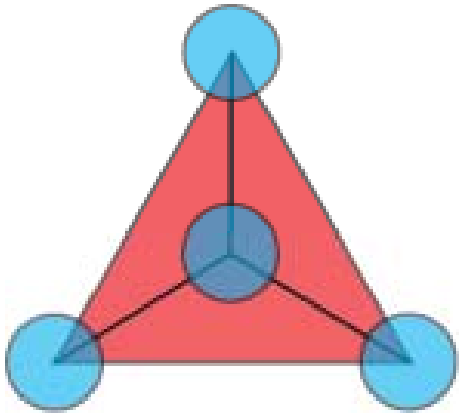
Silicate Structures

The building blocks of the common rock-forming minerals

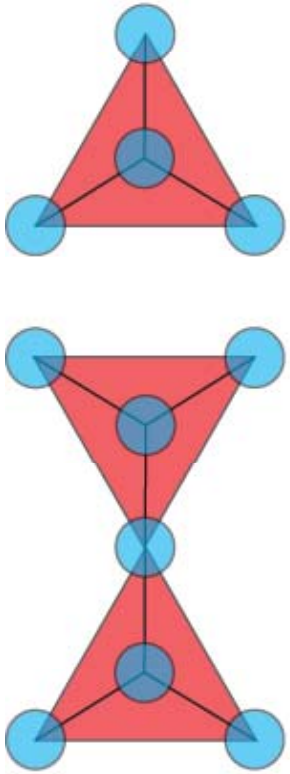
Though there are may minerals that compose the Earth system, silicates (Si and 4O) are especially in the Earth's crust and mantle



The basic unit for all silicates is the (SiO_4) tetrahedron. This is an overall 4- charge.

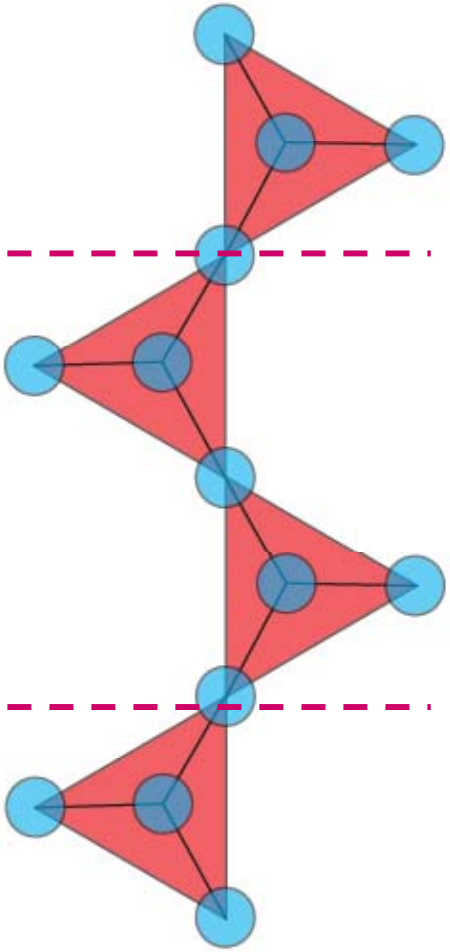
The variety of silicate minerals is produced by the $(SiO_4)^{4-}$ tetrahedra linking to self-similar units sharing one, two, three, or all four corner oxygens of the tetrahedron.

