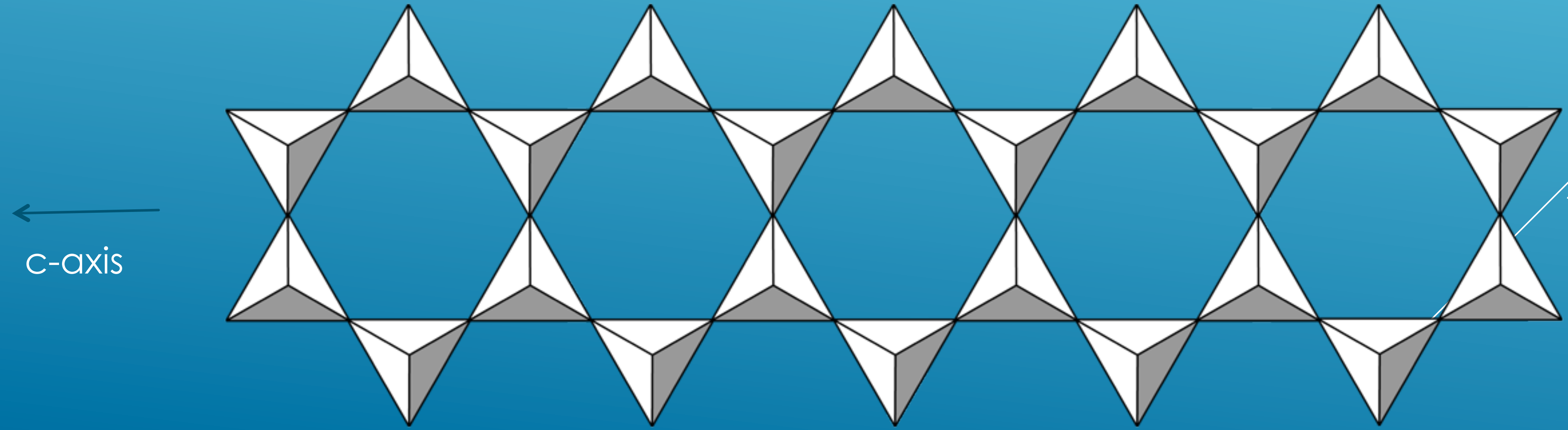
PART 3
CHAIN SILICATES

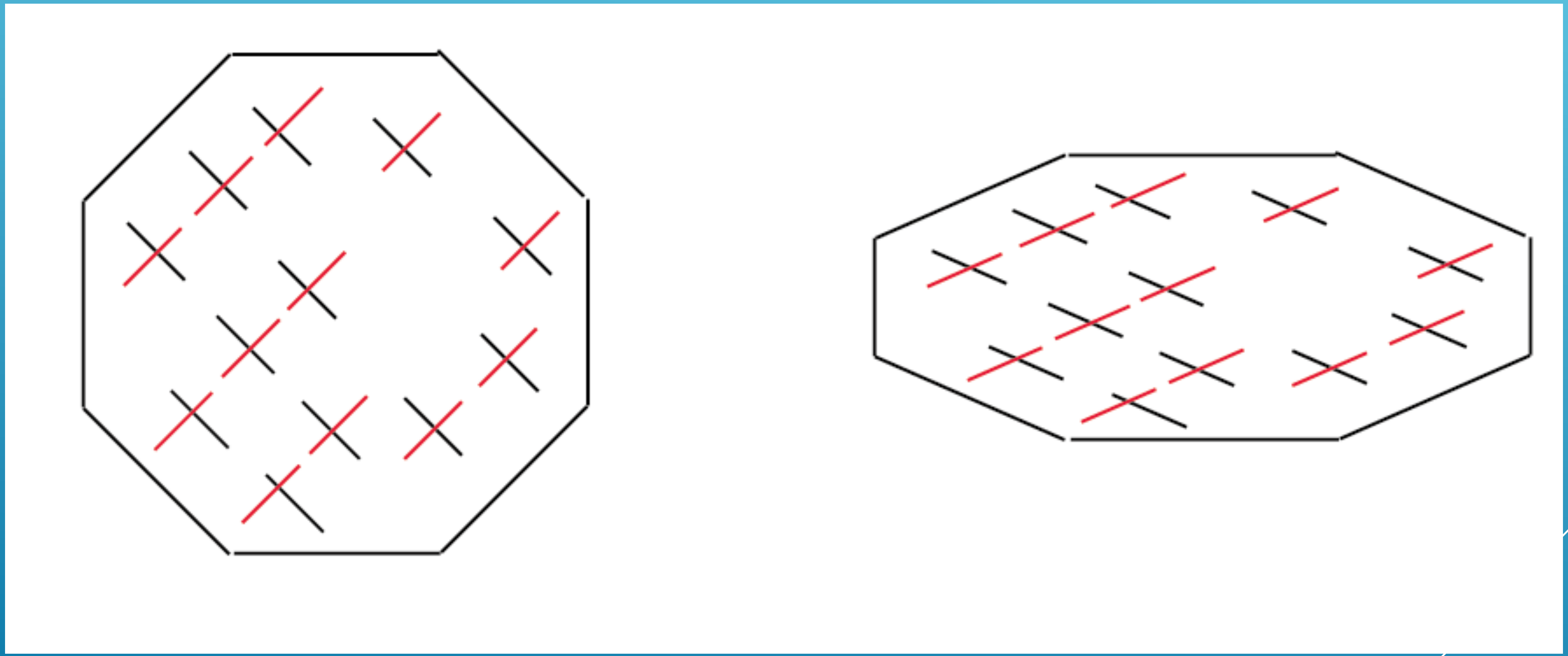
CHAIN SILICATES = INOSILICATES

- **“inos” = chains**
  - **Basic structural group: Si_2O_6 (each tetrahedra shared two corners)**
  - **Simple or double chains linked by cations**



CHAIN SILICATES = INOSILICATES

- **“inos” = chains**
- **2 directions of cleavage in all inosilicates**



Simple chain: 90° pyroxenes

Double chain: 120°: amphibole

CHAIN SILICATES = INOSILICATES

- **Important chain silicates:**
- **Pyroxenes**: simple chain – no water
- **Amphiboles**: double chain – with water

PYROXENES

- **What?**
- **XYZ_2O_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
- **2 groups:**
  - Orthorhombic: **orthopyroxene**
  - Monoclinic: **clinopyroxenes**

ORTHOPYROXENES

- What? (Fe,Mg)SiO_3
- Solid solution between a Mg- and a Fe-end-member:

