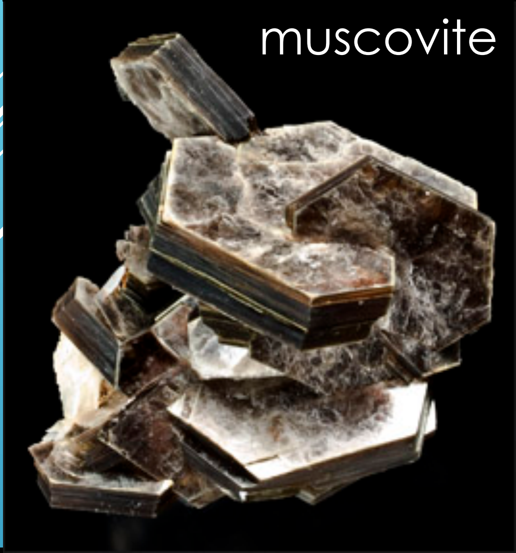
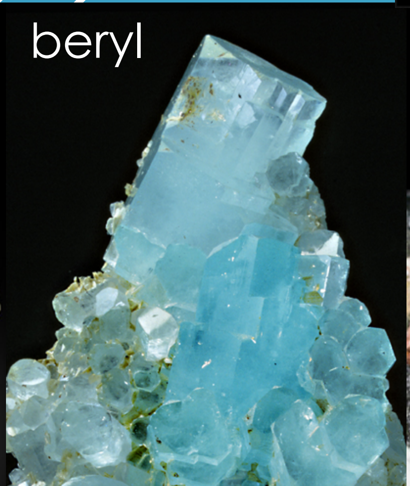
CHAPTER 8: SILICATES MINERALS

Sarah Lambart





CONTENT CHAPT. 8 (6 LECTURES)

- **Part 1: Orthosilicates (= nesosilicates)**
- **Part 2: Sorosilicates & Cyclosilicates**
- **Part 3: Chain silicates (= inosilicates)**
- **Part 4: Sheet silicates (= Phyllosilicates)**
- **Part 5: Framework silicates (= tectosilicates)**

CLASSIFICATION: STRUCTURAL

- **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)**

MAFIC VERSUS FELSIC

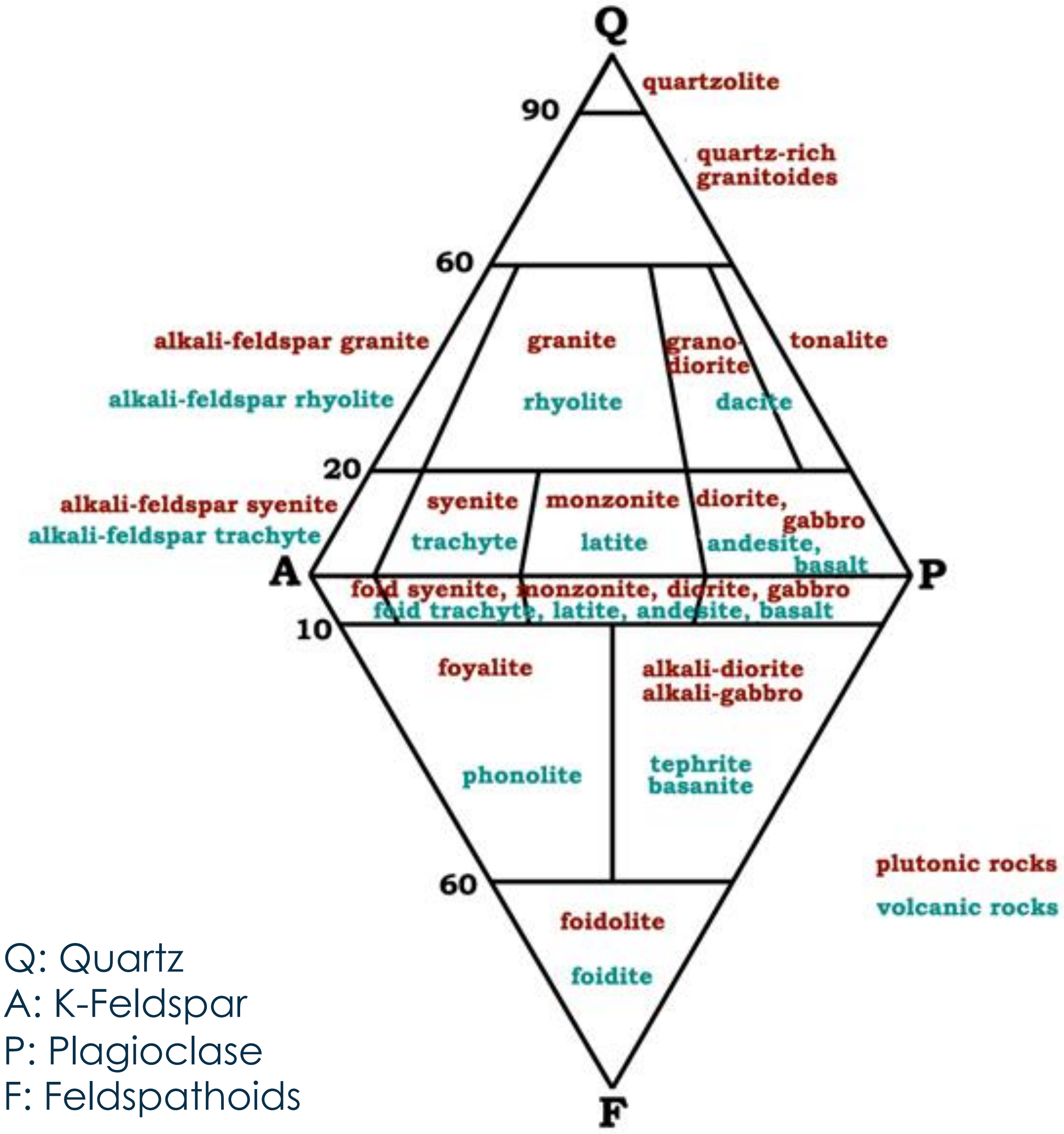
- **Mafic silicate: major cation: Mg and Fe (mafic: magnesia; "ferrum")**
  - **Ex.: biotite, amphiboles, pyroxenes, olivine**

- **Felsic silicates: lack of Fe or Mg as major constituents**
  - **Ex.: feldspars (from which the name is derived), quartz, muscovite, feldspathoïds.**

IGNEOUS ROCKS

- **Mostly silicate (O and Si: most abundant element in Earth's crust)**
- **Silicate in igneous rocks:** quartz, K-feldspar, plagioclase, muscovite, biotite, Ca-clinoamphibole (e.g.: hornblende), Ca-clinopyroxene (e.g., augite), orthopyroxene and olivine, feldspathoids (e.g., leucite, nepheline)
- **Classification**: based on **modal** mineralogy

  ↳volume of rock occupied by each mineral: obtained by "point counting"