$(SiO_4)^{4-}$
Orthosilicates

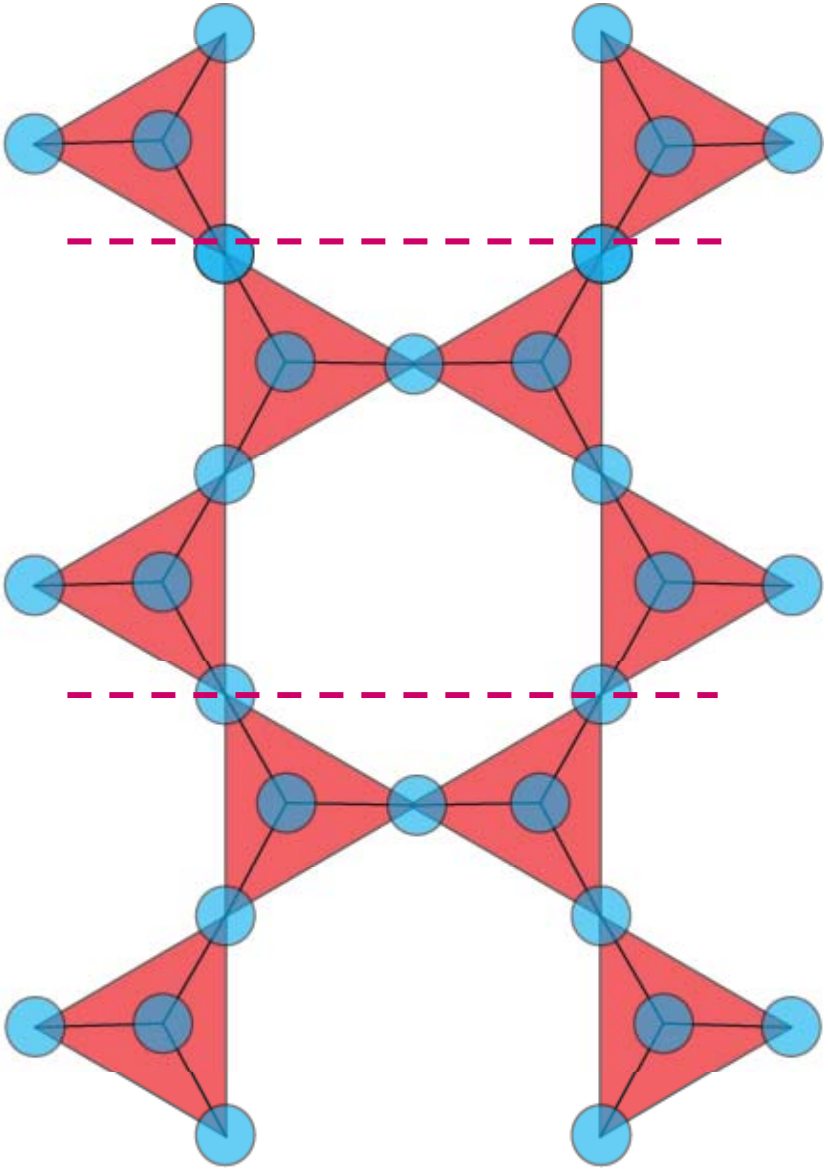


$(Si_2O_7)^{6-}$
Orthosilicates

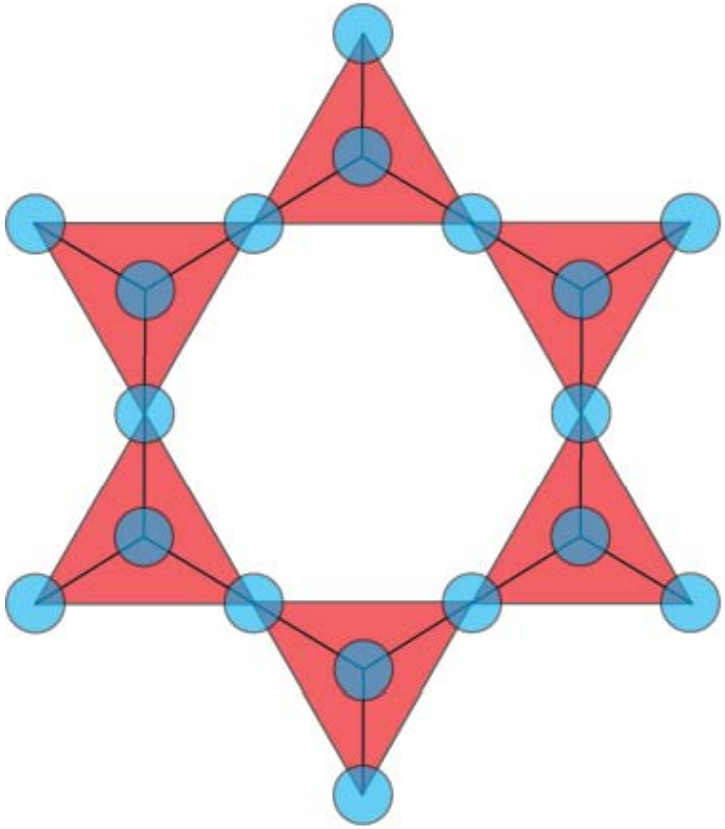
$(Si_2O_6)^{4-}$
Single chain silicates



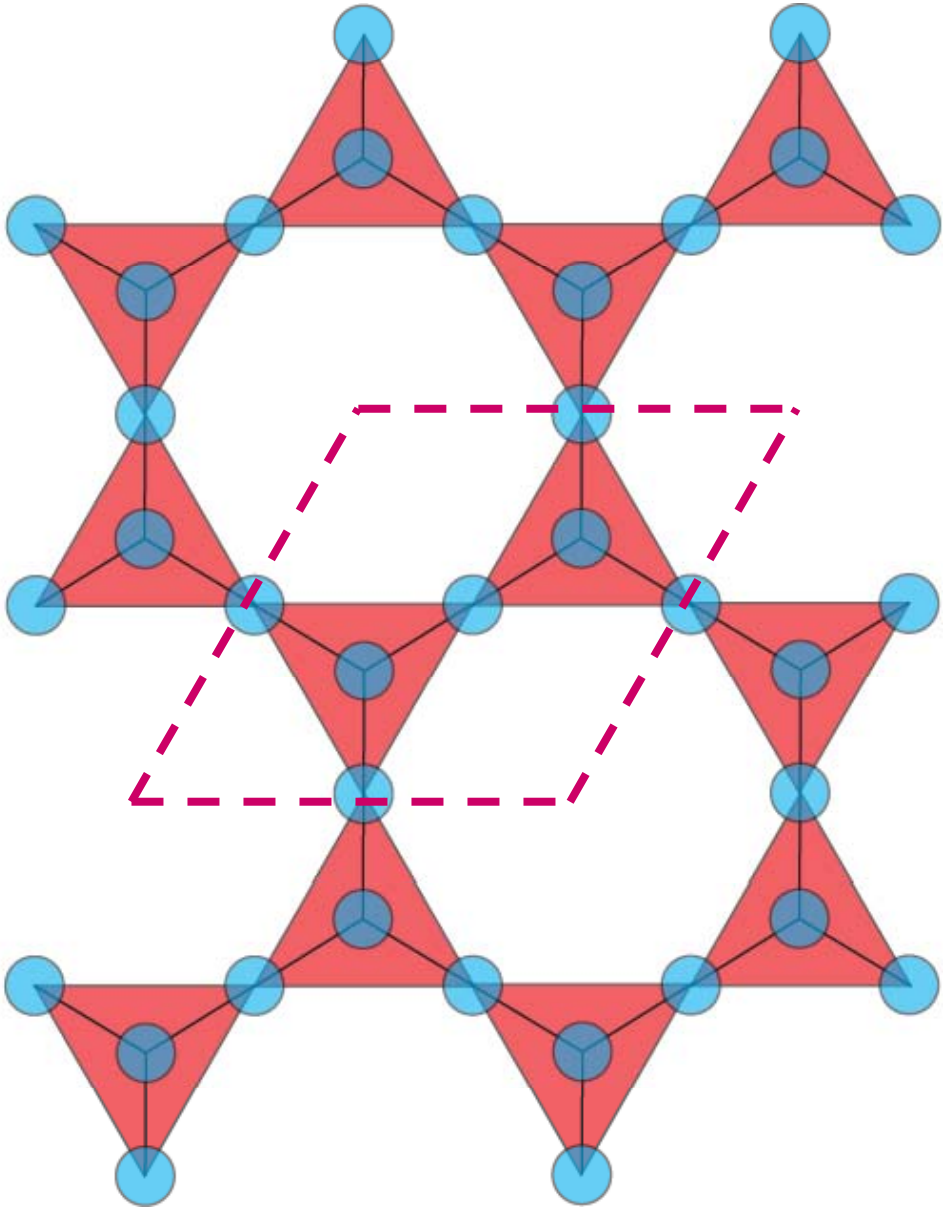
$(Si_4O_{11})^{6-}$
Double chain silicates



$(Si_6O_{18})^{12-}$
Tetrahedral ring (6-fold)

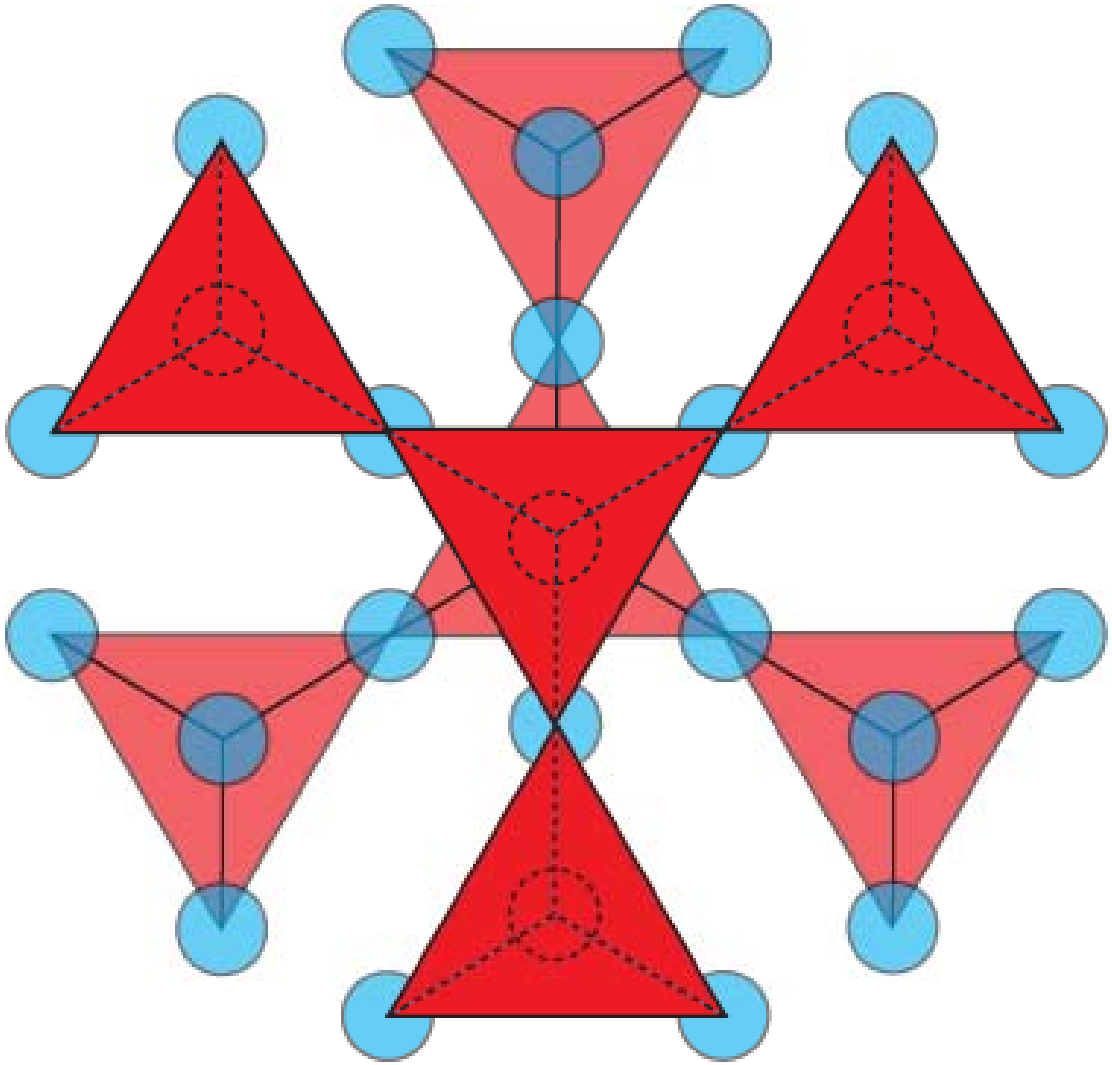


$(Si_2O_5)^{2-}$
Tetrahedral sheet (6-fold)



(SiO_2)

Infinite tetrahedral network



Nesosilicates

- Isolated $(SiO_4)^{4-}$ tetrahedra and bounded to one another via ionic bonds with interstitial cations.