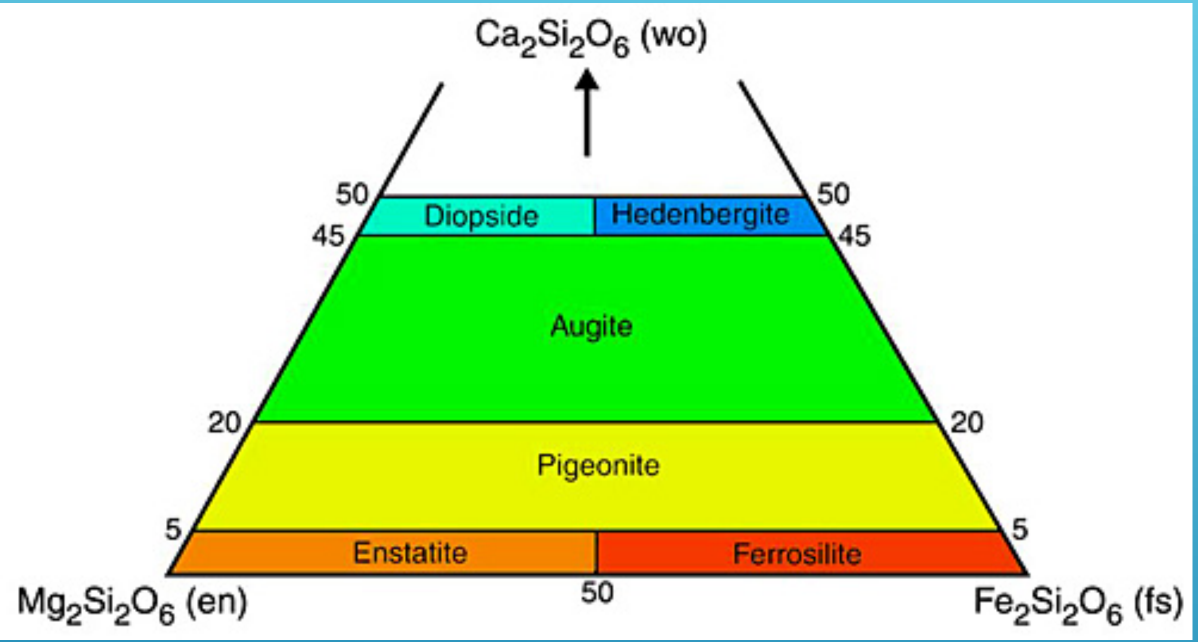
  $MgSiO_3 \leftrightarrow FeSiO_3$

  enstatite   ferrosilite

CLINOPYROXENES

- **What? $(Ca,Na,Mg,Fe,Ti)_2(Si,Al)_2O_6$**
- **Solid solutions:**
  - **The diopside-hedenbergite series:**
    Diopside $CaMgSi_2O_6$ ↔ Ferrohedenbergite $CaFeSi_2O_6$
  - **The sodic pyroxenes:**
    Jadeite $NaAlSi_2O_6$ ↔ Aegerine $NaFeSi_2O_6$ ($Fe=Fe^{3+}$)
  - **Augite: $(Na,Ca)(Mg,Fe,Al)Si_2O_6$** (addition of Al and minor Na substitution to the diopside-hedenbergite series)
  - **Omphacite: $(Na,Ca)(Mg,Fe^{2+},Fe^{3+},Al)Si_2O_6$**: intermediate between augite and jadeite
  - **Pigeonite: $(Ca,Mg,Fe)(Mg,Fe)Si_2O_6$**

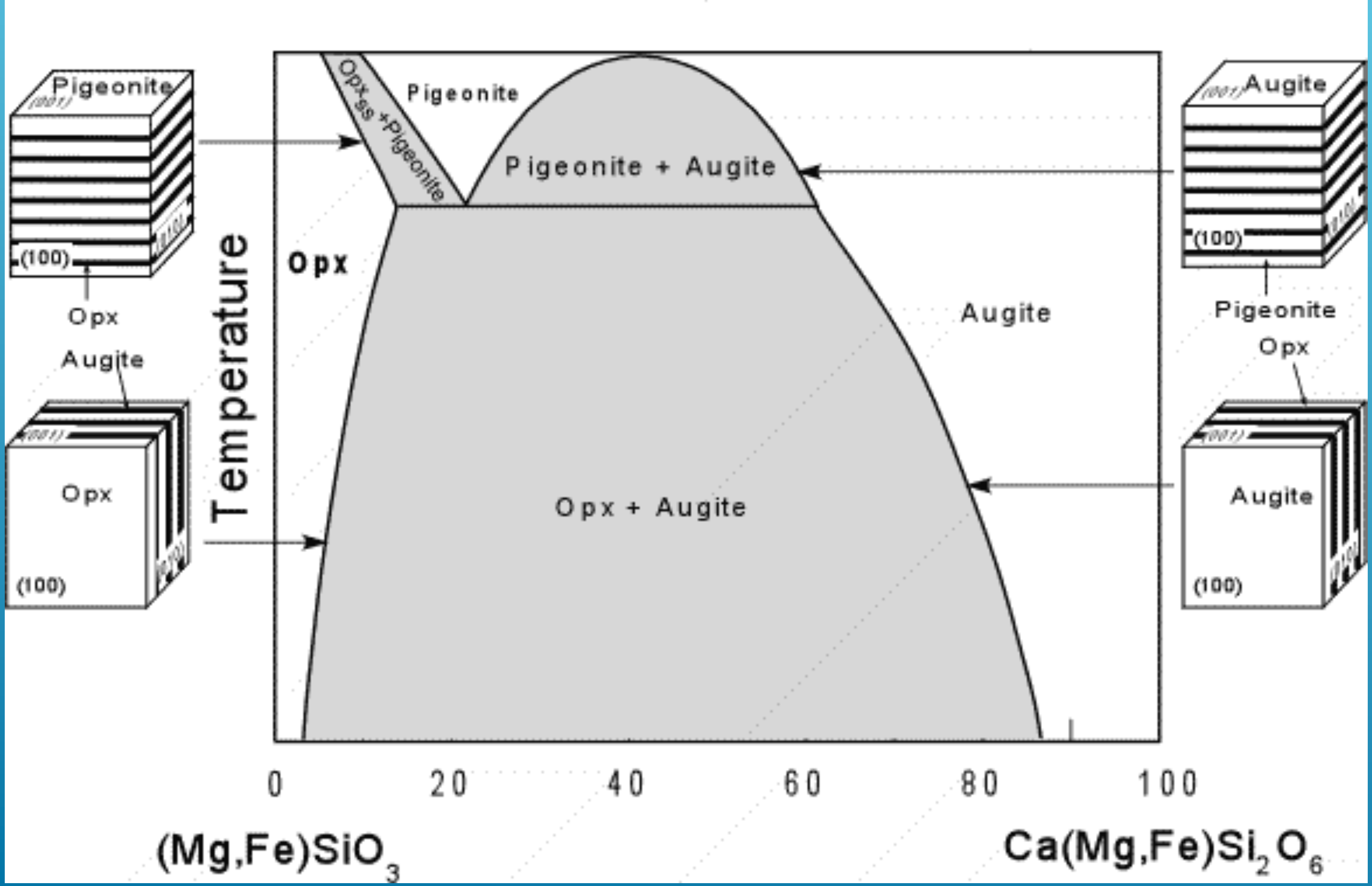
PYROXENES



- **Classification of Al-free pyroxenes** (opx, augite, diopside-hedenbergite series, pigeonite)
- Rq: $CaSiO_3$: wollastonite: inosilicate but not a pyroxene (chains of 3 tetrahedra instead of two)
- **Complete Fe-Mg solid solution for both opx and cpx**
- **The Mg-end member melts at higher temperature (as with most Mg-Fe solid solutions)**

PYROXENES

- **Solid immiscibility between diopside-hedenbergite series and opx series = presence of a solvus**