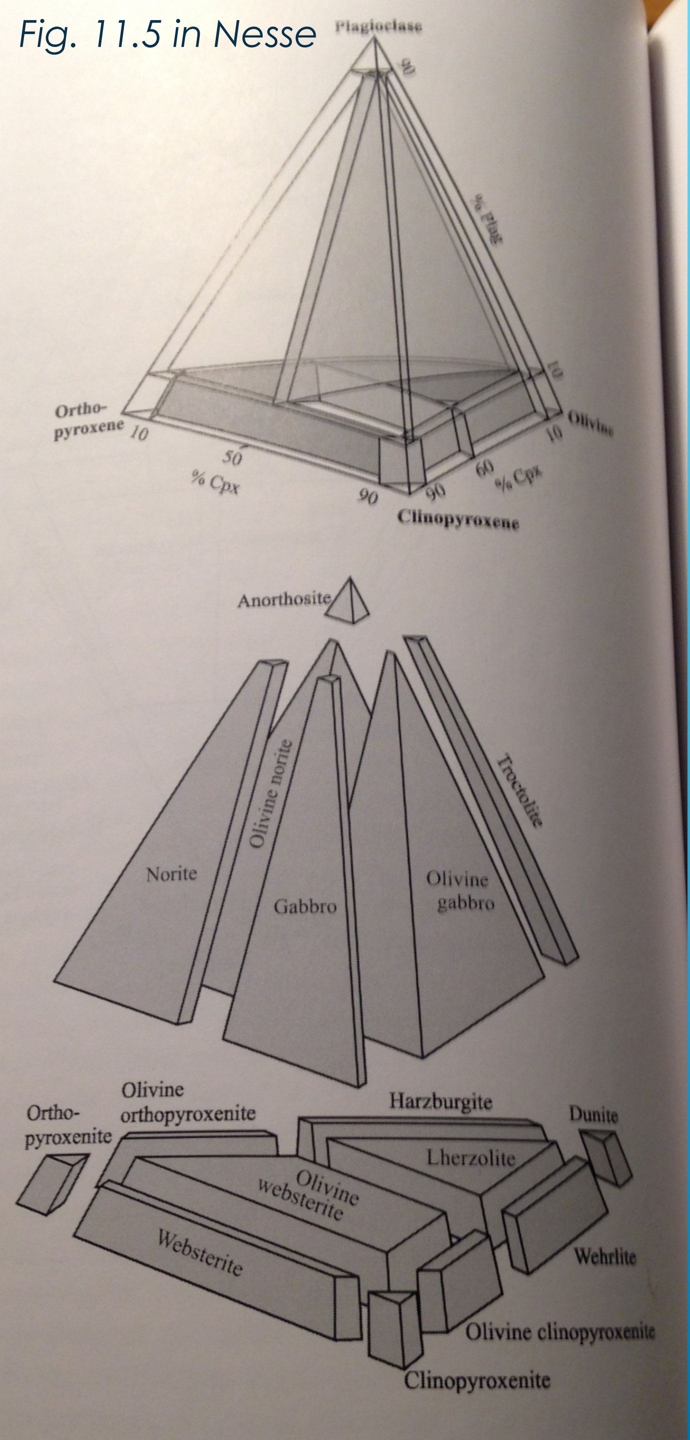
Q: Quartz
A: K-Feldspar
P: Plagioclase
F: Feldspathoids

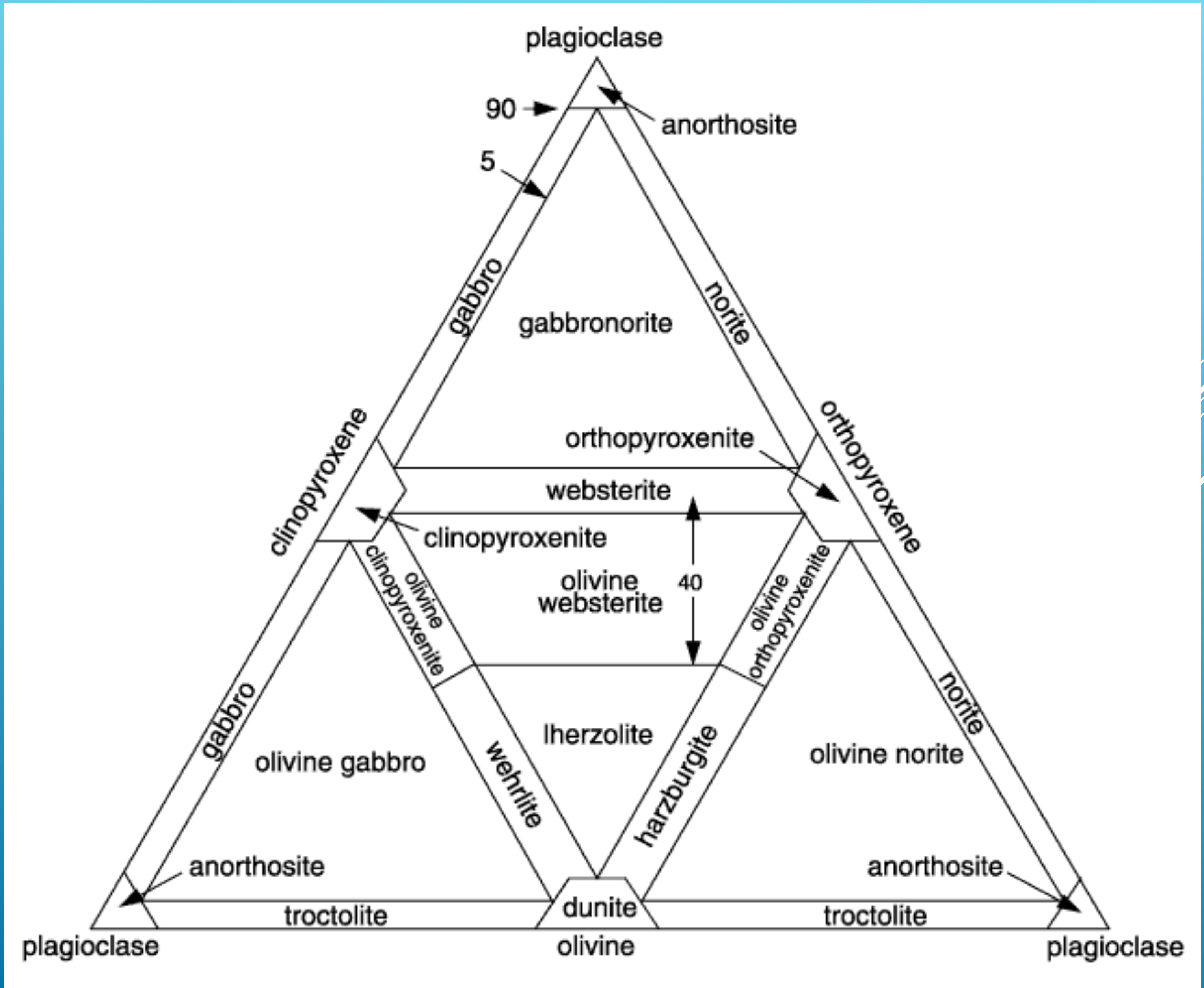
- **Streckheisen classification:** based on **modal** mineralogy
  ↳volume of rock occupied by each mineral: obtained by "point counting"