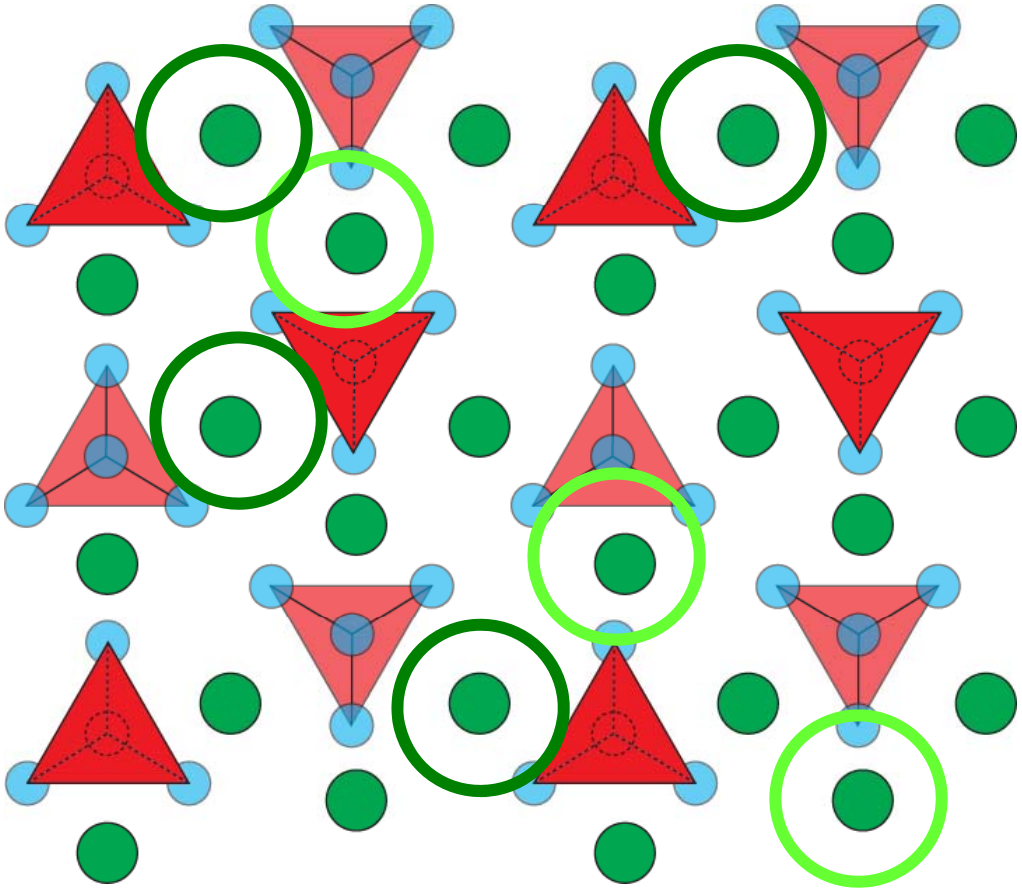
- Dense packing – high density.
- Independent tetrahedral – crystal habits are equidimensional and lack pronounced cleavage.
- Al^{3+} substitution in T-site generally low.

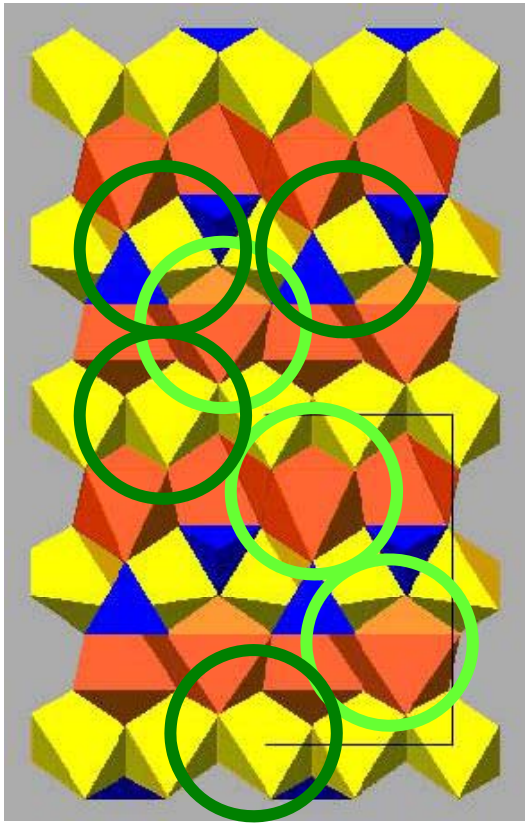
- Many nesosilicates (but not all) have orthogonal crystallographic systems.

Olivine (Forsterite-Fayalite)

$(SiO_4)^{4-}$ tetrahedra linked by divalent atoms in a six-fold coordination.

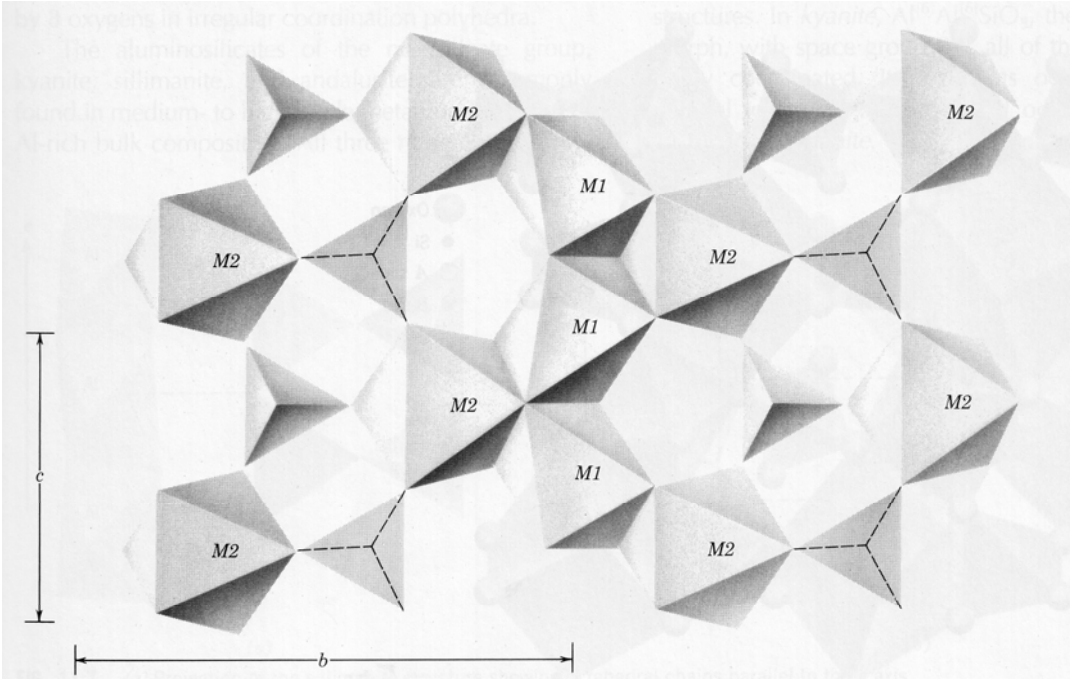
What shape is the interstitial site?





The octahedral sites share edges and are not equivalent

I1



M1 is slightly more distorted relative to the M2 site.

The octahedral sites may be occupied by Mg^{2+} and/or Fe^{2+}, while (Mg + Fe) must = 2.

The effective ionic radius of Mg^{2+} (0.72 Å) is very similar to that of Fe^{2+} (0.78 Å), in 6-fold coordination, and the two elements are totally inter-changeable.

$$Mg_2SiO_4 + 2Fe^{2+} \leftrightarrow Fe_2SiO_4 + 2Mg^{2+}$$

This is called a (continous) **solid-solution**.
And occurs via **simple (cation) exchange (substitution)**.