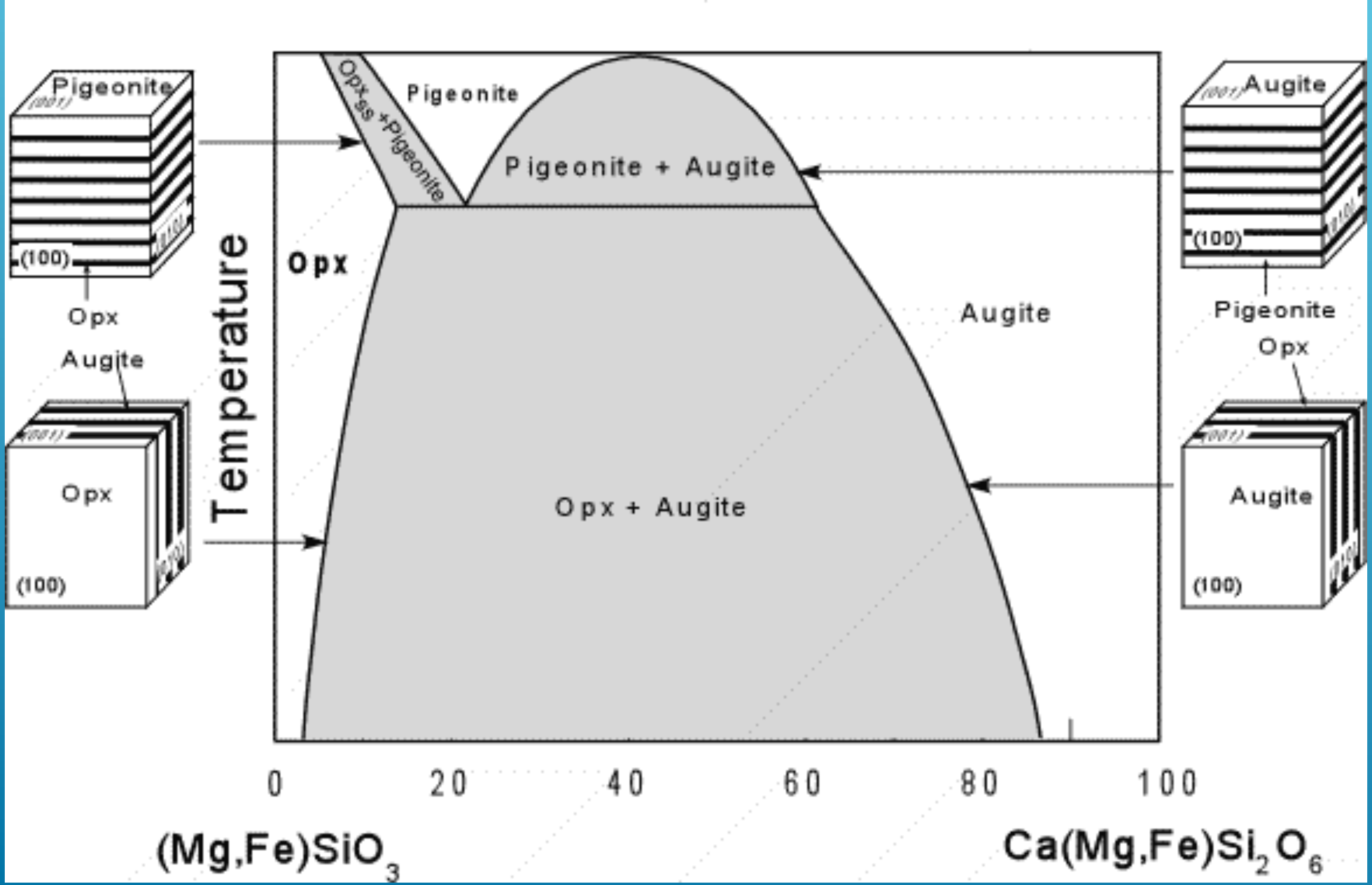


http://www.tulane.edu/~sanelson/eens211/inosilicates.htm

- Rq: **pigeonite:** only stable at high temperature => only found in volcanic rock that cooled fast (volcanic or shallow intrusive rock)

PYROXENES

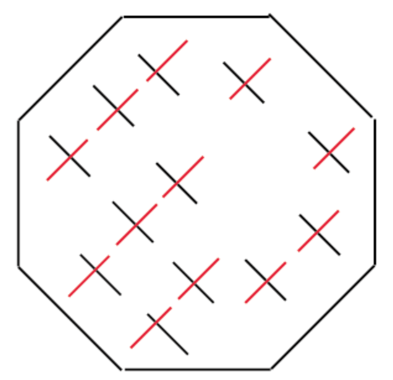
- **Solid immiscibility between diopside-hedenbergite series and opx series = presence of a solvus**



http://www.tulane.edu/~sanelson/eens211/inosilicates.htm

- Rq: In augite:
  - lamella of pigeonite : parallel to (001)
  - Lamella of opx: parallel to (100)

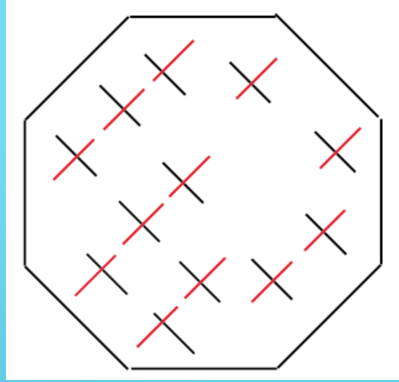
PYROXENES

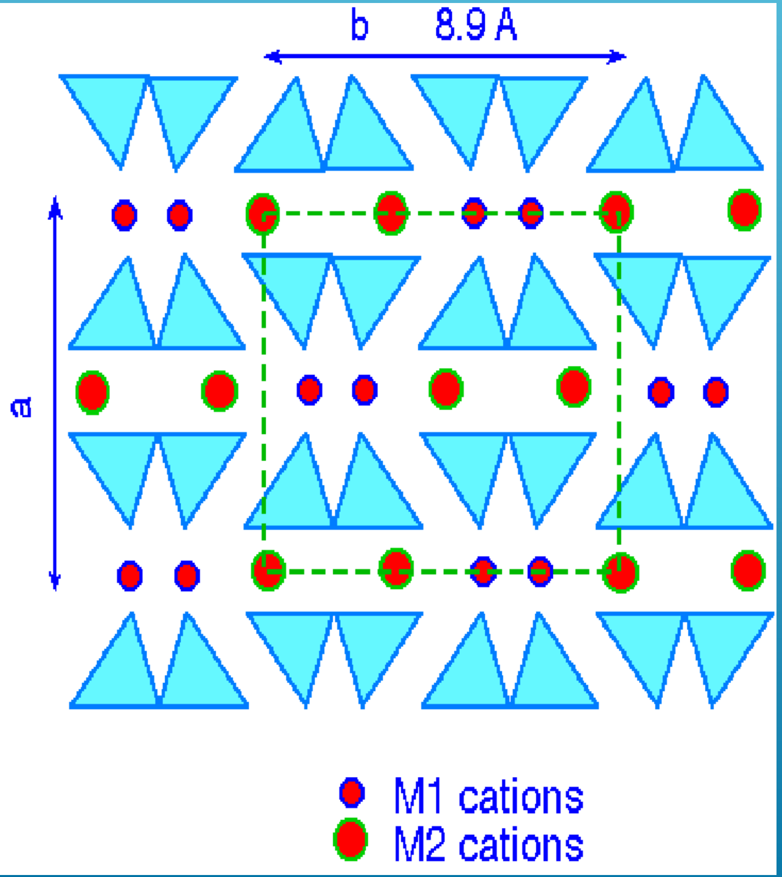


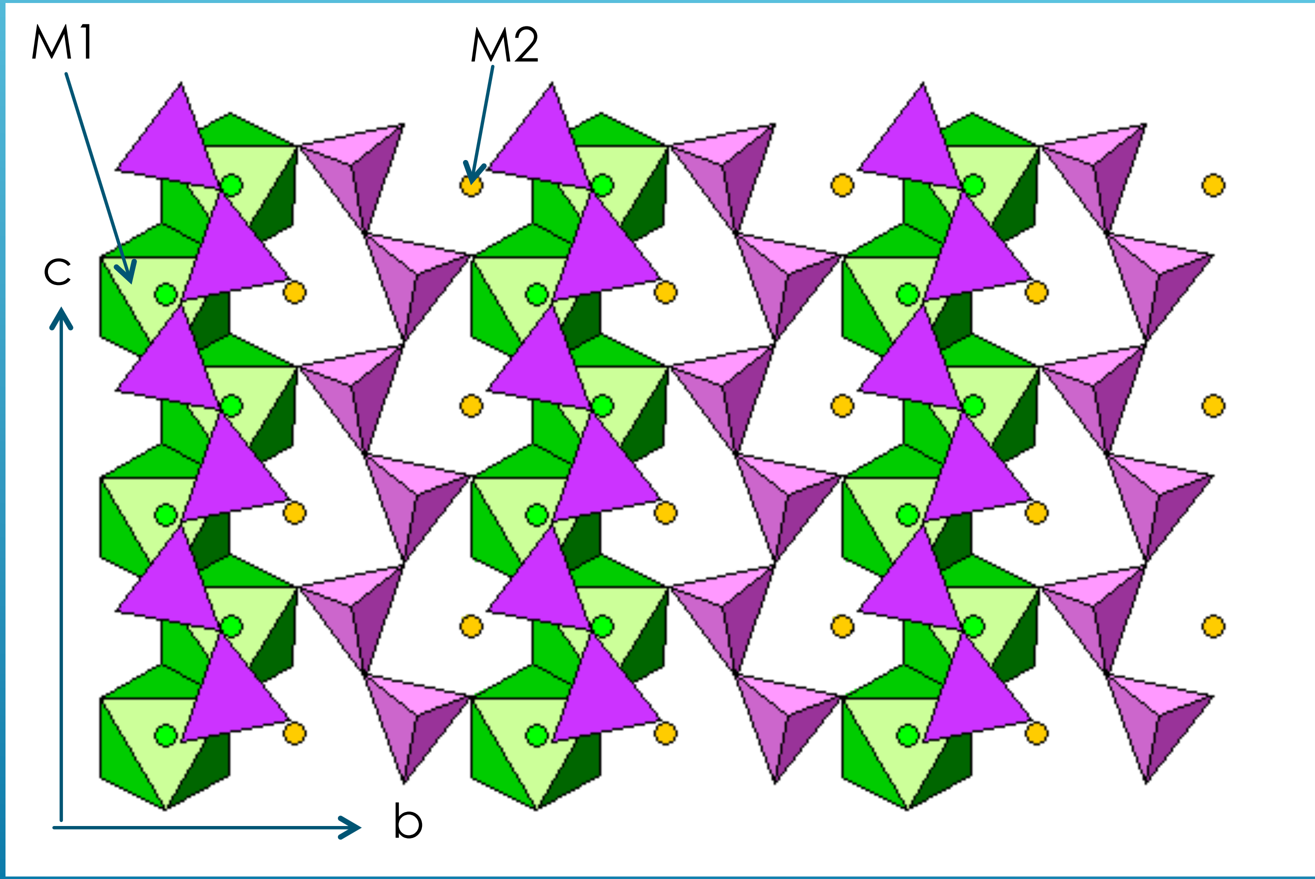
- **Pyroxene vs. amphibole**: cleavages: ~90° vs. ~120°
- **Opx vs. cpx:** in thin section: opx (orthorhombic): only parallel and symmetrical extinction vs. cpx (monoclinic): inclined on all faces except (100)