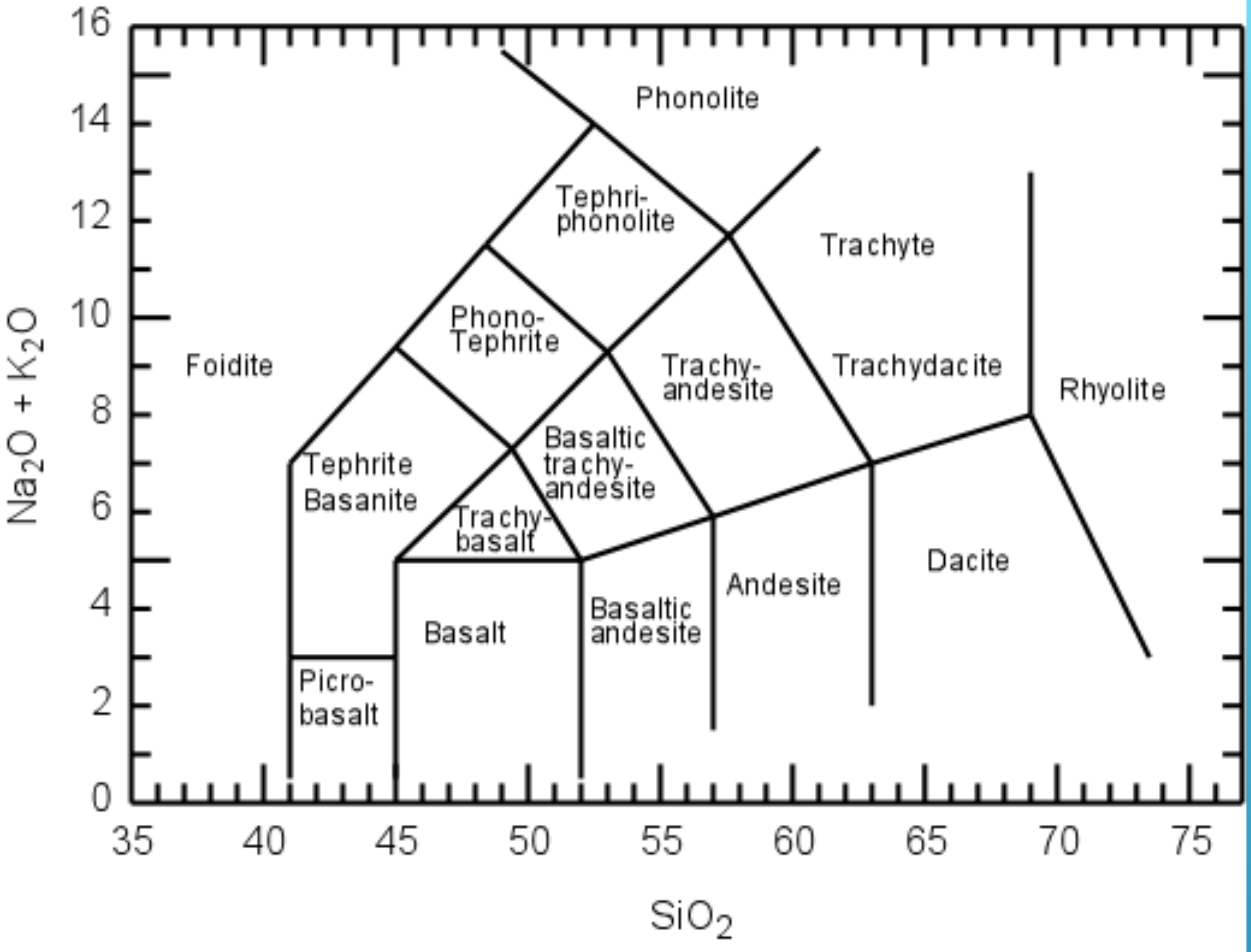
  Mostly for felsic plutonic rocks because
  - *grains in volcanic rocks are often too small*
  - *Quartz and K-feldspar are not major constituents of mafic and ultramafic rocks*

▸ **Mafic and ultramafic rock classifications:** Streckeisen (modal mineralogy)

Fig. 11.5 in Nesse







- **Volcanic rock classifications**: based on chemistry
- Examples:
  - Based on relative amount of SiO_2 and alkalis ($Na_2O + K_2O$)
  - Based on the normative mineralogy

IGNEOUS ROCKS

- **Environments:**
- **Oceanic: mostly mafic rocks**

- mid-oceanic ridges
- Intraplate volcanic center or hot spot: Ex.: Hawaii

- **Convergent plate boundaries**:

- Most common volcanic rock: andesite
- Subduction setting

- **Intracontinental:**

- Continental flood basalt / trapp
- Layered intrusions: mafic bodies = old magma chambers

TERRIGENEOUS SEDIMENTARY ROCKS

Table 11.4 in Nesse

	Particle Name	Millimeters	Rock Type
Gravel	Boulder	256	Conglomerate (if particles are rounded) Breccia (if particles are angular)
	Cobble	64	
	Pebble	4	
	Granule	2	
Sand	Very coarse sand	1	Sandstone (see Figure 11.7)
	Coarse sand	0.5	
	Medium sand	0.25	
	Fine sand	0.125	
	Very fine sand	0.062	
Mud	Coarse silt	0.031	Mudstone (if lacks fissility) Shale (if fissile) Siltstone (if dominantly silt sized) Claystone (if dominantly clay sized
	Medium silt	0.016	
	Fine silt	0.008	
	Very fine silt	0.004	
	Clay sized		

- Always stratified (layered)
- Mostly silicate minerals
- Simple classification: based on grain size

TERRIGENEOUS SEDIMENTARY ROCKS

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

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TERRIGENEOUS SEDIMENTARY ROCKS

- **Mineralogical change once the deposit formed = diagenesis:**
  - **Alteration:** transformation of feldspars into clays
  - **Dissolution:** into pore fluids
  - **Recrystallization:** - small to bigger grains
- after dissolution
  - **Precipitation:** precipitation of ions as new mineral (= recrystallization) or as addition to pre-existing mineral
  - **Change in clay mineralogy** (with time and burial)

TERRIGENEOUS SEDIMENTARY ROCKS

- **Environments:**
  - **Terrestrial:**
    - Fluvial
    - Lacustrine (lake)
    - Eolian (wind)
    - Alluvial fan and fan delta
    - Glacial
  - **Transitional:**
    - Deltaic
    - Tidal
    - Littoral (beach)
    - Estuarian
  - **Marine:**
    - Sublittorial
    - Abyssal plain
    - Bathuall marine fan


The Wave, Arizona

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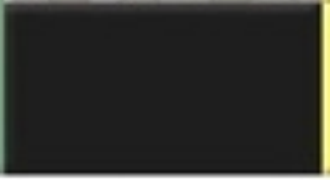
METAMORPHIC ROCKS

- **Mineralogy, texture and/or composition changed as the result of heat, pressure increase, reactive fluids and/or deformation**
- **Classification: based on texture (foliated / non foliated) and/or mineralogy**
- **4 groups: pelites, mafic rocks, Blueschist, Calc-silicate rocks**

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

METAMORPHIC ROCKS

- **Pelites:**
  - derived from mud rocks
  -Al-rich: muscovite, biotite, garnet, staurolite, cordierite, aluminium silicates + quartz and feldspar.
- **Mafic rocks:**
  - mostly derived from basalts and gabbros
  - **4 facies:** greenschist → Epidote amphibolite → Amphibolite → Granulite
- **Blueschist and related rocks:** HP/LT: subduction zones
- **Calc-silicate rocks**: parent contains carbonates