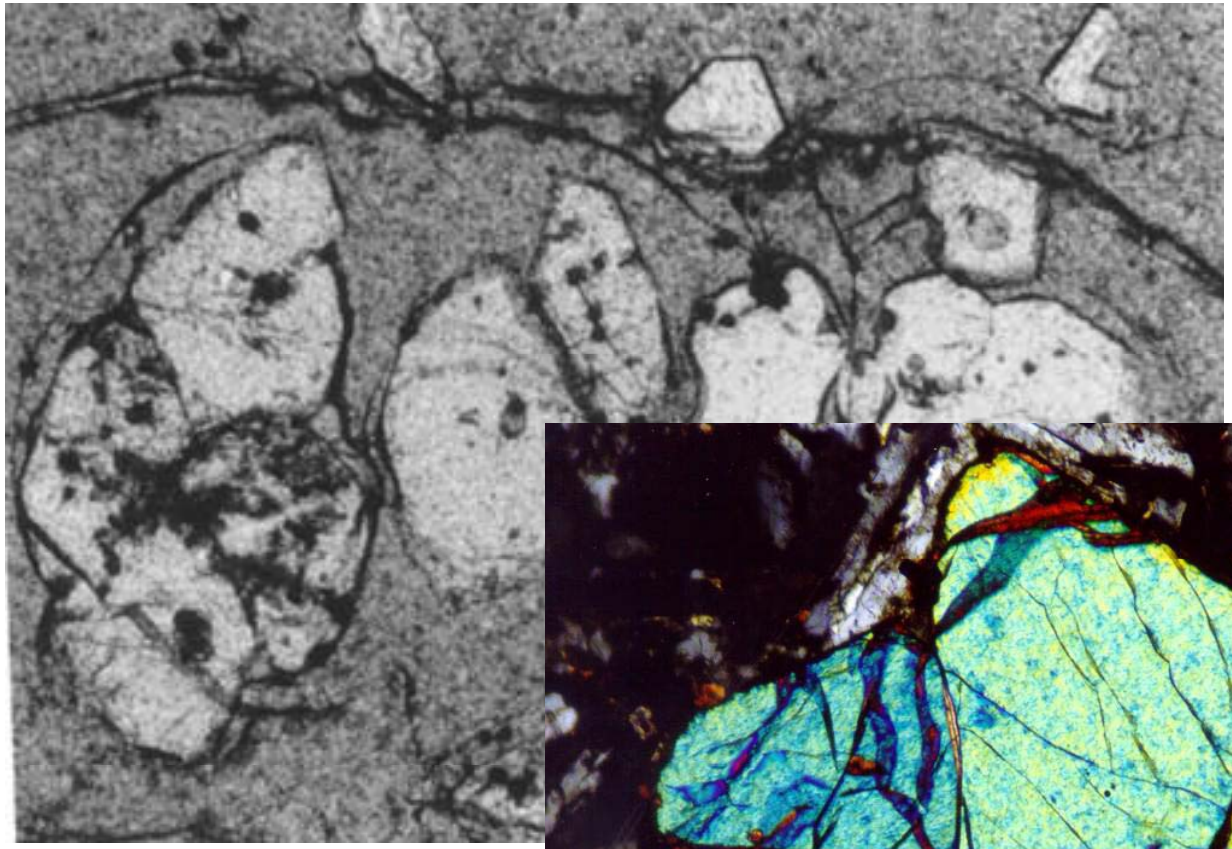
Industrial Olivine

It is mined as a gemstone (peridot), and has industrial uses such as refractory sands and abrasives. It is also an important magnesium ore.

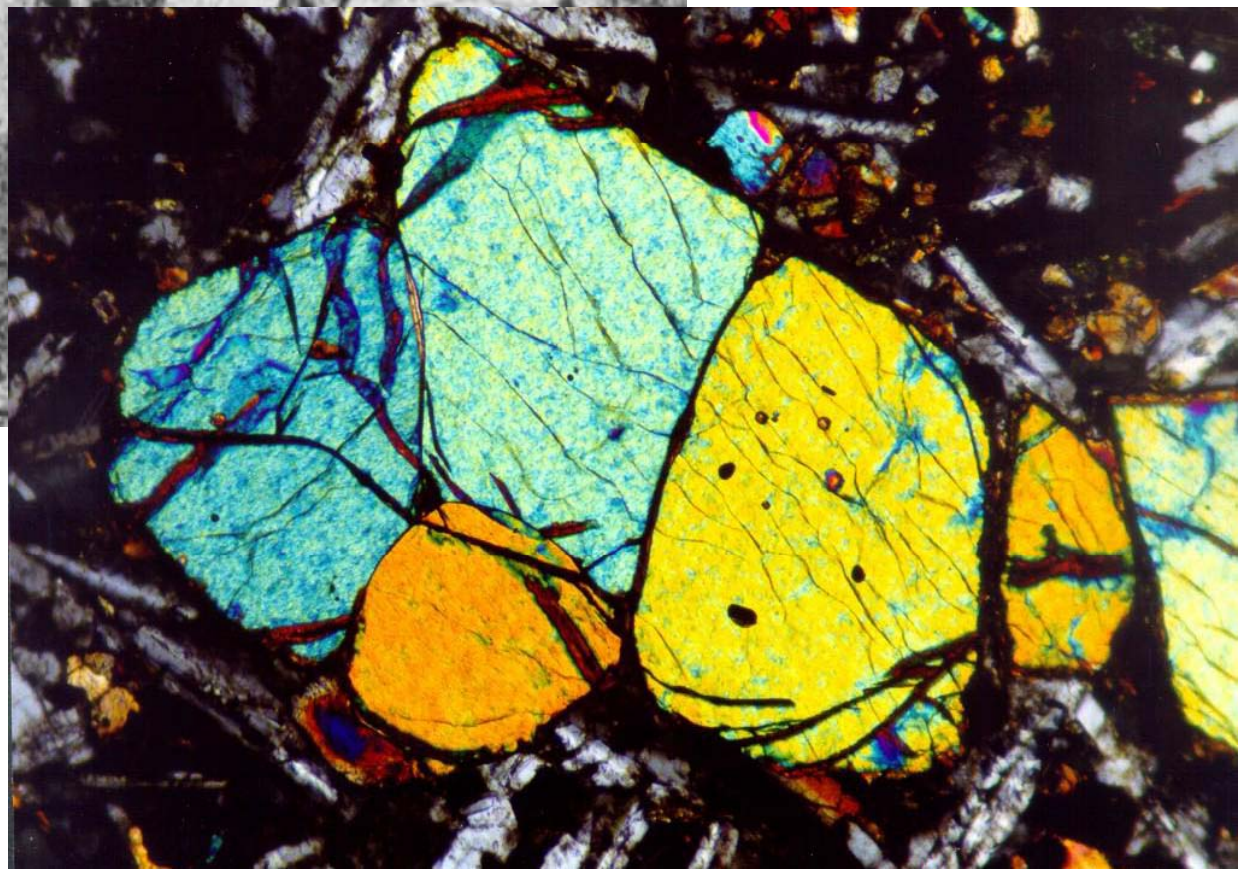
As of the year 2000, the largest producers include Norway, Japan, and Spain.

Slag conditioning, foundry sand, refractories, abrasives, soil conditioning heat storage.

When doped with a small amount of Cr^{2+}, forsterite is one of the few materials that acts as a tunable laser in the near IR region



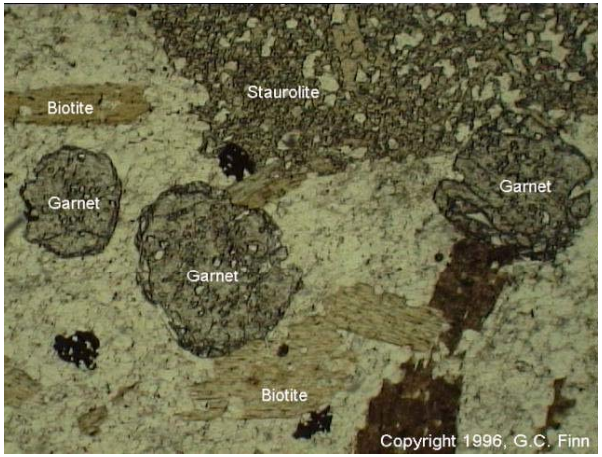
Colorless in ppl except Fe-rich (fayalite) end-member



High birefringence colors (.035-.05) with commonly “stubby” shaped crystals

Garnet (Group)

Garnet group minerals are particularly characteristic of metamorphic rocks.



