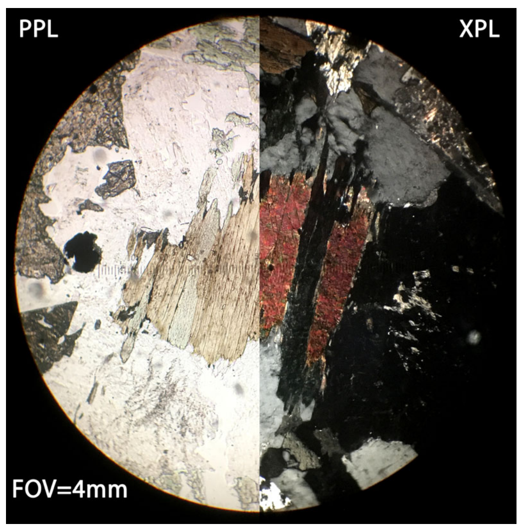
UUOP 32.5



UUOP 20.10

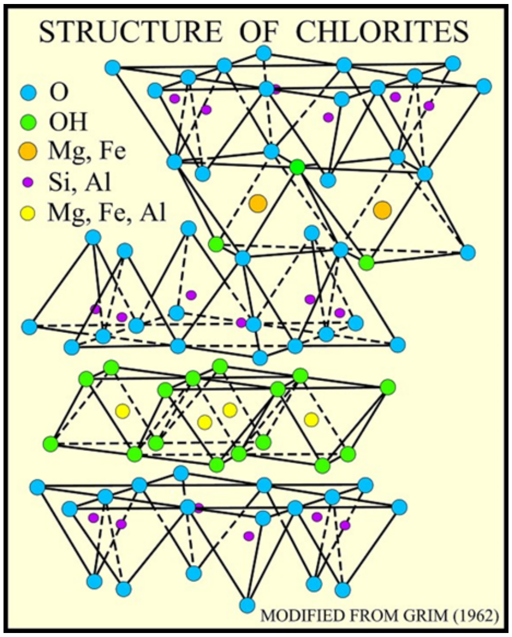
Biotite: Strongly pleochroic (from pale yellow to dark brown, or occasionally dark green), prismatic habit, strong positif relief, one perfect cleavage, 3rd order interferences color (but partly hidden by the color of the mineral), parallel extinction. Can contain zircon inclusions that produced "pleochroic hallo.





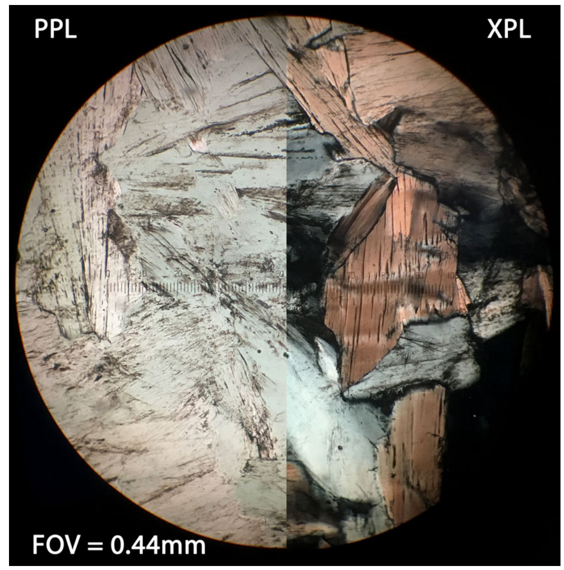
UUOP 12 centered on a biotite grain (brown pleochroic) partly converted into chlorite (green in PPL)

1.6. Chlorite group (TOT+O structure)



- **Structure:** consists of phlogopite T-O-T layers sandwiching a separate octahedral layer.
  Substitutions: - Mg for Fe
  - Al for (Mg, Fe) in both the octahedral sites
  - Al for Si

- **Where?** low grade metamorphic rocks – associated with actinolite, epidote, and biotite.