METAMORPHIC ROCKS

- **Environment:**
  - **Contact metamorphism:** immediate vicinity of igneous intrusion (few mm to several km) – almost no deformation
  - **Regional metamorphism:** large volume of rock – orogenic belt – deformation closely related (in time and space)
  - **Burial metamorphism:** continuation of the diagenesis
  - **Hydrothermal metamorphism:** produced by hot aqueous solution – along fault and fracture
  - **Shock metamorphism:** impact of meteorite
  - **High strain metamorphism:** intense shearing – reduction grain size

PART 1
ORTHOSILICATES

ORTHOSILICATES = NESOSILICATES

- "nesos" = island: tetrahedra isolated by cations

- Important orthosilicates:
  - Olivine
  - zircon
  - Garnet
  - Alumino-silicates (sub-nesosilicates)

OLIVINE

- **What?**

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

  forsterite ↔ fayalite
- Olivines: **solid solution** between 2 end-members (ferrous and magnesium) : Substitution of Fe by Mg (or Mg by Fe) **can be total** (extensive substitution)
- Notation: Fo85 = 85% of Mg_2SiO_4 (forsterite) in the solid solution = $(Mg_{.85}Fe_{.15})_2SiO_4$

OLIVINE

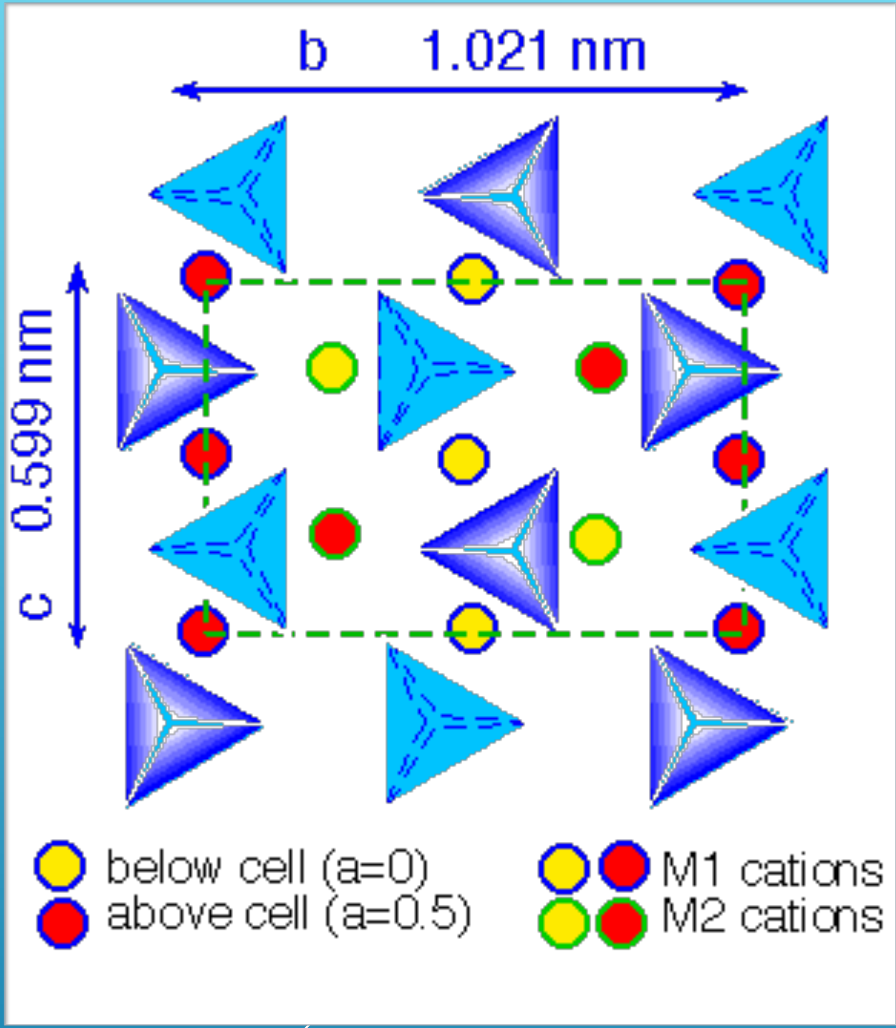
- **Where?**

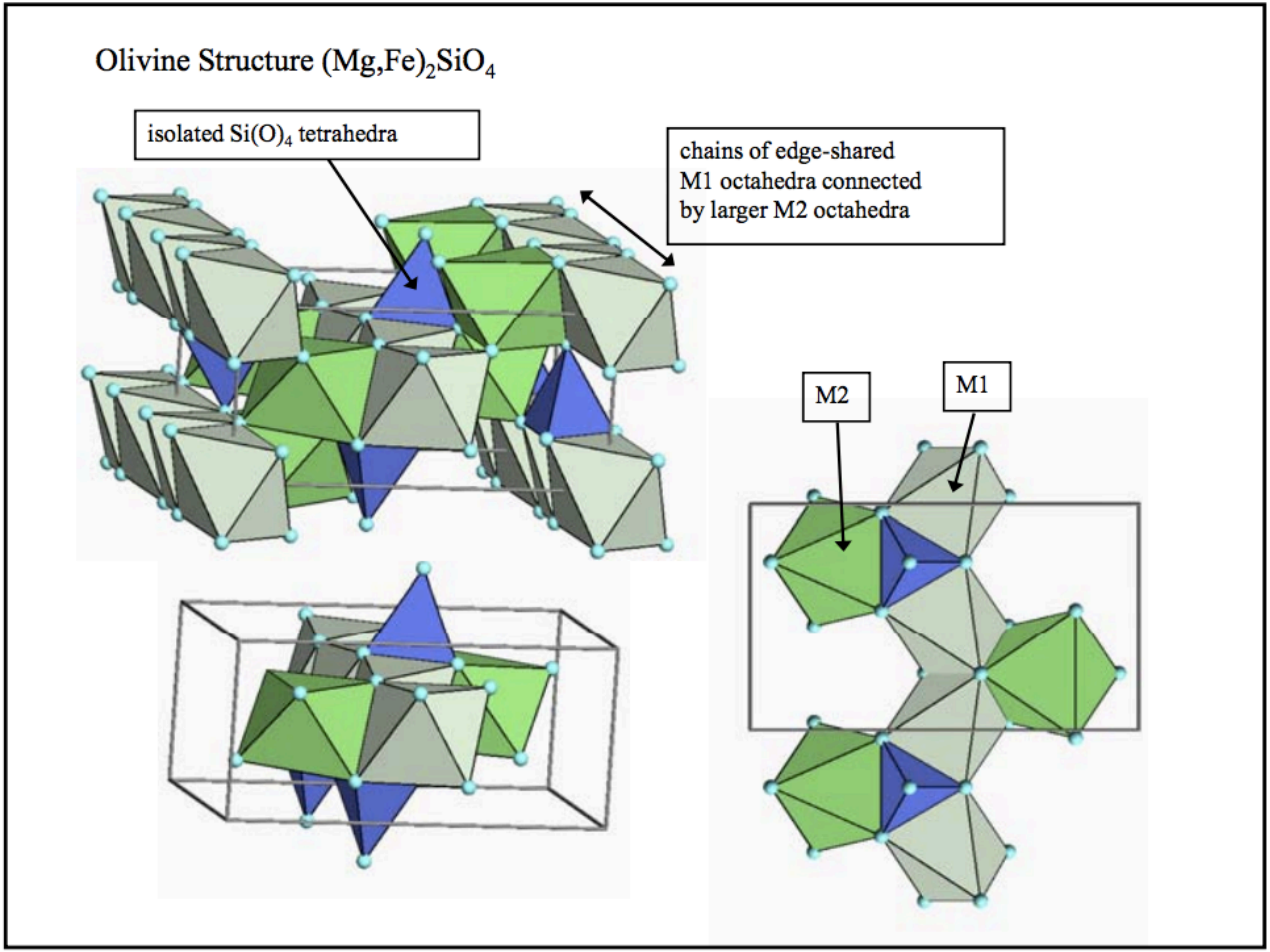
- Basic and ultrabasic rocks
- Major constituent of the upper mantle
- Almost pure forsterite (>Fo_{95}) in some magnesium marble
- Almost pure fayalite (<Fo_{10}): rare but exist in some granites