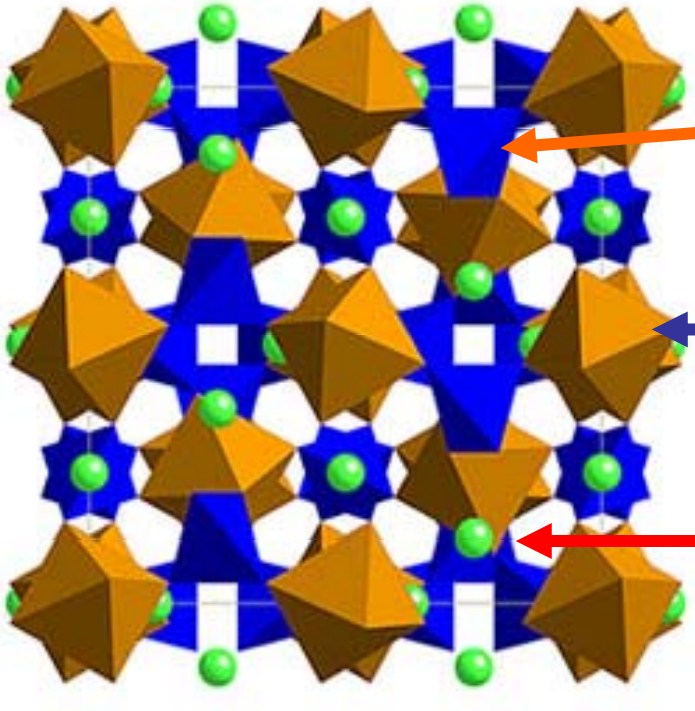
Garnet is an isometric (cubic) mineral and has 7 compositional isomorphous end-members.

Garnet has a generalised structural formula of $A_3B_2Si_3O_{12}$

A = Mg ,Fe^{2+}, Mn or Ca (pyrope, almandine, spessartine and grossular).

B = Al, Cr, or ($Fe^{3+} \pm$ Ti). (The latter two give uvarovite and andradite).

The A-site is 8 coordinated, the Y -site is 6-coordinated (octahedral) and inated (tetrahedral)

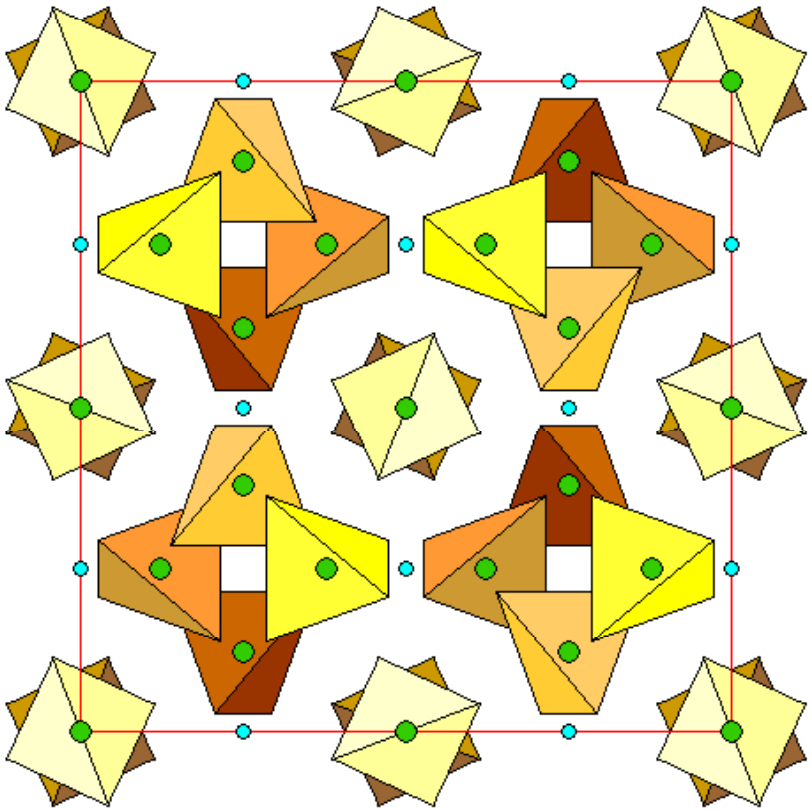


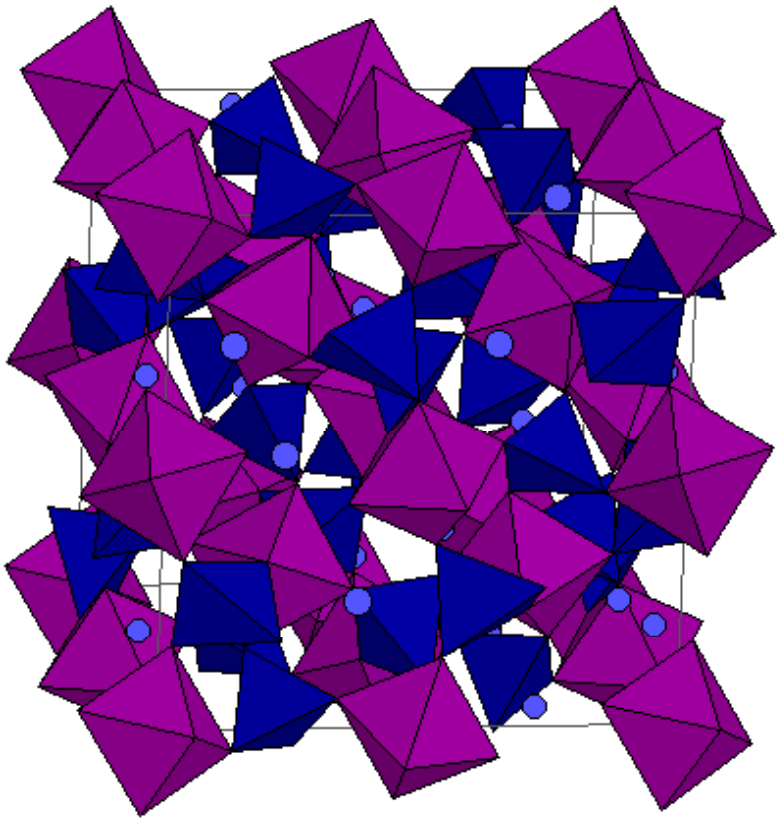
Isolated $(SiO_4)^{4-}$ tetrahedra

are linked to distorted octahedrons (the B-site).

And, to distorted dodecahedrons (the A-site).

Two alternative views





Characteristic Properties

Most garnets are isotropic, and therefore isometric.

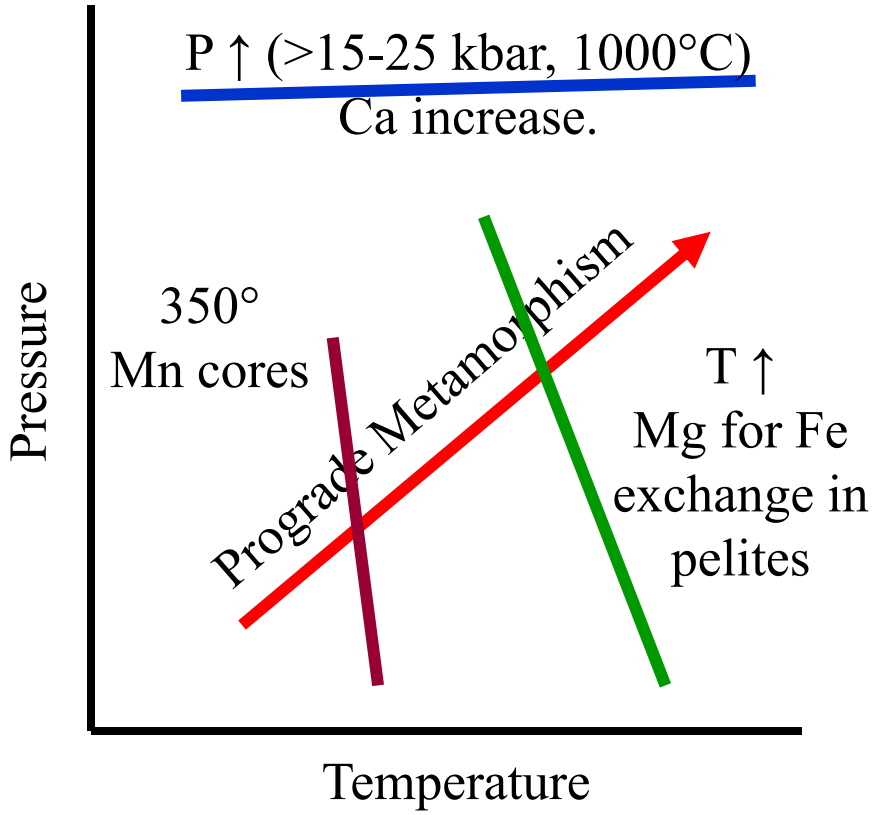
They have a hardness of 6-7½, no cleavage and subconchoidal fracture.

They have a wide range of colors, including reds, browns, greens, yellows, pinks or even white.

Medium to high relief, often pinky in thin section and of course are permentantly extinct under cross-polars.