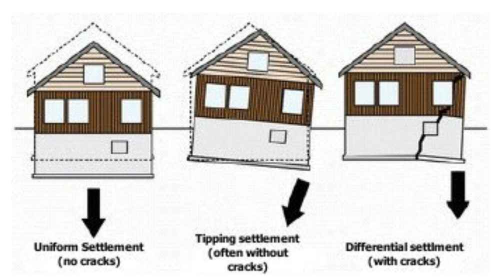
-
- **In thin section**
  - Pleochroic: colorless to pale green
  - 1st order birefringence color - sometime shows anomalous birefringence color (blue or brown)
  - 1 perfect cleavage
  - Often replaces biotite (see above)

1.7. Clay minerals

- **What?**
- Products of chemical weathering – main constituent of mudrock (mudstone, claystone, shale)
- 40% minerals in sedimentary rocks
- Understanding their behavior: important economic use (ceramic), civil engineering (clay swelling)
- Product of chemical Weathering: destabilization of minerals form in depth are not stable at the surface of Earth:
- Identification? Too thin/small to be recognize in hand samples or petrographic microscope ⇒ **use of the X-ray technique**
- **Structure**

Kandites	Smectites	Illites
T-O	T-O-T	T-O-T+c

One particular type of clays are very important to identify for civil engineering applications. We call them the "**expanding clays**".
Expanding clays expands by incorporation free water in their structure and contract when the mineral dehydrates. The presence of such clay in the foundations of a house or a building can generate important damage in the structures.
Can you guess what is the structure of the expanding clays? (Answer below)



- **Common clay minerals**
  - Kandites (T-O structure)
    Most common: **kaolinite** $Al_2Si_2O_5(OH)_4$
    Where? Weathering of hydrothermal alteration of aluminosilicate minerals

  - **Smectites** (T-O-T structure)
    Structure similar to pyrophyllite
    Possibility to absorb water between the TOT sheets: cause volume of the mineral to increase in contact with water : expanding clays
    Most common: Montmorillinite.

  - **Illites** (T-O-T+c structure)
    The most common in soils.
    Not an expanding clay
    Formed by alteration of minerals like muscovite and feldspar.

Tectosilicates 1

Sunday, November 1, 2020 11:17

2. Framework silicates = tectosilicates

"tecto" = framework

This group of minerals represent 2/3 of the Earth's crust

Important tectosilicates: **Quartz, plagioclase, alkali feldspars and felspathoids** **(nepheline, sodalite and leucite)**

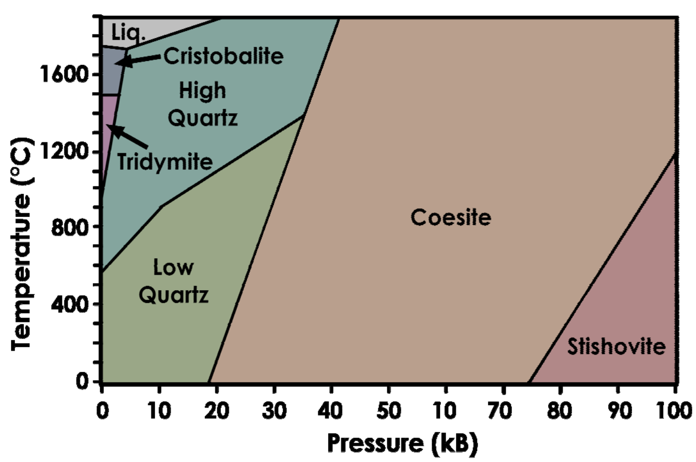
2.1. General structure

- **All the O in the SiO_4 tetrahedra is shared with other tetrahedra: ratio Si:O = 1:2**
- Si - O bonds: strong covalent bonds + interlocked structure ⇒ **high hardness**.
- BUT, repulsion of cations in TO_4 ⇒ **open structures**:
  Can accommodate large cations (Ca^{2+}, K^+, Na^+) ⇐ substitution of Si for Al in the TO_4
  Low density
  Ex: Quartz (2,65) vs Forsterite (3.27) while Z(Si) = 28.09 and Z(Mg)=24.31