PYROXENES

- **Structure**







PYROXENES

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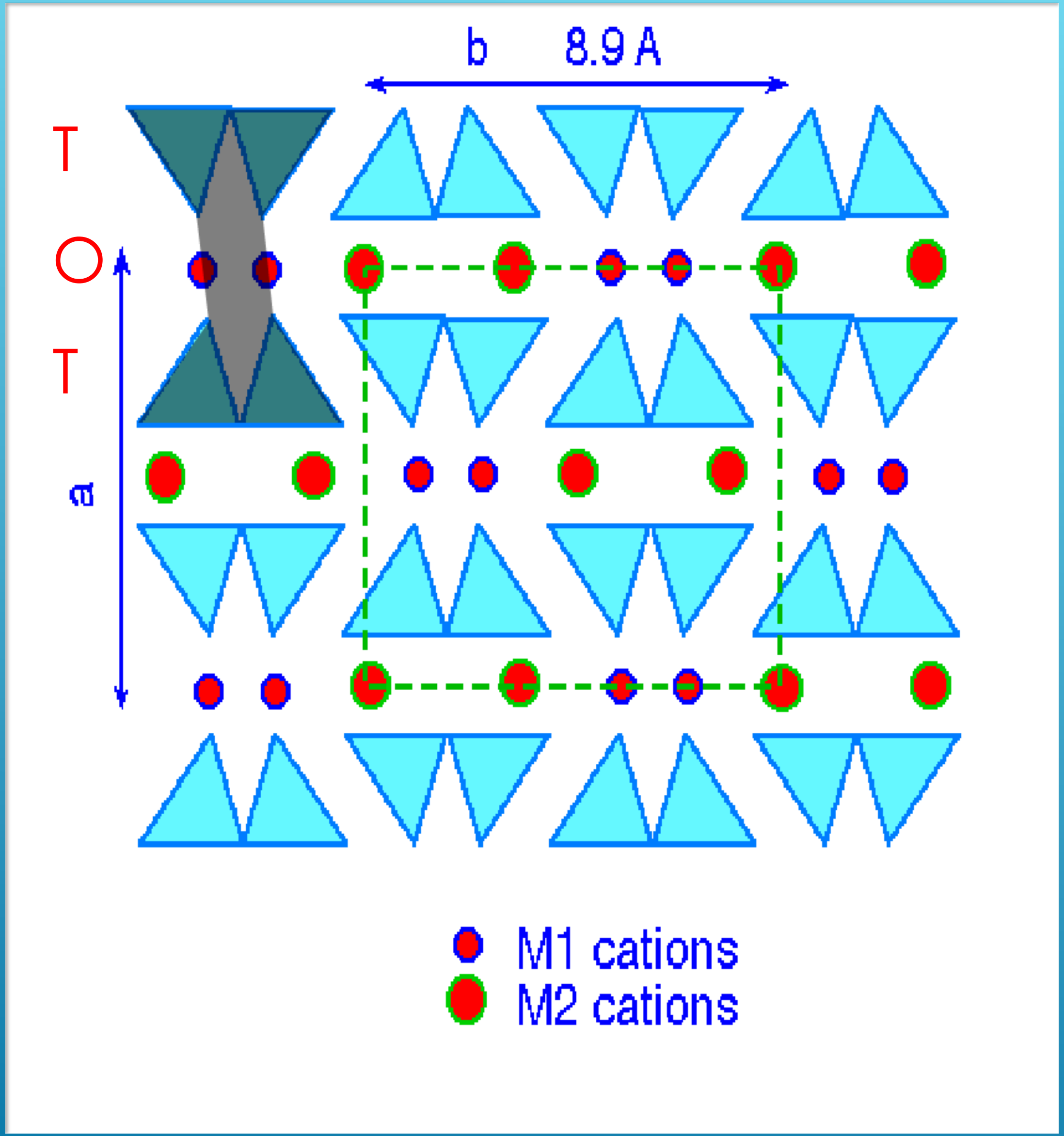

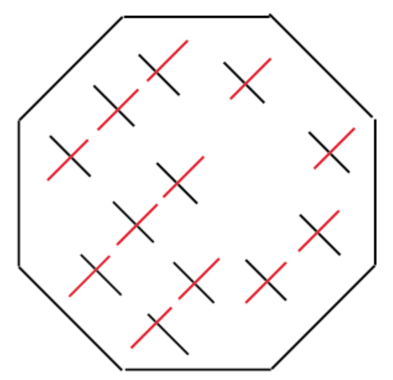

PYROXENES

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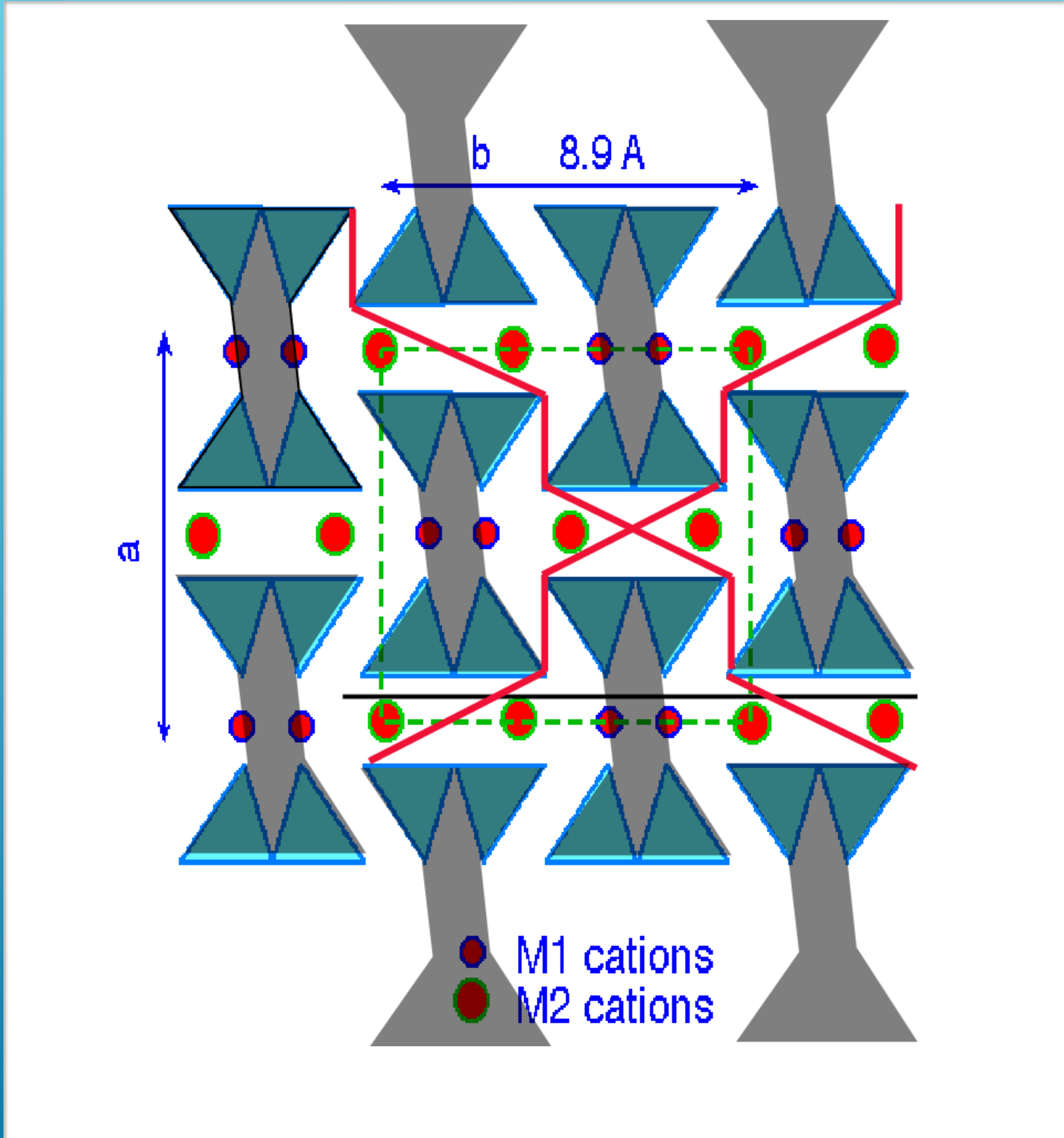