Paragenesis and Composition

Pure end-member compositions of garnet are rare. The majority are some intermediate composition, which is determined by a combination of factors.



$Fe_3Al_2Si_3O_{12} + KMg_3AlSi_3O_{10}(OH)_2$

↕

$Mg_3Al_2Si_3O_{12} + KFe_3AlSi_3O_{10}(OH)_2$

This reaction is a classic thermometer.

Exchange between Mg, Fe, Ca and Mn is favourable because of similarities in ionic radii and same charge.

Industrial and Economic Importance

All species, except uvarovite are cut as gemstones.
The most valuable are green andradite (*demantoid*) from the Urals and almandine from Gore Mountain (NY)

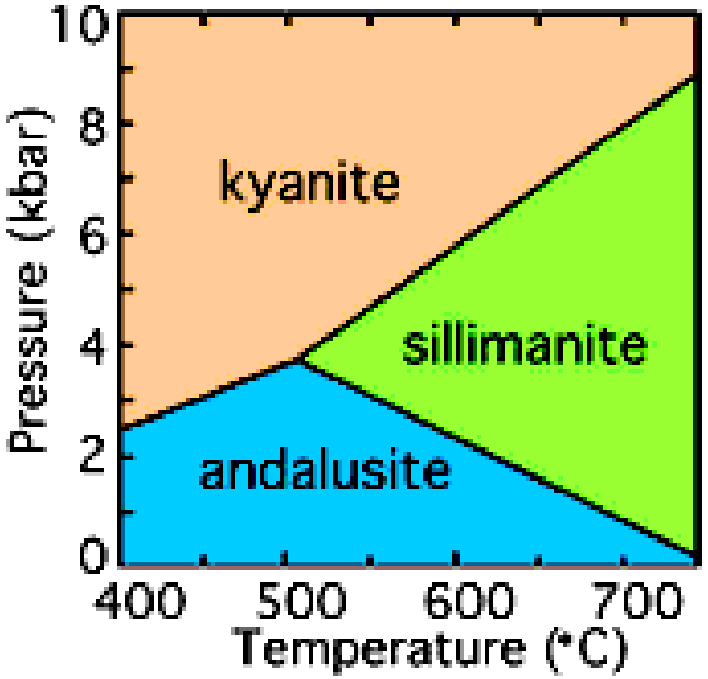
The subconchoidal fracture and angular fracture, coupled with the high hardness, also make garnet a valuable abrasive.

Aluminosilicates (Al_2SiO_5)

This is the general term for the three minerals ***kyanite, sillimanite*** and ***andalusite***.

These three minerals are **polymorphs**, and may be found in metamorphosed aluminous rocks.

The stability of the phases is very well known of is of great value to metamorphic petrology



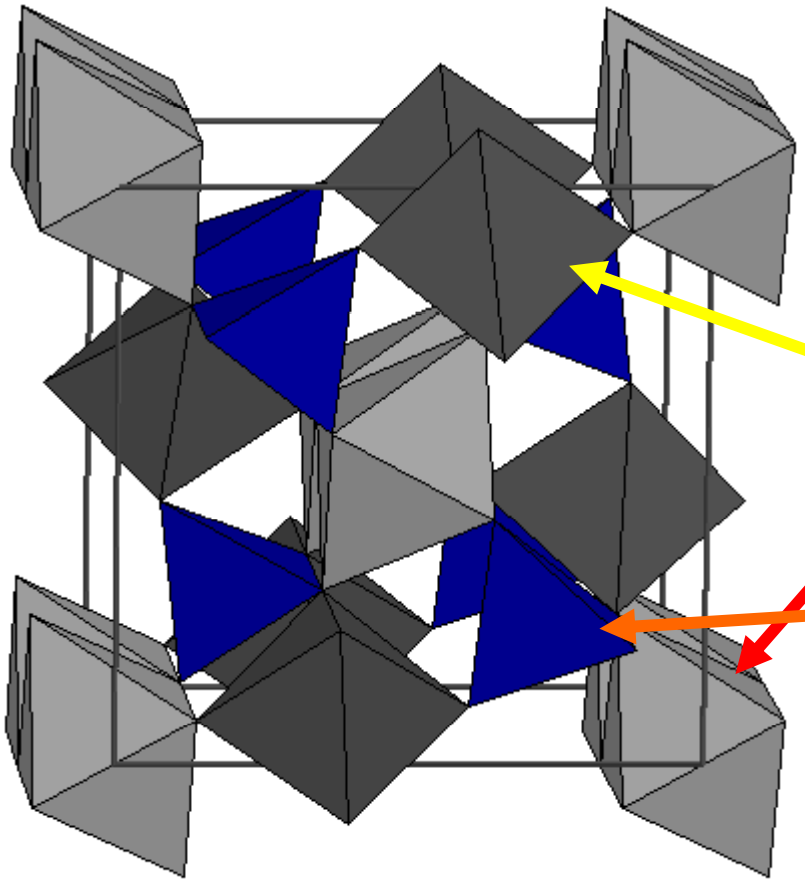
This is a famous diagram and can be used as a first approximation of metamorphic conditions.

Kyanite – High pressure – Subduction zones

Sillimanite – High pressure and temperature (regional)

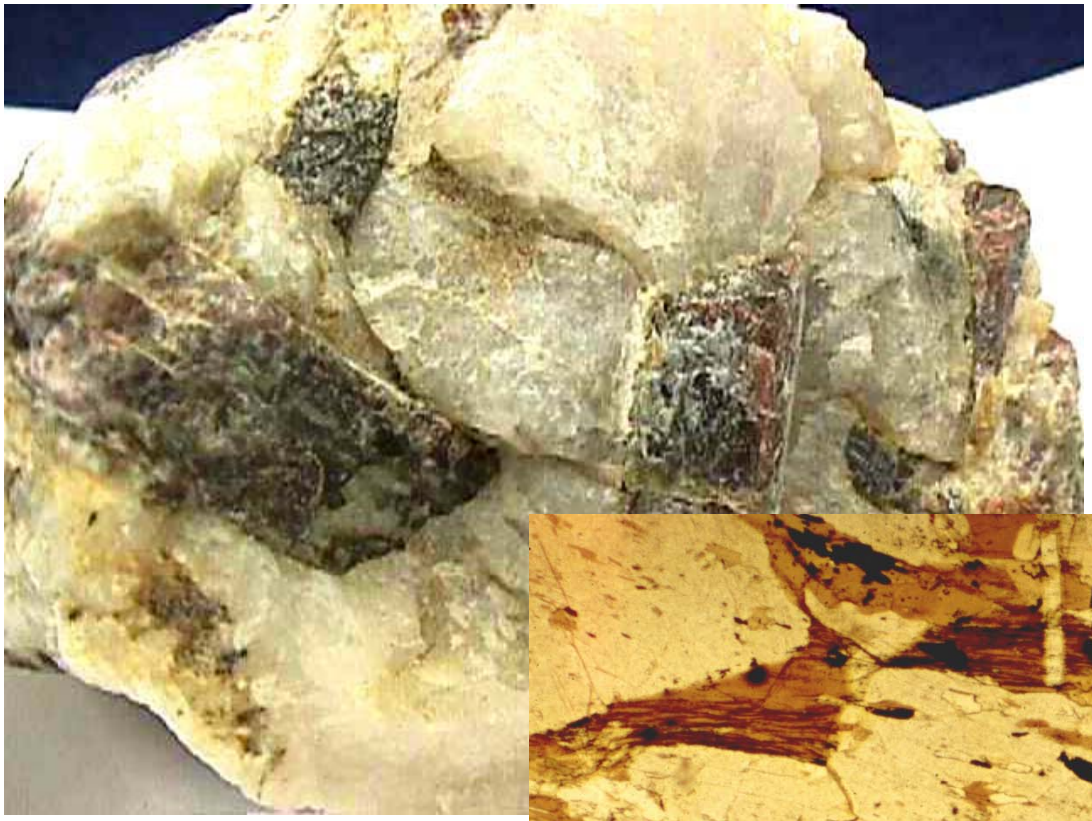
Andalusite – High temperature – thermal metamorphism.