OLIVINE

- **Structure**

- Chain of edge-shared octahedra (M1 sites) connected by larger (M2) octahedra (Fe and Mg occupy both sites with no preference)
- Octahedra crossed-link by independent SiO4 tetrahedra

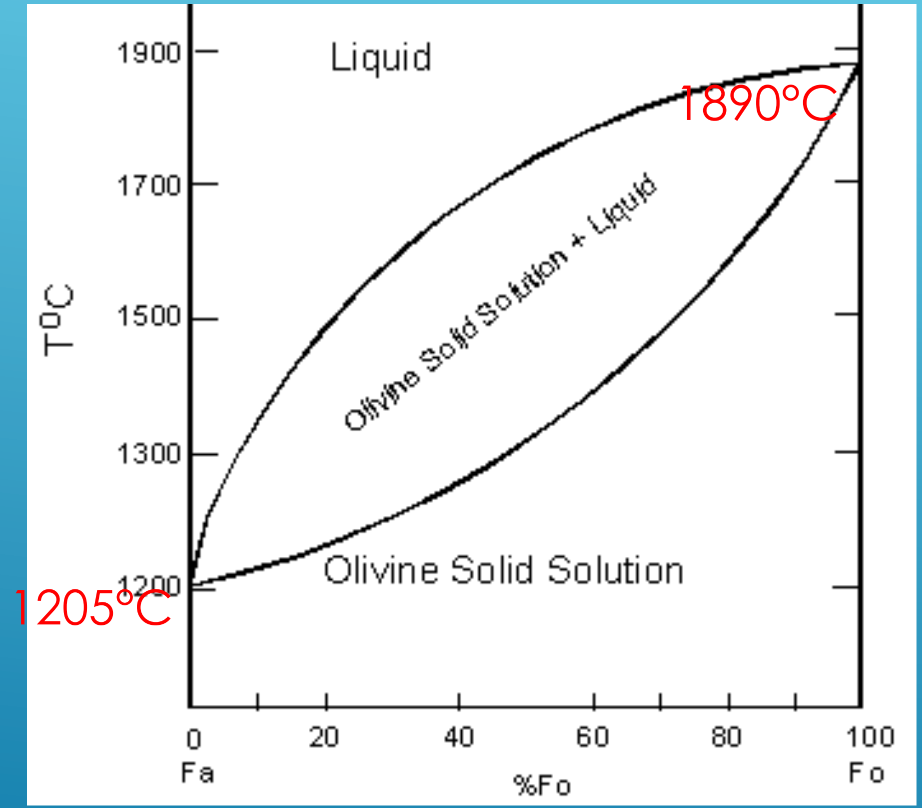




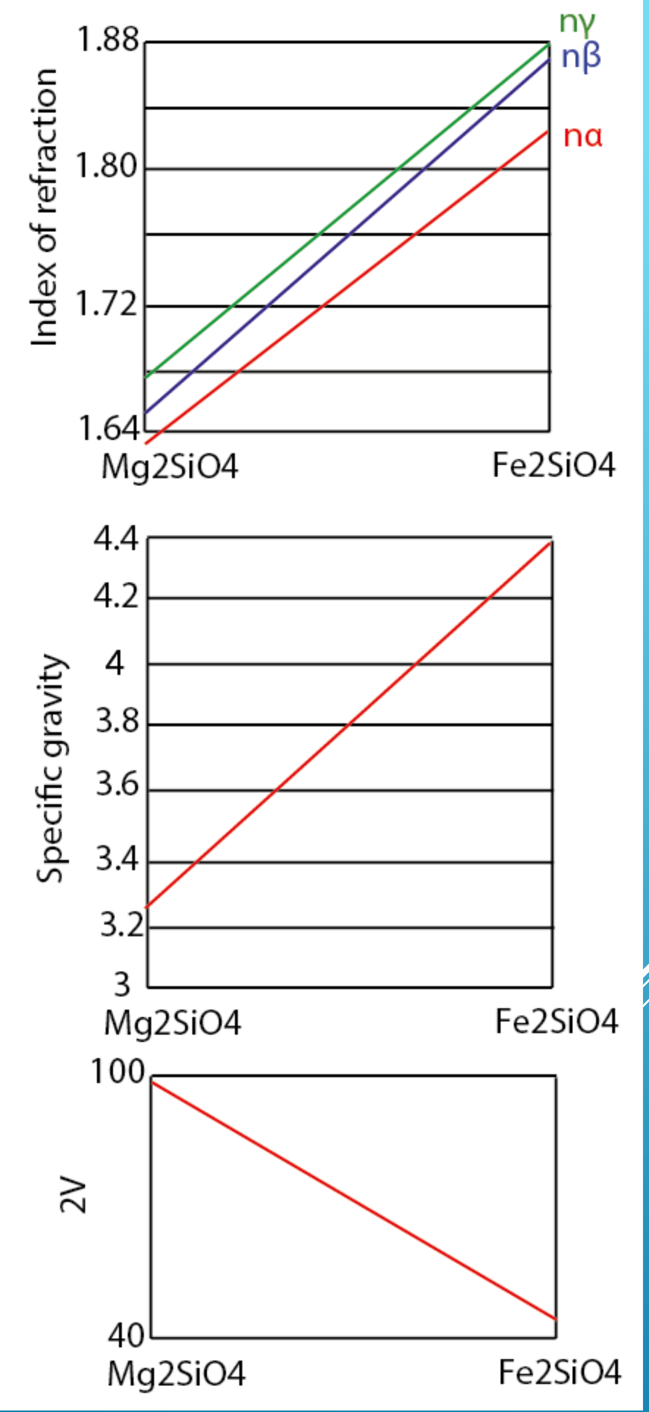
Source: James J. Wray http://www.wray.eas.gatech.edu/