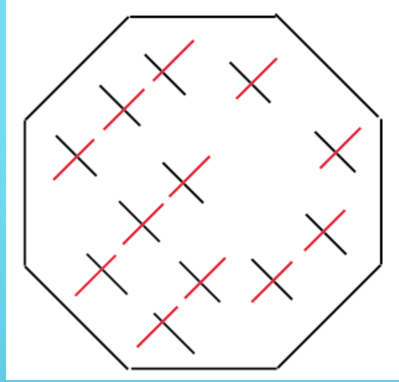

PYROXENES

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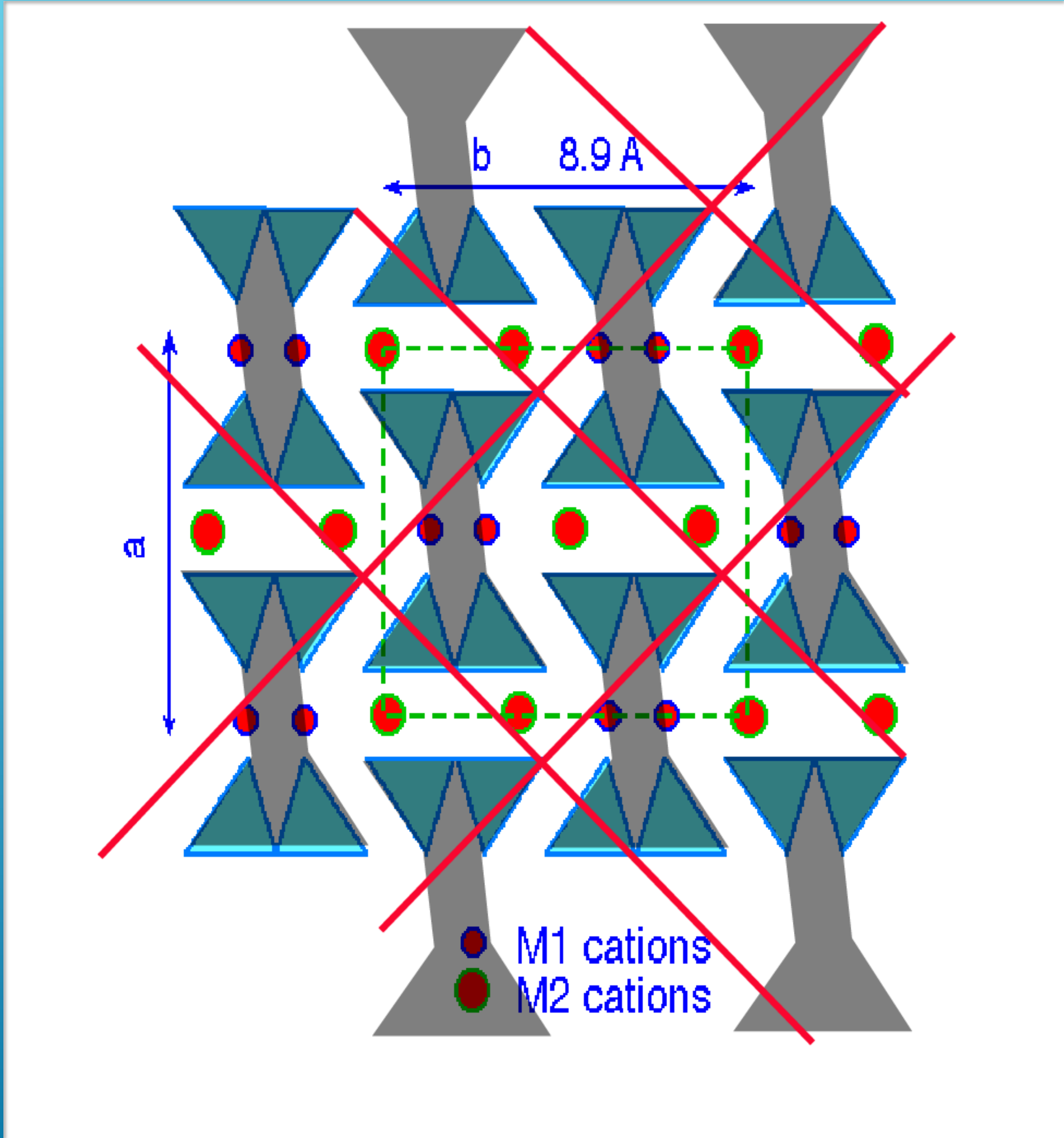
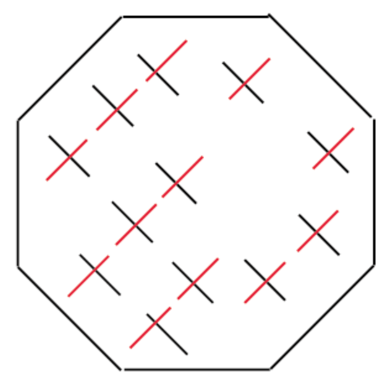




PYROXENES

- **Where?**
- **Augite:** - plutonic and volcanic igneous rocks

  - high-grade metamorphic rocks: gneiss and granulite

Rq: cleavage = 90° - dark green, thin section: inclined extinction, biaxial positive, 2V = 60°, δ augite (2nd or 3rd order) > δ opx, high relief, colorless to brown or green, no pleochroism

- **Opx (=hyperstene):** - plutonic and volcanic igneous rocks

  - meta-igneous rocks

Rq: cleavage = 90° - brown, thin section: parralel extinction, lower δ , pleochroism: light pink to light green, optic sign: close to enstatite (Mg): + (2V = 60-90°) ≠ intermediate (Fe): - (2V= 50-90°)

PYROXENES

- **Pigeonite** : - in volcanic rocks

  - as exsolution lamella in shallow intrusive rocks

- Rq: cleavage = 90° - brown, thin section: 2V=0-30°, no pleochroism, inclined extinction

- **Aegerine:** sodic pyroxenes: found in alkalic igneous rocks associated with sodic amphiboles, alkali feldspars, and nepheline:

  - plutonic rocks: alkali granites, quartz syenites, and nepheline syenites

  - Volcanic rocks: peralkaline rhyolites.