Andalusite – $Al^{[6]}Al^{[5]}SiO_5$ - orthorhombic

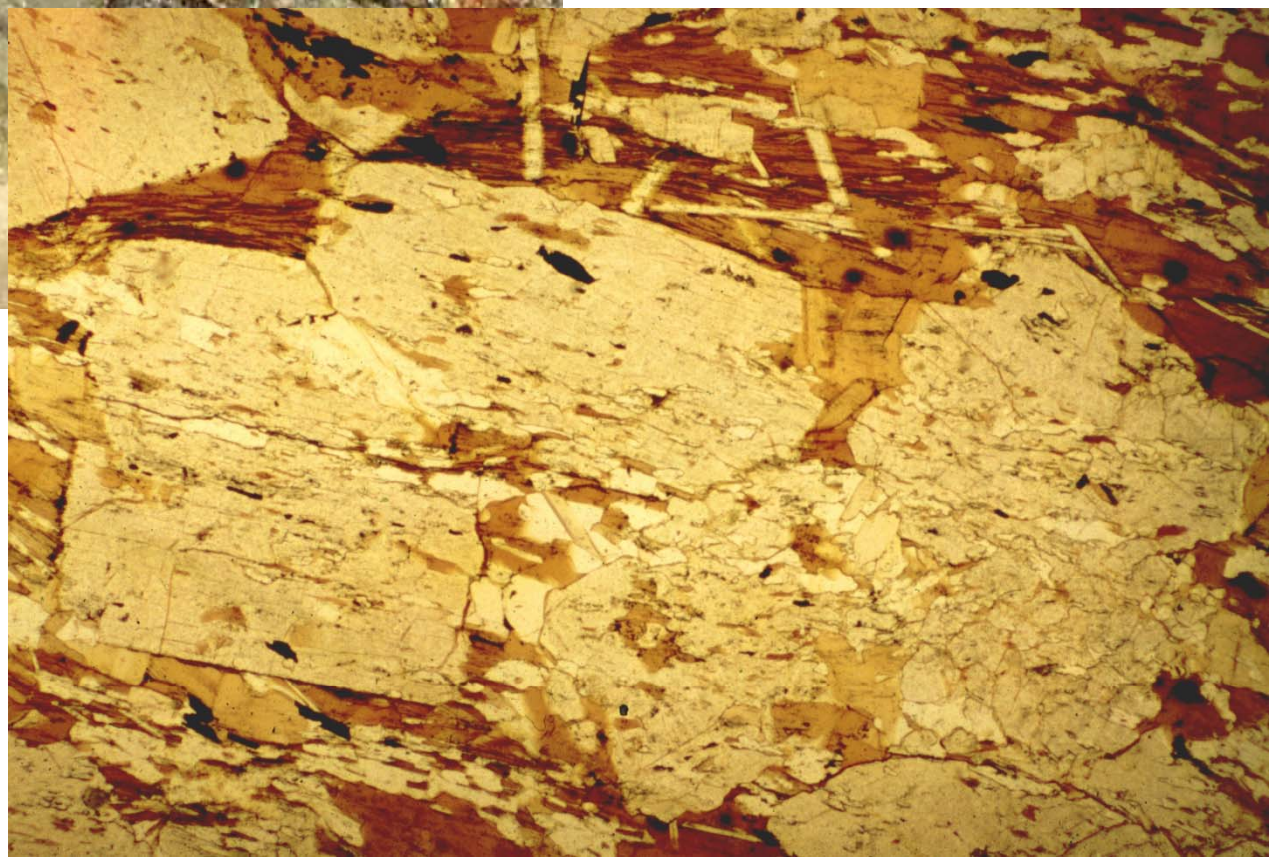


The structure of the mineral consists of chains of AlO_6 octahedra parallel to the c-axis.

Cross linked by AlO_5 polyhedra and SiO_4 tetrahedra.

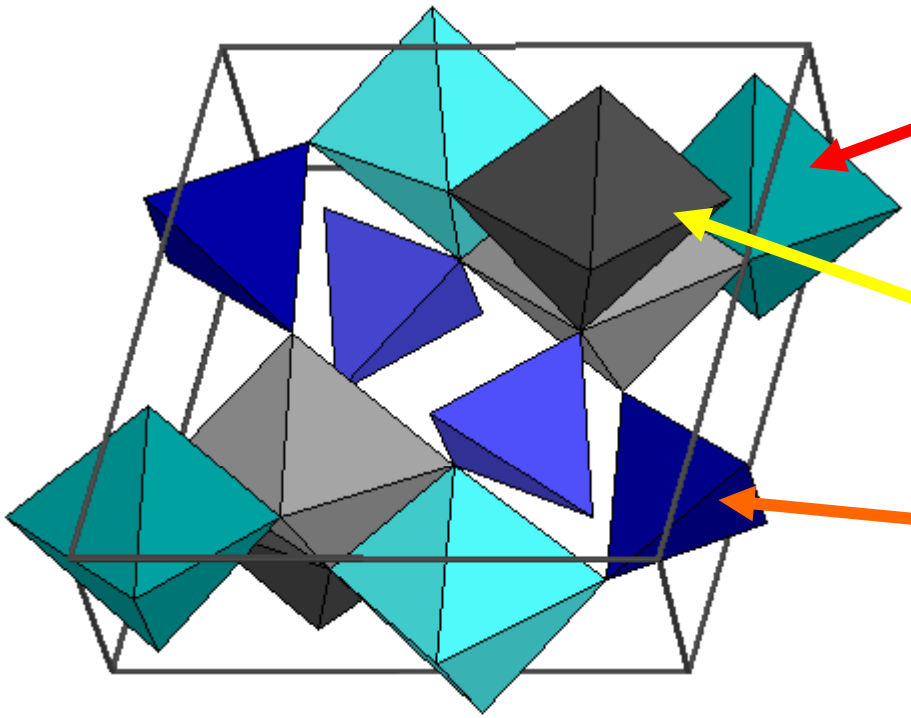


Andalusite is length fast, has a high 2V, and is biaxial negative.



May be riddled with inclusions of quartz and micas (“Chiastolite cross”)