2.2. SiO2 minerals

- **9 polymorphs**

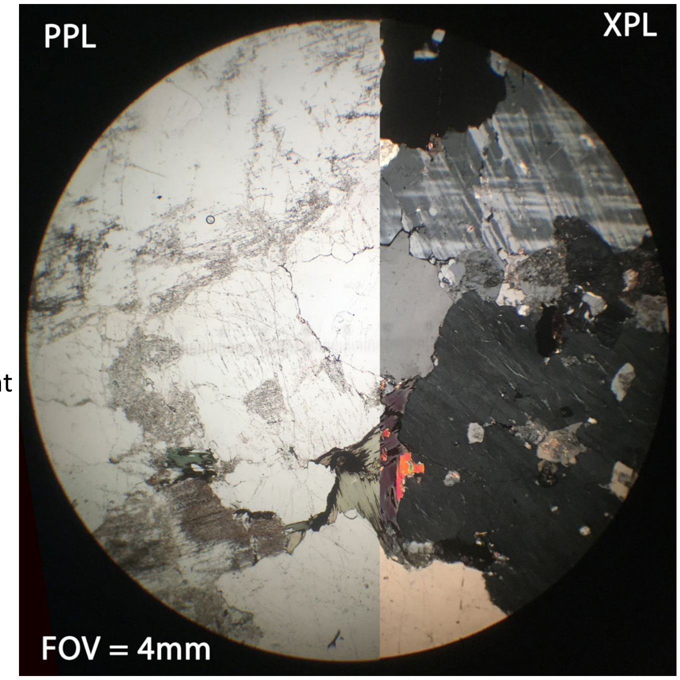
Name	Crystal System	Density (g/cm^3)	Comment
Stishovite	Tetragonal	4.35	High pressure
Coesite	Monoclinic	3.01	
Low (α) quartz	Hexagonal	2.65	Low pressure
High (β) quartz	Hexagonal	2.53	
Kaetite (synthetic)	Tetragonal	2.50	
Low (α) Tridymite	Mon. or orth	2.26	
High (β) tridymite	Hexagonal	2.22	
Low (α) cristobalite	Tetragonal	2.32	
High (β) cristobalite	Isometric	2.20	



- **Quartz**
  - Crystals from microscopic to several tons
  - Habit: Euhedral (in cavities), anhedral (ex.: in granite), microcrystalline masses (chert) or as fibrous masses (chalcedony)
  - **Where?** - One of the most common minerals
    - siliceous igneous rocks (rhyolite, granite)
    - metamorphic rocks – all grades
    - varieties of sedimentary rock (main constituent of sand) because highly resistant to weathering
  - **In thin section**

- Colorless
- Very low relief
- 1st order interference color
- Can shows undulary extinction

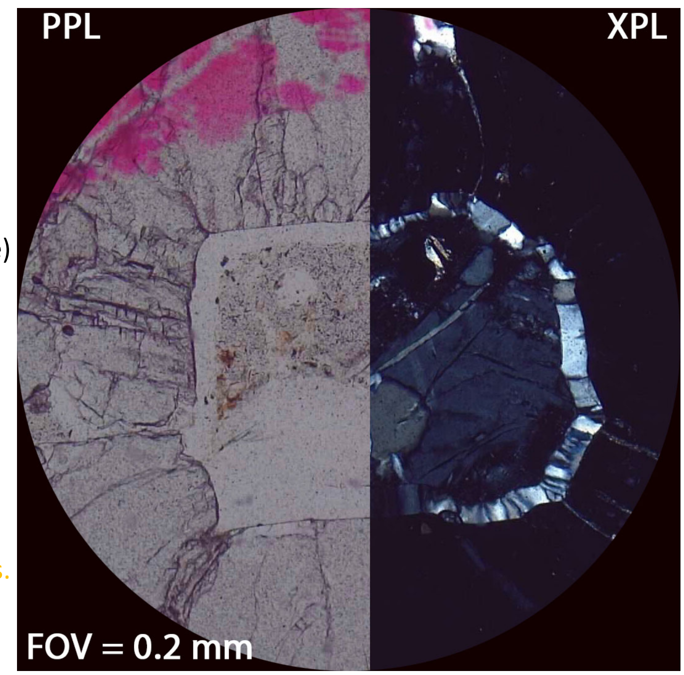
UUOP 36.8: Thin section centered on a quartz grain. In comparison to orthoclase (tabular), quartz is equant and often looks "cleaner"



- **Coesite and Stishovite**

  High pressure polymorphs
  - **Where?** In ultra high pressure metamorphic rock (coesite) and as the result of a meteorite impact (stishovite)

    Preserved coesite inclusions in pyrope garnet (with a rim of quartz) indicate peak metamorphic pressure > 2.5 GPa (90 km depth). The partial conversion of coesite into quartz resulted into the fracturation of the garnet due to the lower density (higher volume) of quartz.
    Rock: pyrope-phengite-kyanite-quartz-rutile UHP "whiteschist" from the Dora Maira area in the Italian Alps.
    Credits: Etienne Medard