Rq: cleavage = 90° - dark green/black/brown, thin section: low extinction angle (≠ augite), green brown pleochroism

PYROXENES

- **Jadeite** : - in high pressure metamorphic rocks: can be formed by reaction: Albite ($NaAlSi_3O_8$) →Jadeite ($NaAlSi_2O_6$) + Quartz (SiO_2)

  - as exsolution lamella in shallow intrusive rocks

- Rq: cleavage = 90° - light/medium green, thin section: low relief – small 2V – low , colorless

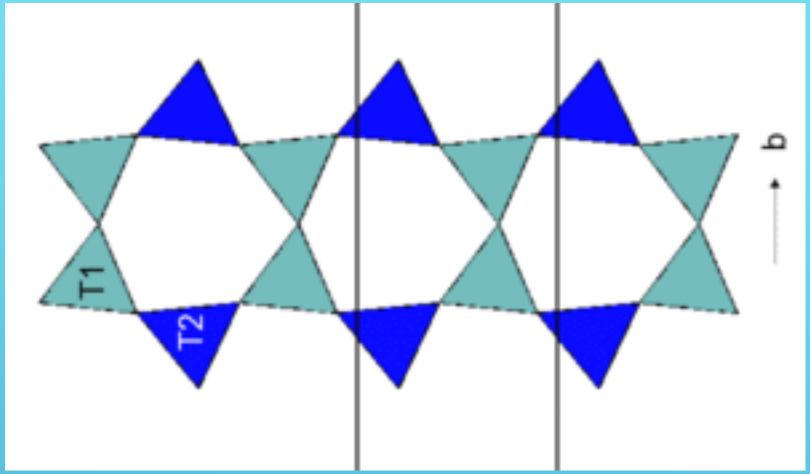
- **omphacite:** formed at high pressure (upper mantle or lower crust):

  - in eclogite (associated with garnet): HP metamorphosed basalt or gabbro

Rq: cleavage = 90° - green/dark green, thin section: high positive relief, colorless or pale green, larger 2V than augite and darker color than jadeite

AMPHIBOLES

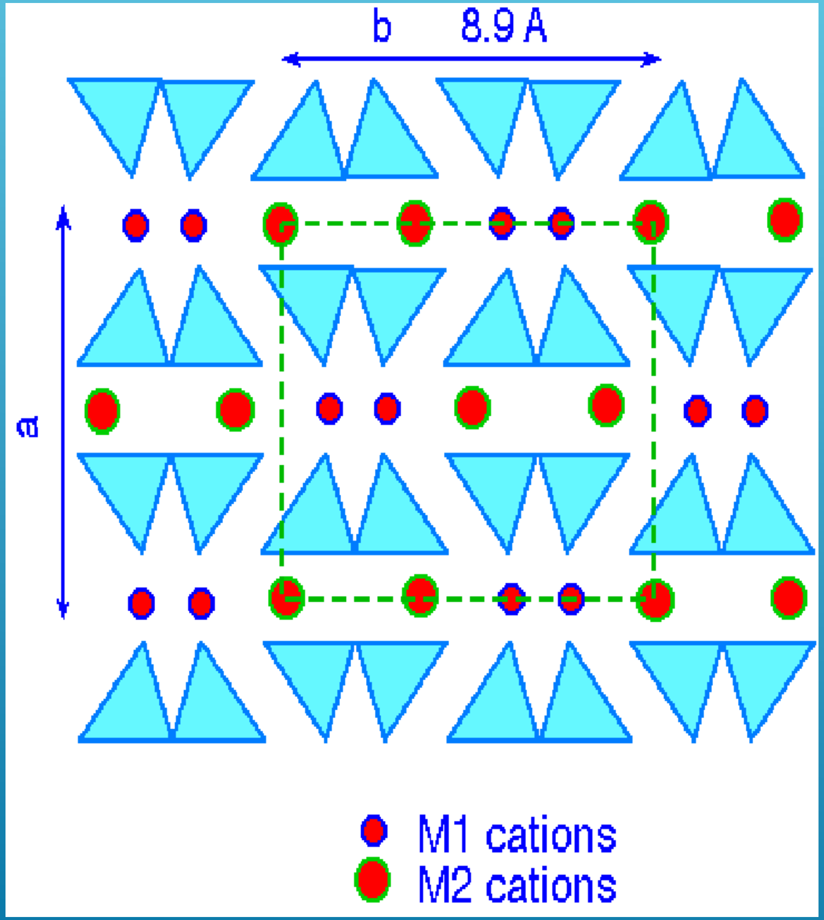
- **What?**
- **Basic structural unit: $(Si_4O_{11})^{6-}$**
- **$W_{0-1}X_2Y_5Z_8O_{22}(OH,F)_2$: HYDROUS MINERAL**
  - W = Na^+, K^+: sites A – CN = 10 or 12
  - X= Ca^{2+}, Na^+, Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}: Sites M4 – CN = 6 or 8
  - Y = Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+} or Ti^{4+}: octahedral sites M1
  - Z = Al^{3+} or Si^{4+}: Tetrahedral sites
- **Solid-solution:**
  - Complete substitution of Na and Ca and of Mg and Fe end-members
  - Partial substitution of Si by Al or OH by F