OLIVINE ▸ Solid solution

Olivine phase diagram

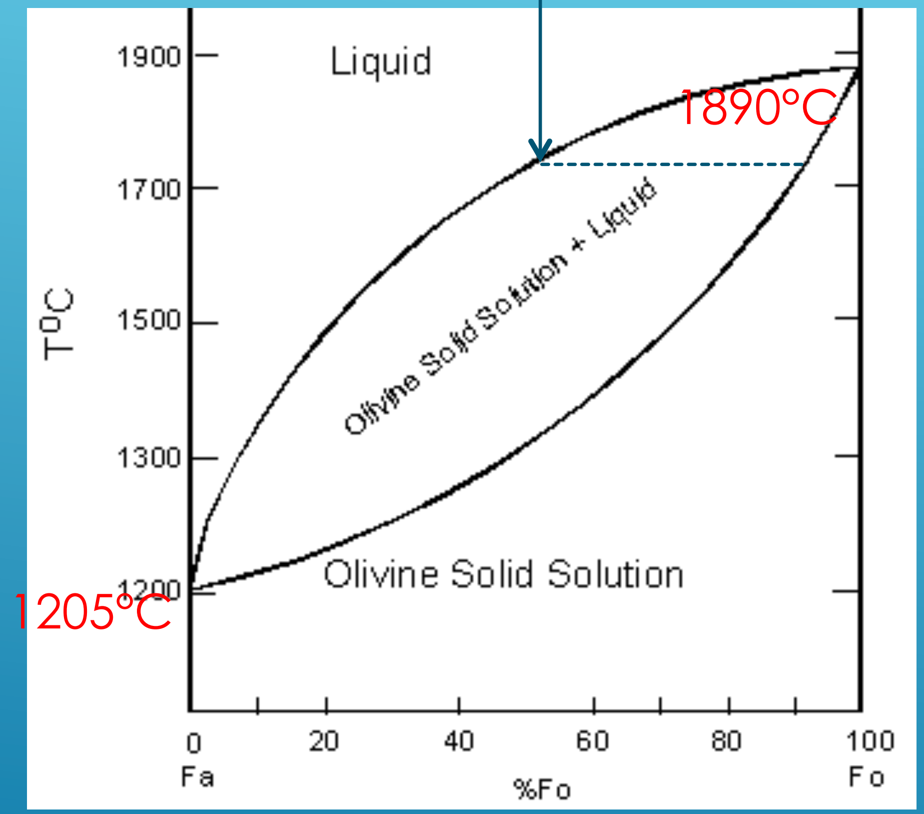


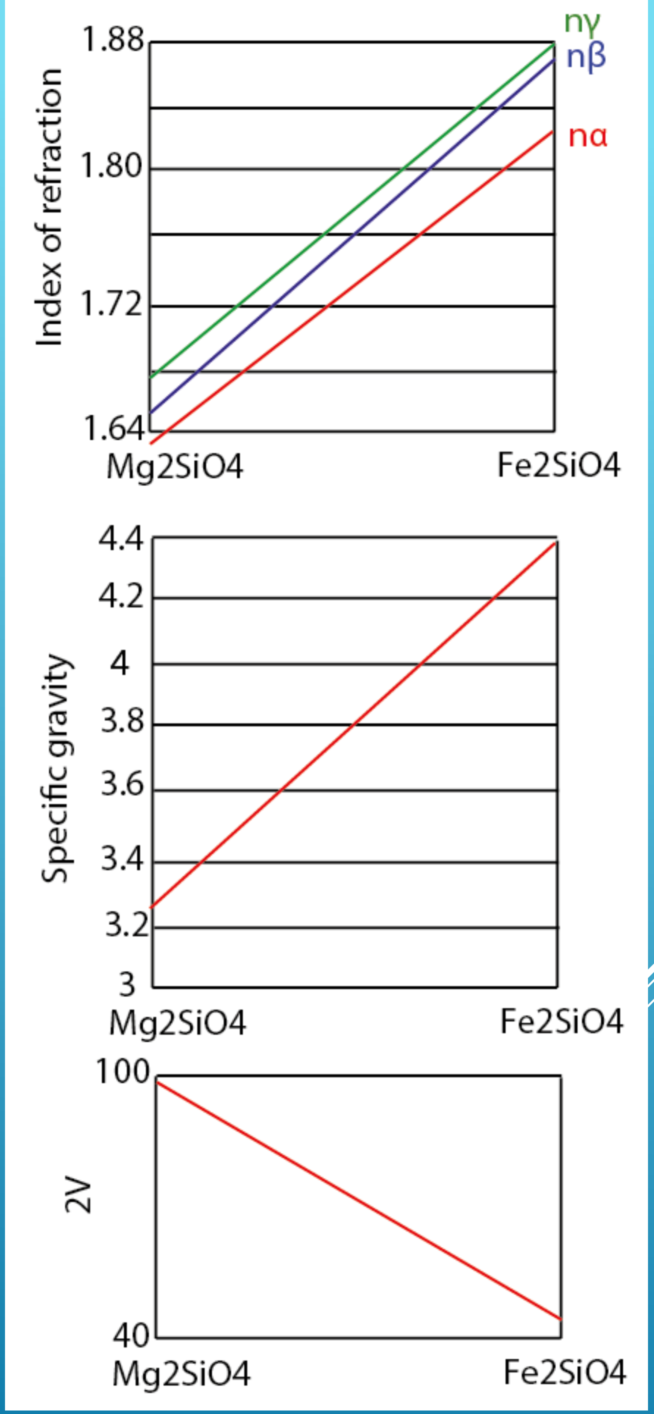
Incongruent melting: liquid and solid don't have the same composition