- **Trydinite and cristobalite**

  High temperature polymorphs
  - **Where?** Igneous rocks that cooled rapidly: rhyolite, associated with cristobalite and sanidine

- **Opal:**

  amorphous: $SiO_2 \cdot nH2O$
  - Where? Crystallize at low temperature – in fracture or faults of many different rocks

Tectosilicates 2

Sunday, November 1, 2020 12:06

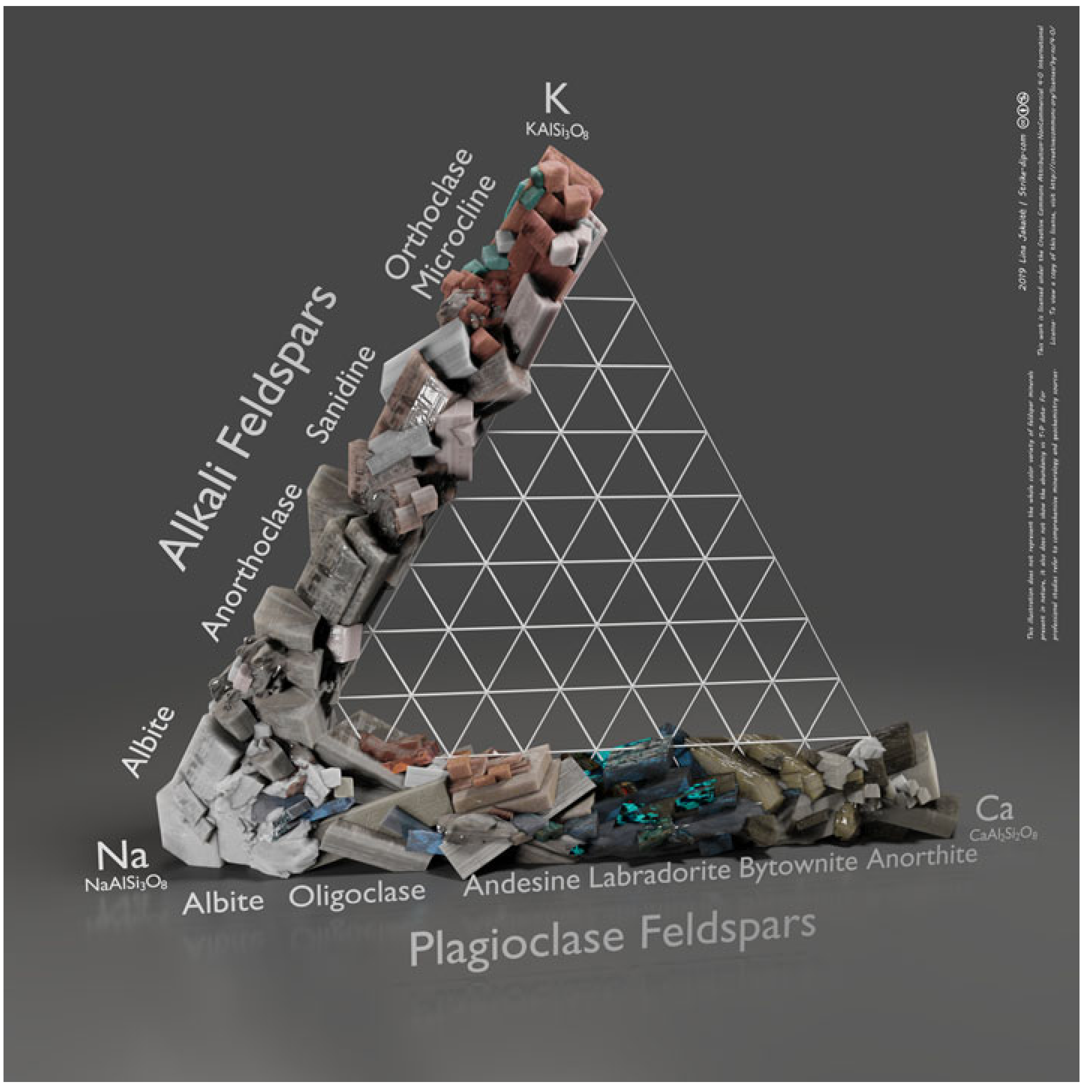
2.3. Felspars

- **Most common mineral in Earth's crust**
- 3 end-members:

  Orthoclase (K) Albite (Na) Anorthite (Ca)

  Alkali feldspar solid-solution **Plagioclase solid-solution**

The alkali felspars and the plagioclase represent two complete solid-solutions. However there is a very large immiscibility gap between the potassic end-member and the calcic end-member.
Less than 5% Ca can be substituted with K and less than 5% K can be substituted with Ca, respectively.