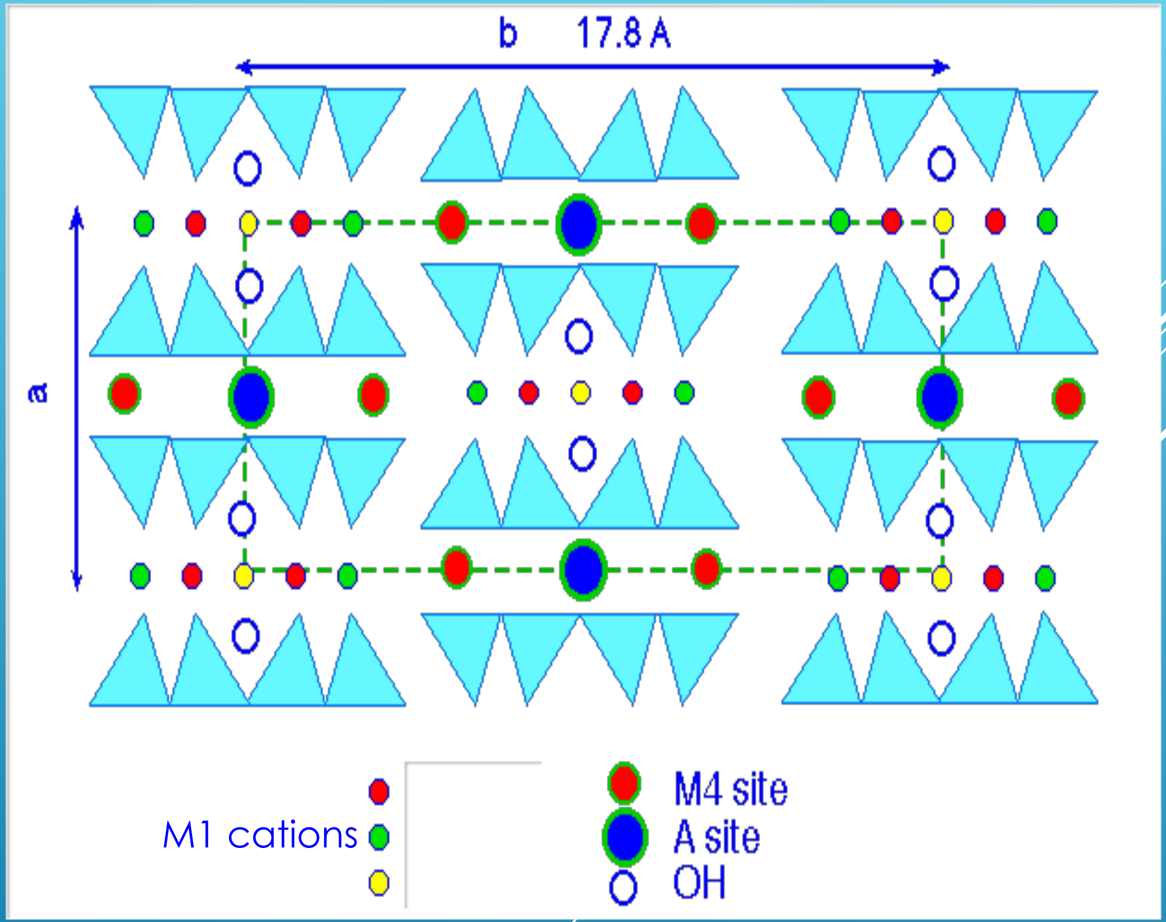
Si_4O_{11}

AMPHIBOLES

- **Structure**



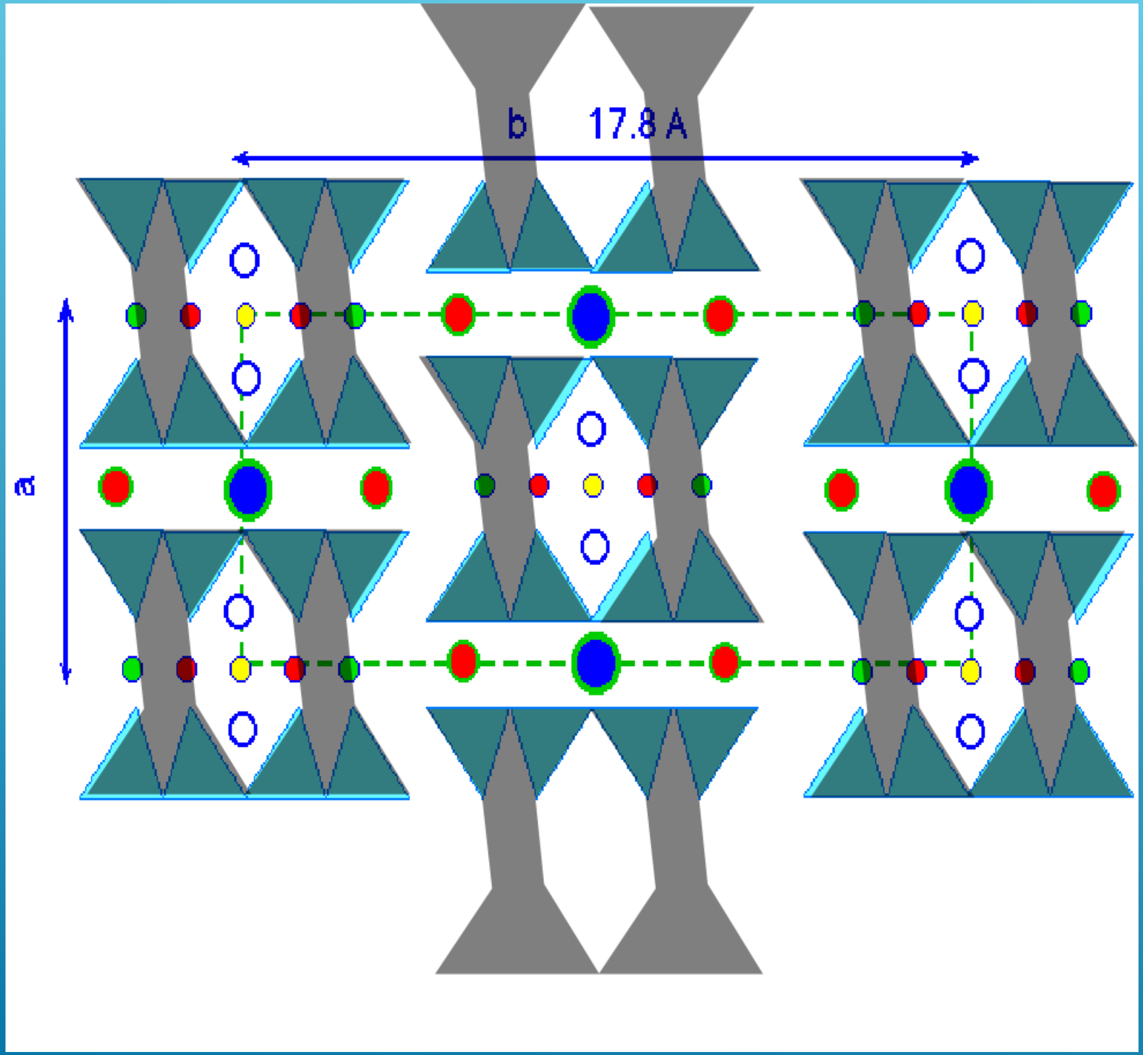
pyroxene



amphibole

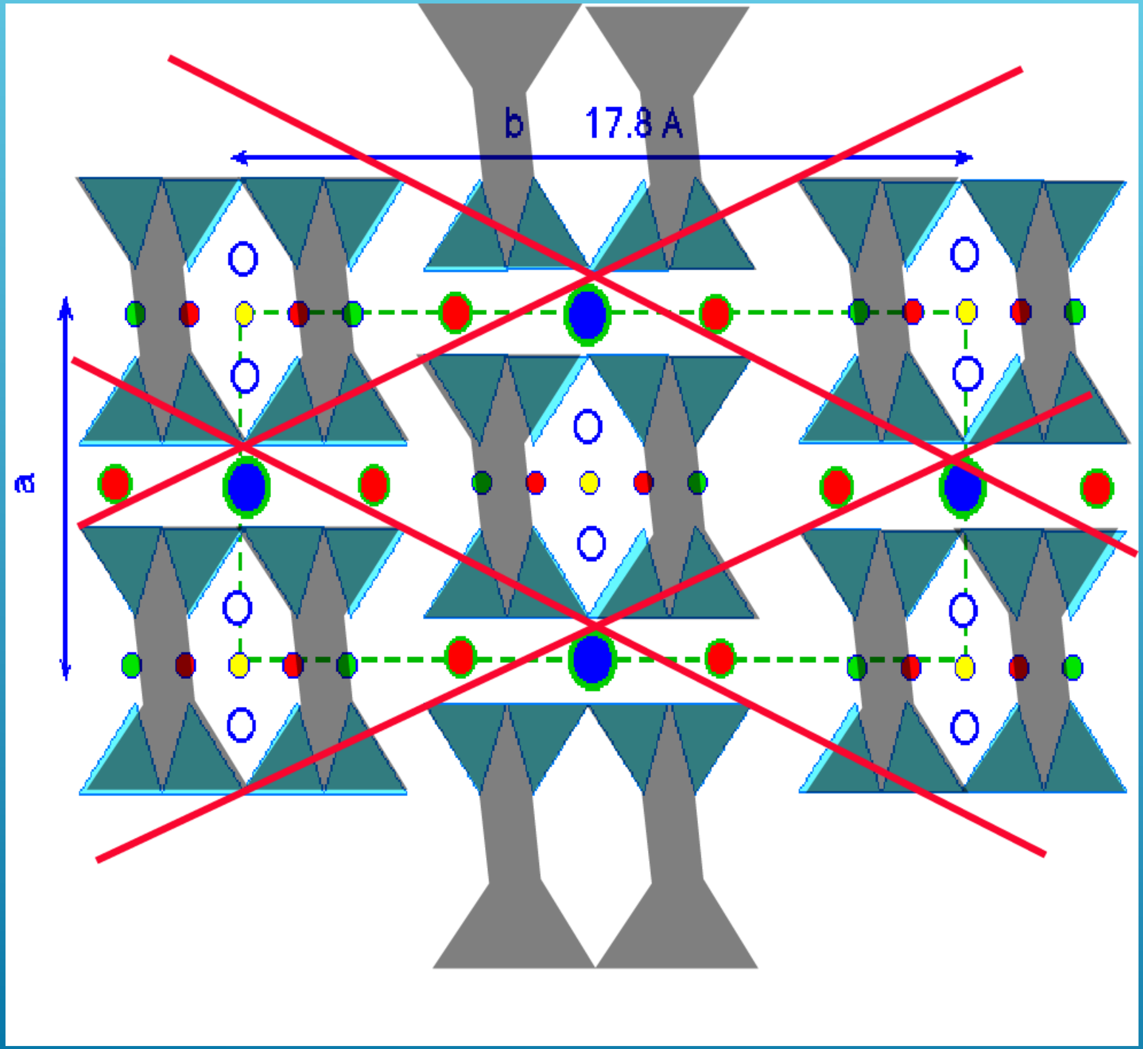
AMPHIBOLES

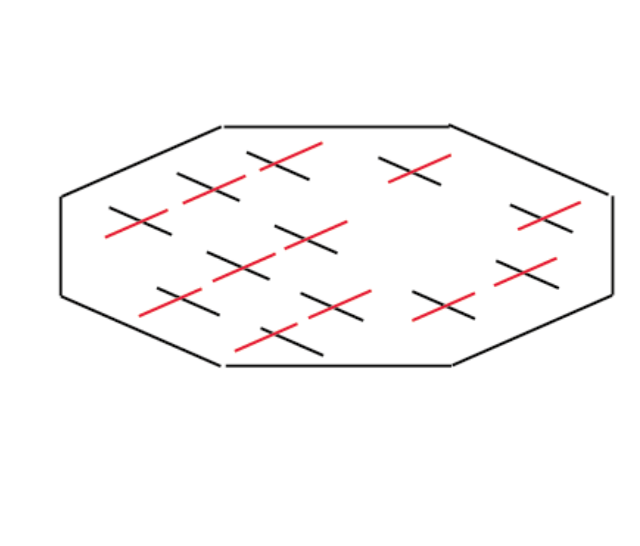
- **Structure**



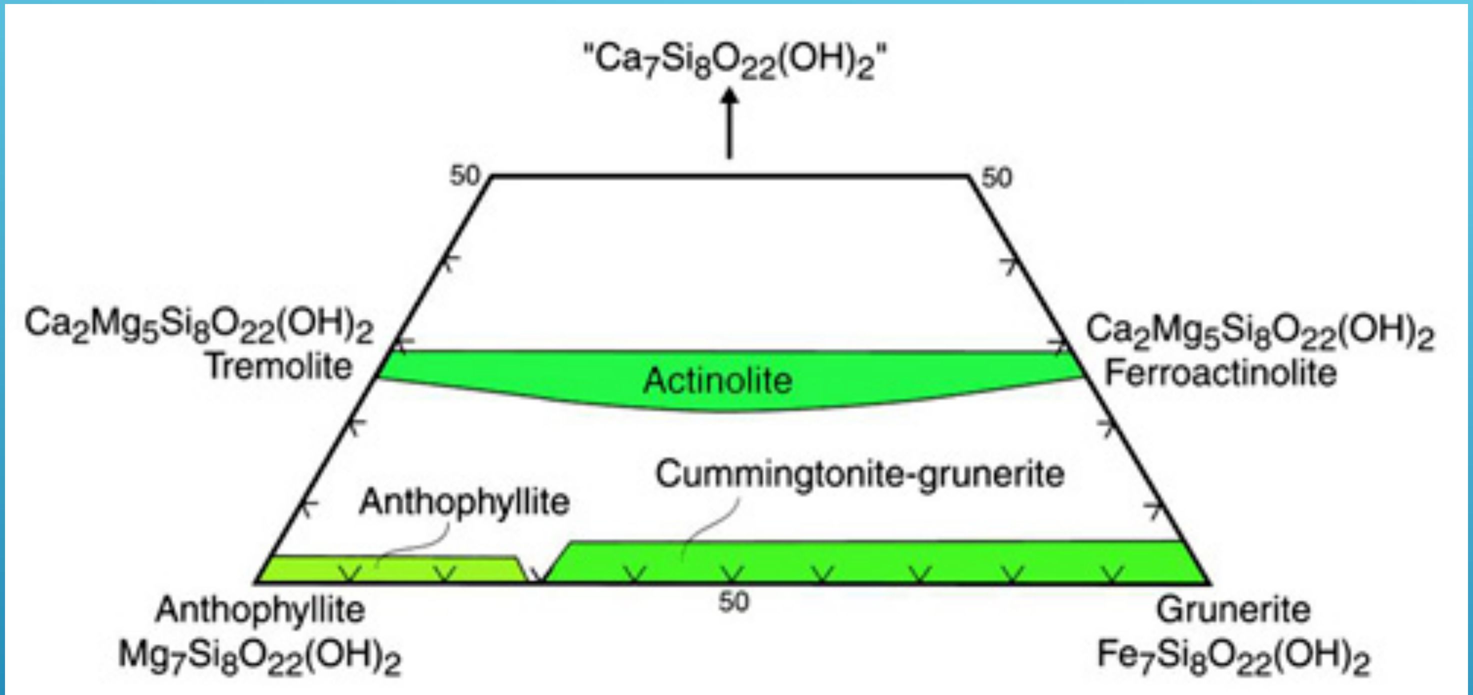
AMPHIBOLES

- **Structure**





AMPHIBOLES



- **Classification of non sodic amphiboles**
- **Most common amphibole: Hornblende**

$(Ca,Na)_{2-3}(Mg,Fe,Al)_5Si_6(Si,Al)_2O_{22}(OH,F)_2$

(addition of Al and minor Na substitution to the tremolite-ferroactinolite series)

AMPHIBOLES

- **orthorhombic:**
- Anthophyllite: from hydrothermal alteration of ultrabasic rocks
- **Monoclinic:**
- **Hornblendes:**
  - Ca-rich: green hornblende – in intermediate plutonic rocks (diorite, granodiorite)