OLIVINE ▸ **Solid solution**

Olivine phase diagram





Incongruent melting: liquid and solid don't have the same composition

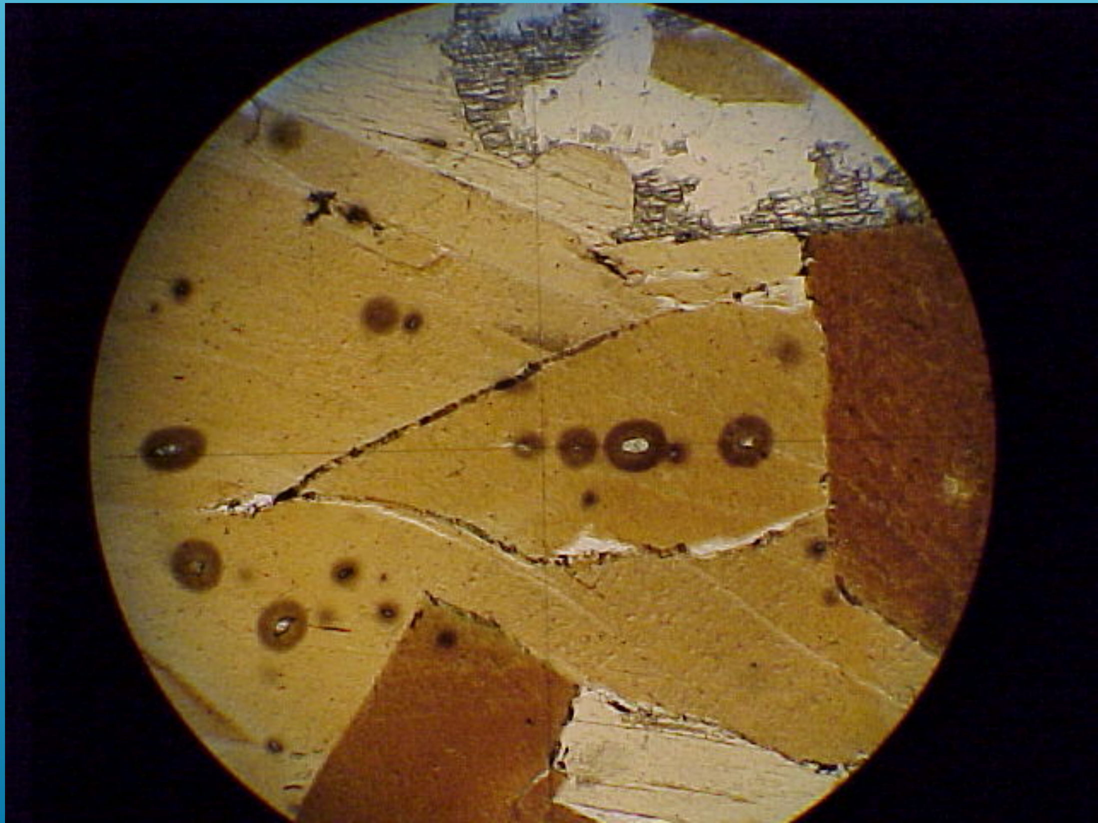
ZIRCON

- **What?**

- $ZrSiO_4$
- Zr can be substituted by Hf, U or Th but complete substitutions are rare
- U and Th: radioactive elements: allow the dating of rocks: oldest zircon: 4.4 Gy (Australia; Feb. 2014) vs. oldest rock: 4.03 Gy vs. oldest fossil: 3.4 Gy vs oldest proof of life (4.1Gy? – Sep. 2015)

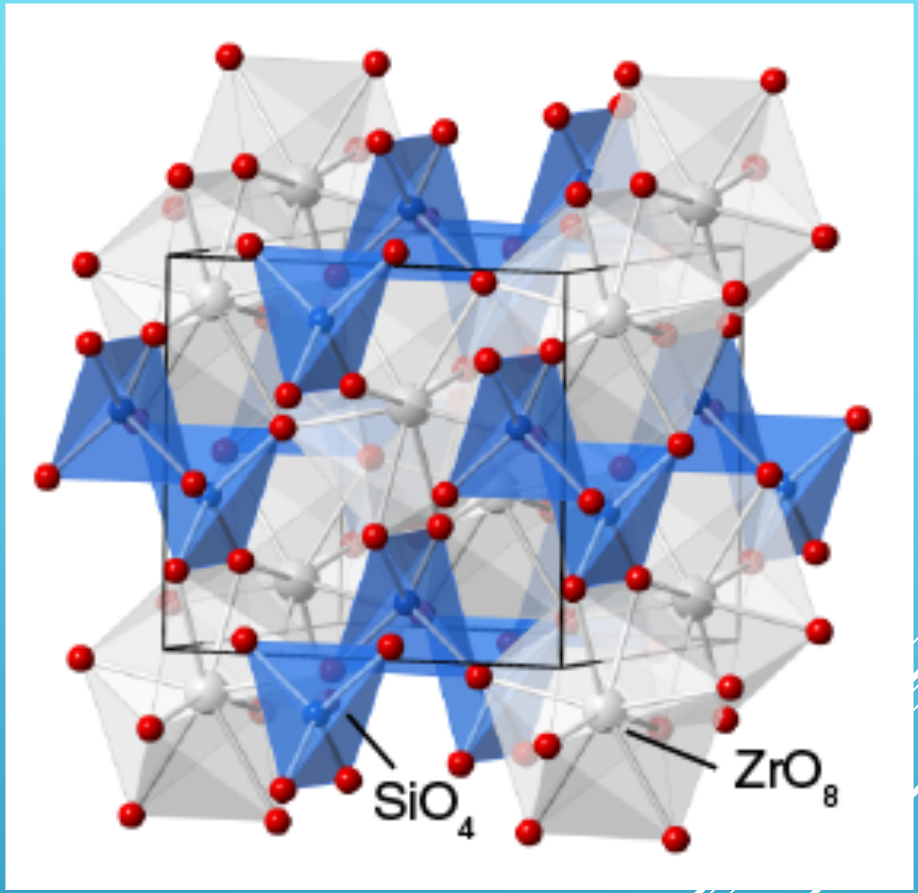
ZIRCON

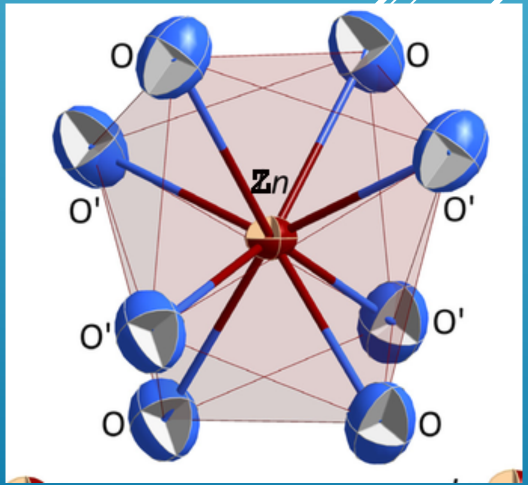
- **Where?**
- In granitoid (quartz + feldspar)
- Zircon: extremely resistant to alteration => in detritic sedimentary rocks
- As inclusion in biotite



ZIRCON

- **Structure**
- Zr: large cation => CN = 8
- System: tetragonal





GARNET

- **What?**

- $X_3^{2+}Y_2^{3+}[SiO_4^{4-}]_3$
- Aluminous garnet: Y = Al
  - $Mg_3Al_2(SiO_4)_3$: **py**rope
  - $Fe_3Al_2(SiO_4)_3$: **al**mandine
  - $Mn_3Al_2(SiO_4)_3$: **sp**essartine