Credits: Strike-dip.com

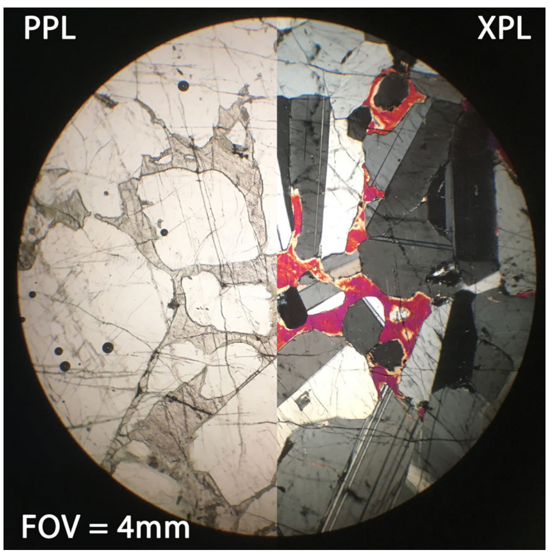
(note that while this representation is nice to appreciate the various colors of the feldspars, it is not perfectly accurate as the plagioclase series seems to be able to incorporate up to 10% K while we just saw that the maximal amount is 5%).

- **Plagioclase: $(Ca,Na)(Al,Si)_4O_8$**
  Most common feldspar
  Forms by the crystallization of a magma
  Solid-solution with coupled substitution $Na^{+}+Si^{4+} \leftrightarrow Ca^{2+}+Al^{3+}$

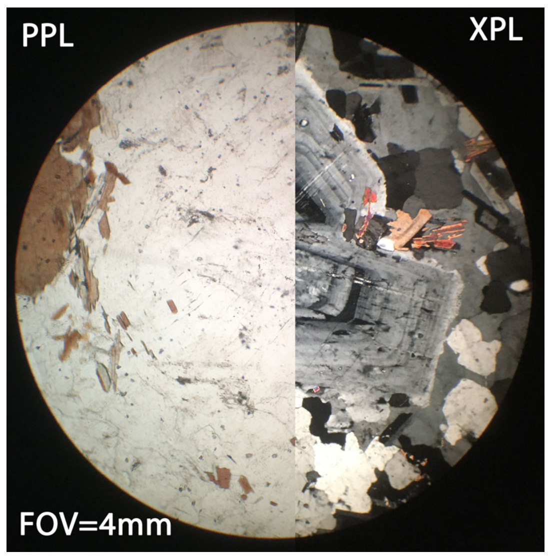
  Where?
  - in basalts, andesites, dacites, rhyolites, gabbros, diorites, granodiorites, and granites: with albite twinning.
  - in metamorphic rock: no twin
  - not common in clastic sedimentary rock (less stable than alkali feldspar)

  In hand sample: Grey to white colored and shows perfect {100} and good {010} cleavage. Can show zoning and twins.

  In thin section:
  - Colorless
  - Tabular
  - Very low relief
  - Negative elongation
  - Low interference colors
  - Often show polysynthetic twins (diagnostic property)
  - Often show zoning = incomplete reaction of crystals with liquid during cooling of a solid solution