  - Fe,Mg-rich: brown hornblende – in intermediate lavas
- **Sodic amphiboles: in alkaline rocks**
  - Glaucophane - $Na_2Mg_3Al_2Si_8O_{22}(OH)_2$: HP-LT metamorphism (blueschist)
  - Riebeckite - $Na_2Fe_2Fe_3Si_8O_{22}(OH)_2$
  - Arfvedsonite – $Na_3Fe_4FeSi_8O_{22}(OH)_2$

AMPHIBOLES

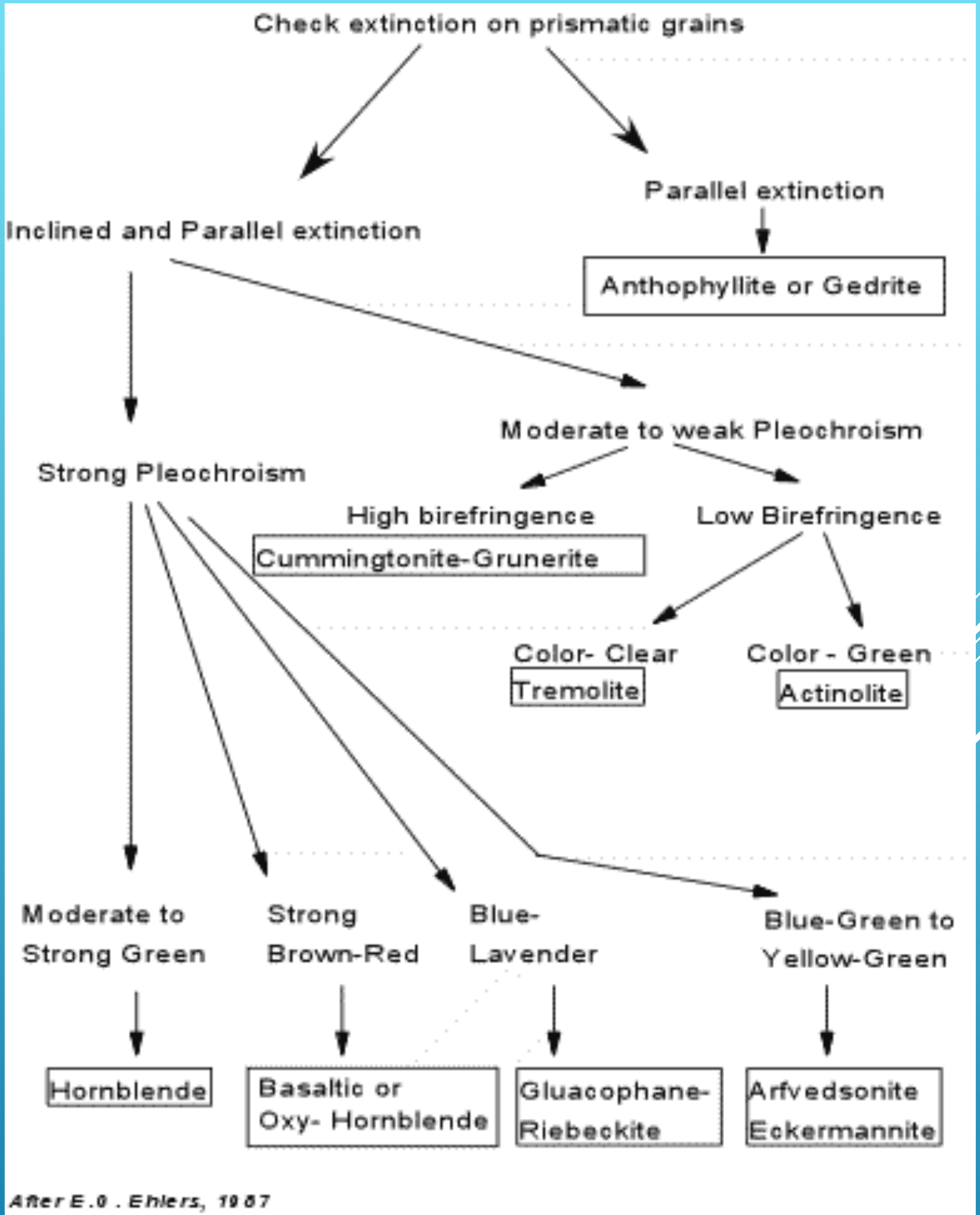
- **Hydrous mineral:**
  - Not stable at very high temperature: dehydration of amphiboles give pyroxenes
  - **Si:O ratio:** higher in amphiboles (4:11) than pyroxenes or olivine: Si-richer rocks

- **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

AMPHIBOLES

- **Distinction of the different amphiboles in thin section**



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