Pyralspite group

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

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

Ugrandite group

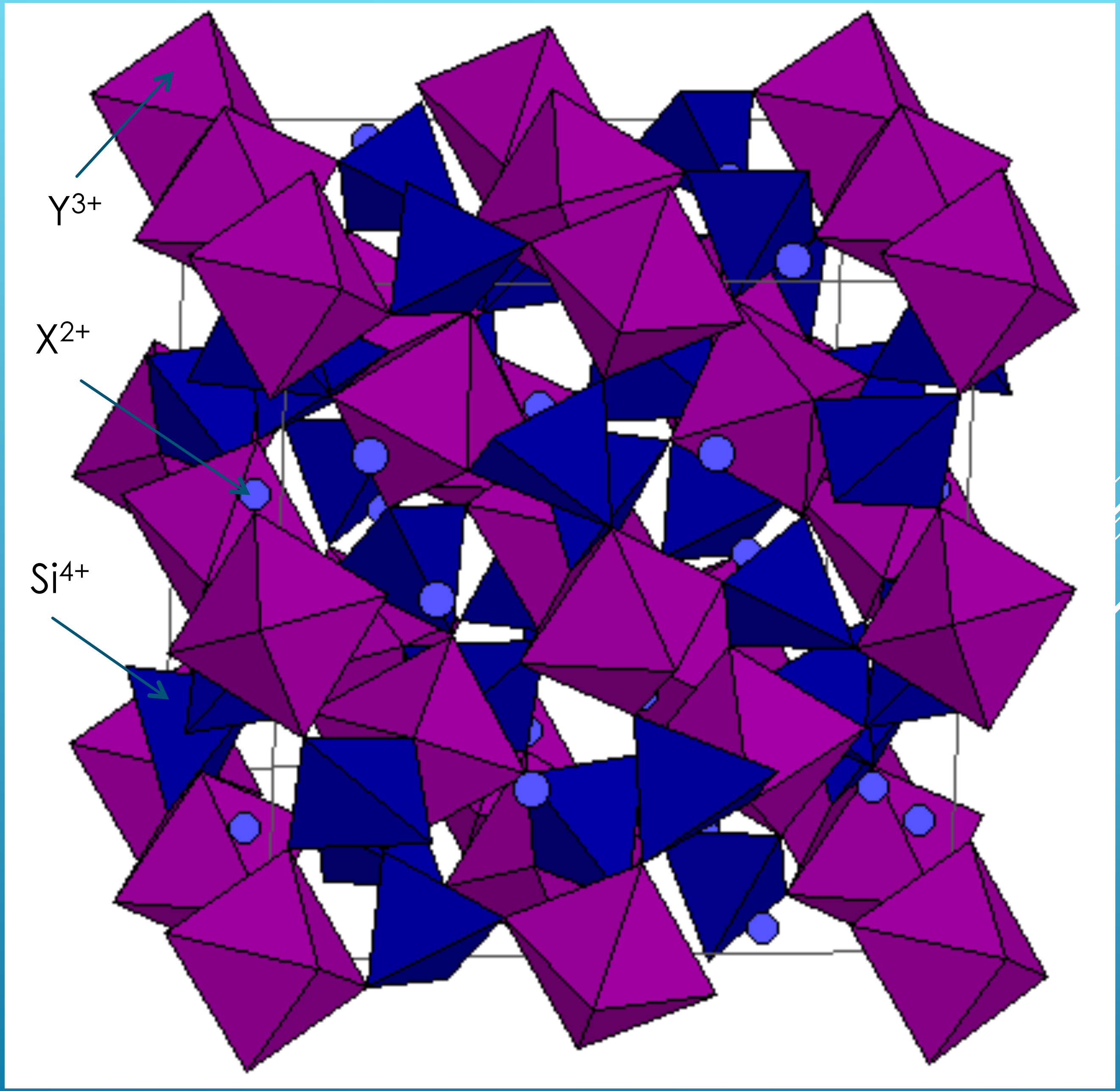
most common: ss grossular and andratite

GARNET

- **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**

GARNET

- **Structure**
- System: isometric
- Si^{4+}: tetrahedra (CN = 4)
- Y^{3+}: octahedra (CN = 6)
- X^{2+}: CN = 8



ALUMINUM SILICATE

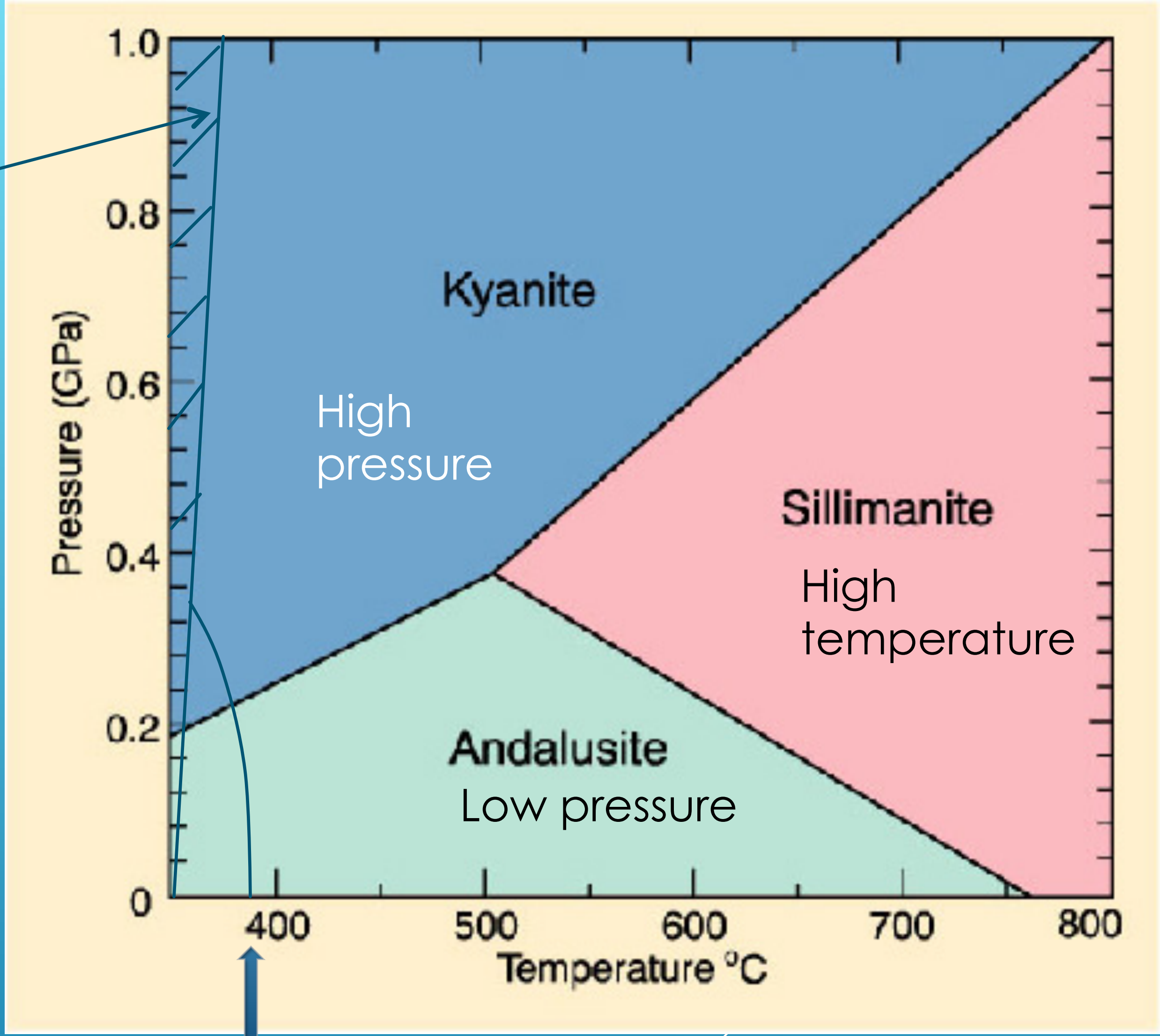
- **What?**

- **Al_2OSiO_4 => Al_2SiO_5:** Oxygen outside of the tetrahedra. O's do the links between the tetrahedra.
- Andalusite – sillimanite – kyanite: polymorphs

ALUMINUM SILICATE

- **Where?**
  - **Exclusively metamorphic**
  - **Al-rich rocks in clays and pelites**
  - **Indicator of metamorphic conditions**

Conditions that do not exist on Earth



Aluminum silicate apparition curve

ALUMINUM SILICATE

- **Structure**
- Andalusite:
  - Orthorhombic
  - Mostly pure (but possible substitution of Al with Mn^{3+} or Fe^{3+})
- Sillimanite:
  - Orthorhombic
  - Mostly pure (minor amount of Fe^{3+}, Cr^{3+} or Ti^{4+})
- Kyanite:
  - Triclinic
  - Mostly pure (minor amount of Fe^{3+}, Cr^{3+} or Ti^{4+})