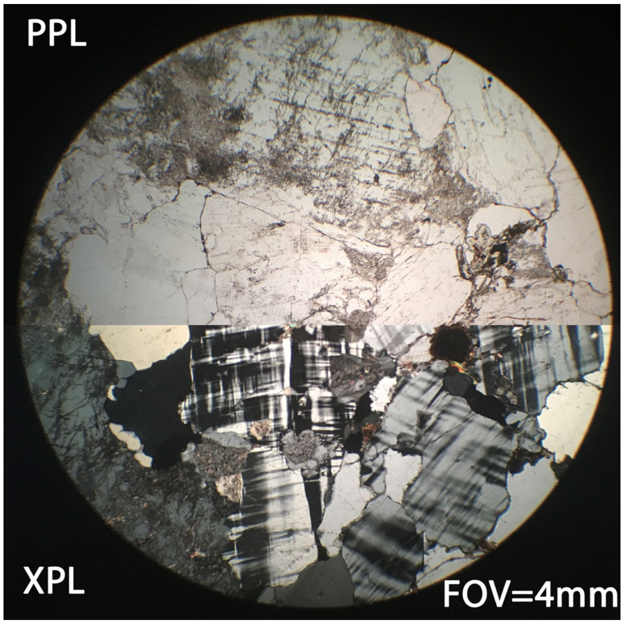


UUOP 34

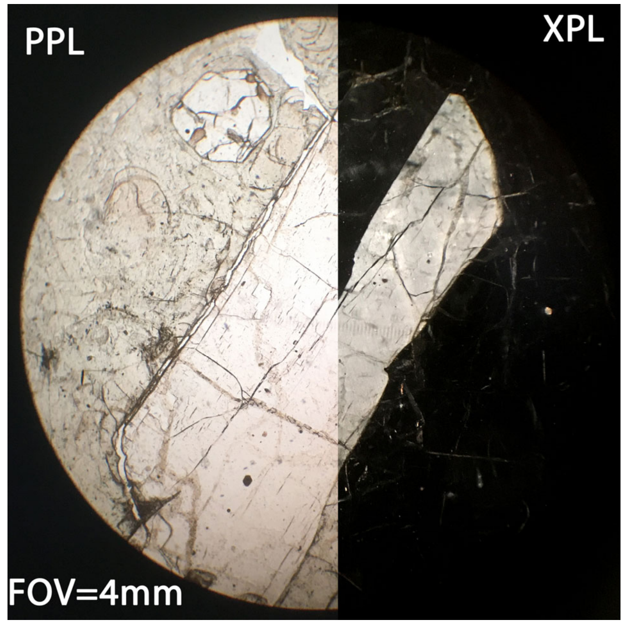


UUOP36.1

- **Alkali felspars: $(K,Na)AlSi_3O_8$**
  - **Where?**
    - Sanidine in volcanic rock, orthoclase and microcline in plutonic rocks. Orthoclase is also in K - Al rich metamorphic rocks.
  - **In hand sample:** White (albite) to blue/pink (microcline).
  - **In thin section:**
  - Colorless
  - Tabular
  - Twin: Sanidine = Carlsbad twin / Microcline = crossed-hatched twins (diagnostic property)
  - Negative elongation
  - 1st order interference colors



microcline - UUOP36.8



Sanidine- UUOP 65.2

Tectosilicates 3

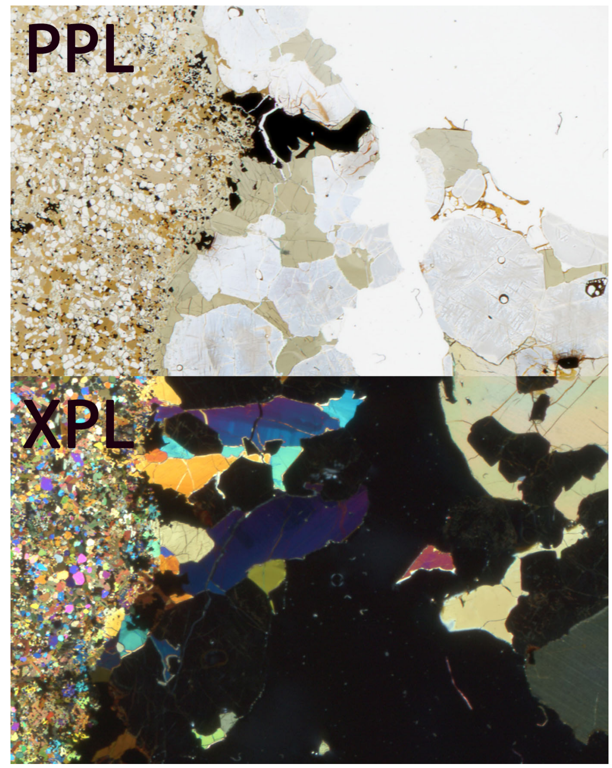
Sunday, November 1, 2020 13:15

2.4. Feldspatoids

- **What?**
  Similar structure and physical properties than feldspars
  Common feldspatoids: nepheline, leucite, sodalite group
  Smaller Si/(Na+K) ratio ⇒ **never found with quartz**
  In alkali-rich and silica-poor igneous rocks (not common)

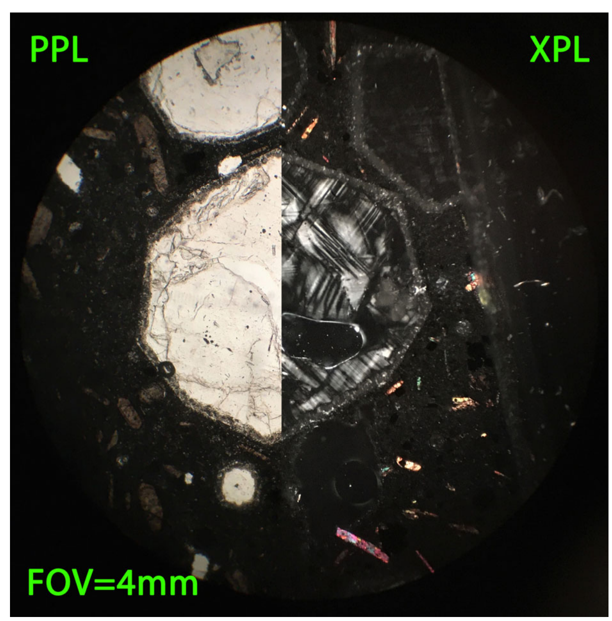
- **Nepheline (Na,K)$AlSiO_4$**
  - **Where?** In both volcanic and plutonic alkali-rich igneous rocks
    Ex: nepheline syenite, foidite, phonolite
  - **Associated minerals:** K-feldspar, Na-rich feldspar, biotite, sodic and sodic calcic amphibole and/or pyroxene
  - **Identification :** hard to distinguish from feldspars in hand specimen – yellowish color alteration - fluorescent.
    Easier in this section because hexagonal: nepheline is uniaxial while feldspars are biaxial (see lab 8). *However it requires to look at the "interference figure" - we did not explain this property this semester.*

- **Sodalite group: Hauyne**
  - **Where?** In silica-poor, igneous rocks
  - **Associated minerals:** nepheline, leucite, augite, sanidine, biotite, phlogopite and apatite
  - **Identification :** dark blue in hand sample and light to dark blue in thin section. Isometric



Contact between a fine grain cumulate (Left) and a Si-poor alkali-rich lava with large crystals of hauyne (equant - light blue in PPL - isometric) - Cap Verde - **FOV = 2*1.5cm**

- **Leucite $KAlSi_2O_6$**
  - **Where?** Mostly in potassium-rich volcanic rocks
  - **Associated minerals:** plagioclase, nepheline, sanidine, cpx, sodic or sodic-calcic amphiboles
  - **Identification :** hexagonal habit - crossed hatched twins



UUOP9

Personal assessment

Sunday, November 1, 2020 15:23

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

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

A – A igneous rock can contain quartz, plagioclase, orthoclase and nepheline in equilibrium
B – A volcanic rock can contain sanidine, augite, olivine and leucite in equilibrium.
C – The Si:O ratio of nepheline is higher than the Si:O ratio of muscovite.
D – There is no vacant site in muscovite.
E – Mafic rocks are usually denser than felsic rocks because they contain heavier elements.
F – Most phyllosilicates are hydrous minerals because free water can be incorporated between the "sheets".

2) **After performing a bulk rock analysis of my sample, I determine that it fits the chemical composition: $K_{.3}Ca_{.7}Al_{1.4}Si_{2.6}O_8$. Can you guess what mineral(s) form this rock?**

3) **List the main differences and common points between the structure of Biotite and Talc .**

4) **I am looking at a mineral in thin section and the mineral is colorless in PPL, show a strong relief, a perfect cleavage and 3rd interference colors. This mineral could be**

A – Talc
B – Muscovite
C – Sanidine
D – Biotite

5) Fill the Table. If cleavage is not expected, state "N/A".

Silicate group	# of cleavages	Angle of intersection
Phyllosilicate		
Single-chain silicate		
Double-chain silicate		
Tectosilicate		