Kyanite – $Al^{[6]}Al^{[6]}SiO_5$ - triclinic

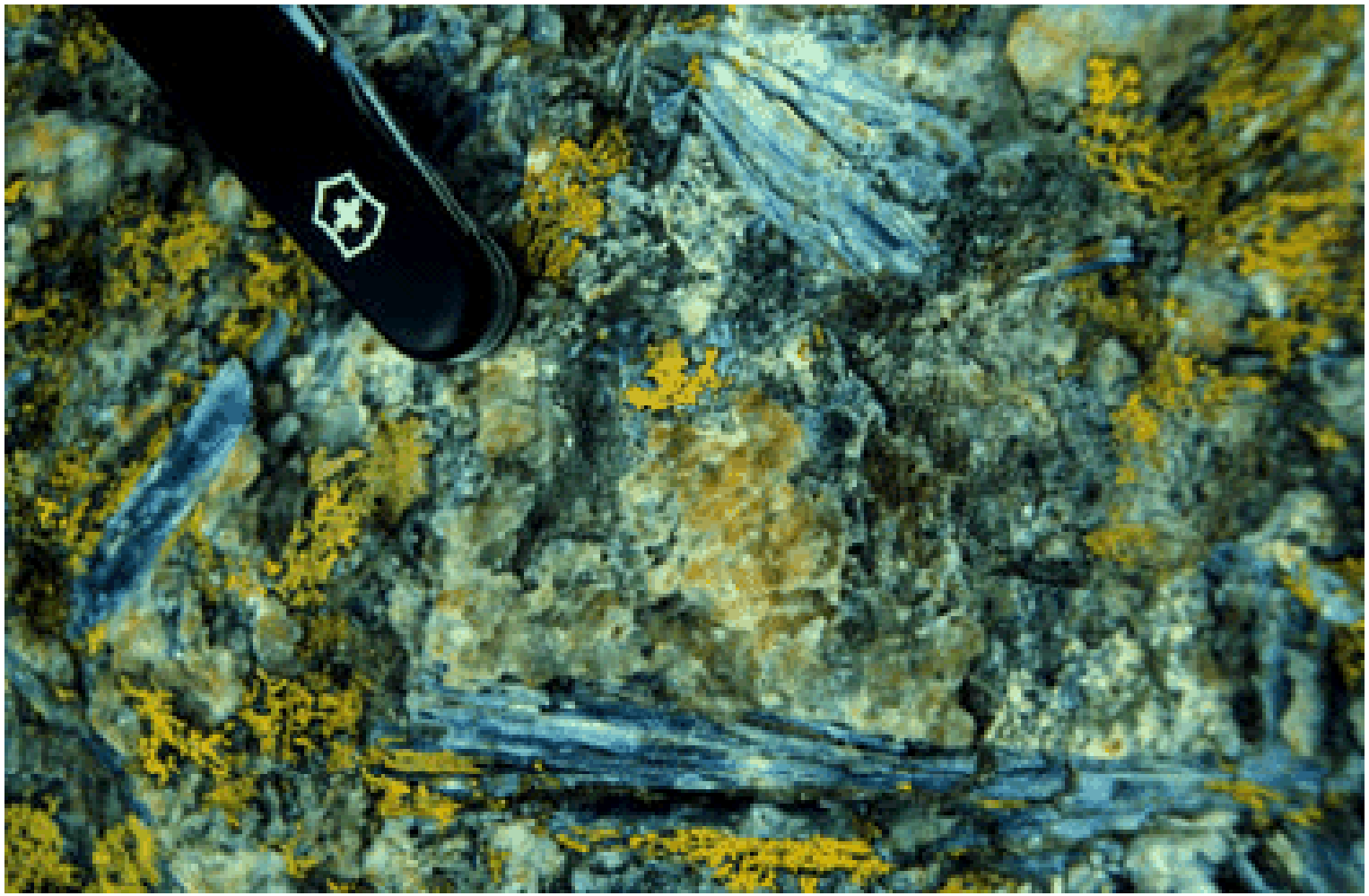


The structure of the mineral consists of chains of AlO_6 octahedra.

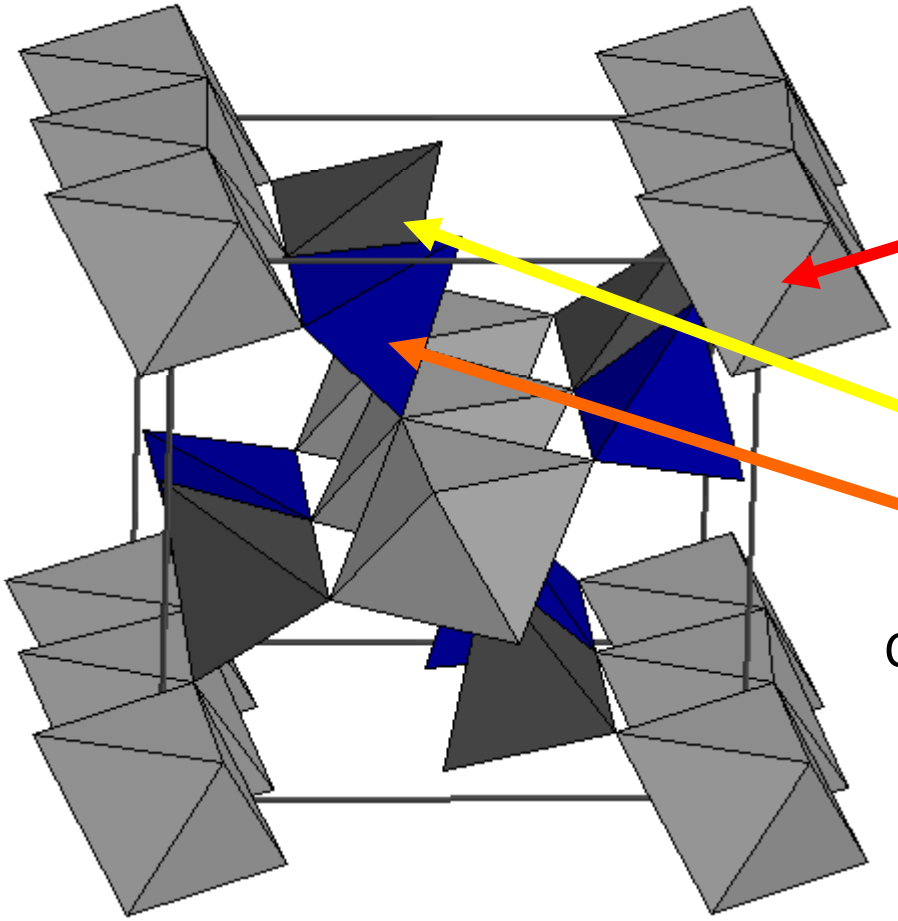
Cross linked by AlO_6 octahedra and SiO_4 tetrahedra.

Kyanite is typically colourless in TS. Has high relief, low BR, excellent cleavage, has a high 2V, and is biaxial negative.
In the most part, it also has oblique extinction.

Kyanite is typically colourless in TS. Has high relief, low BR, excellent cleavage, has a high 2V, and is biaxial negative.
In the most part, it also has oblique extinction.



Sillimanite – $Al^{[6]}Al^{[4]}SiO_5$ - orthorhombic

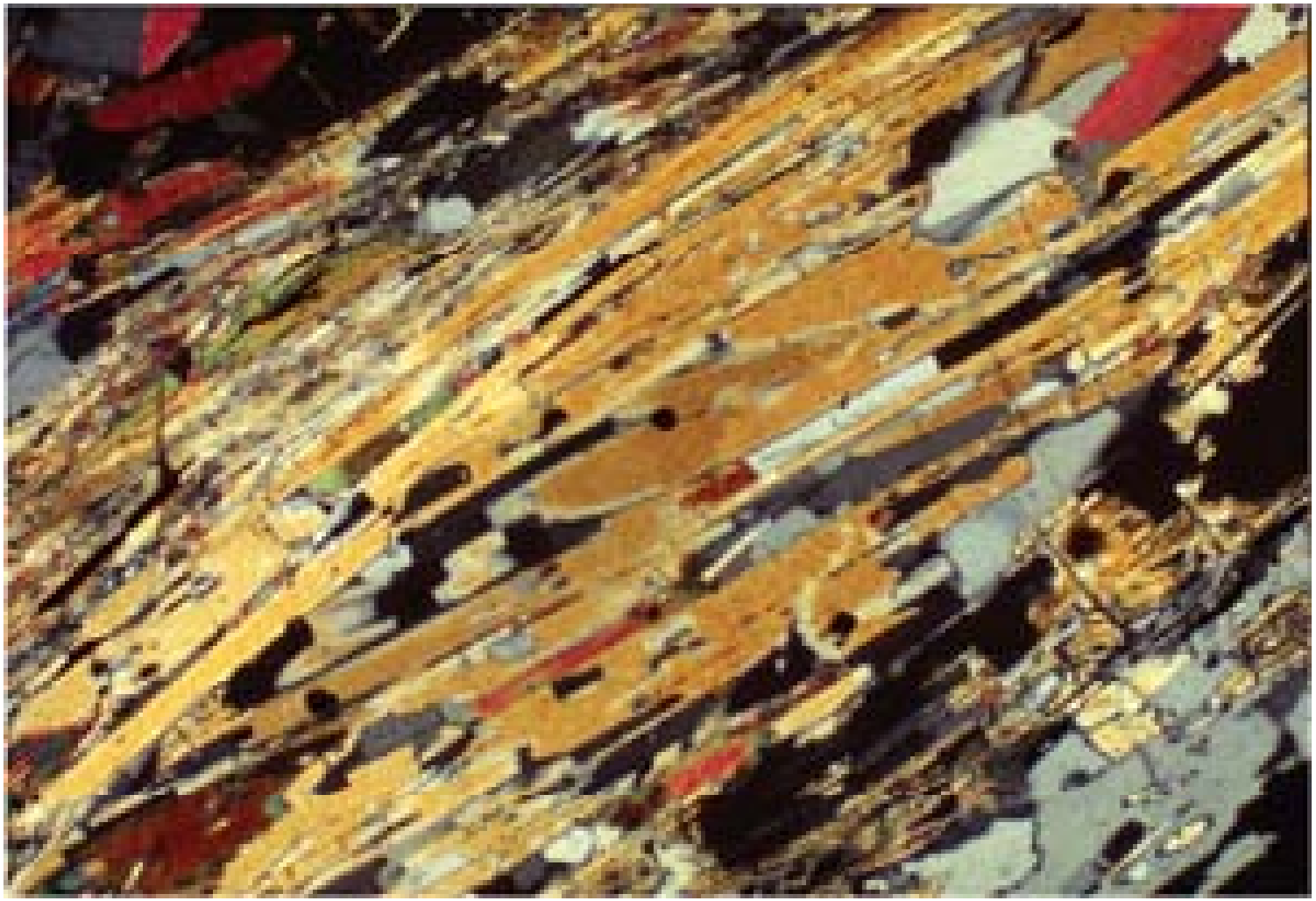


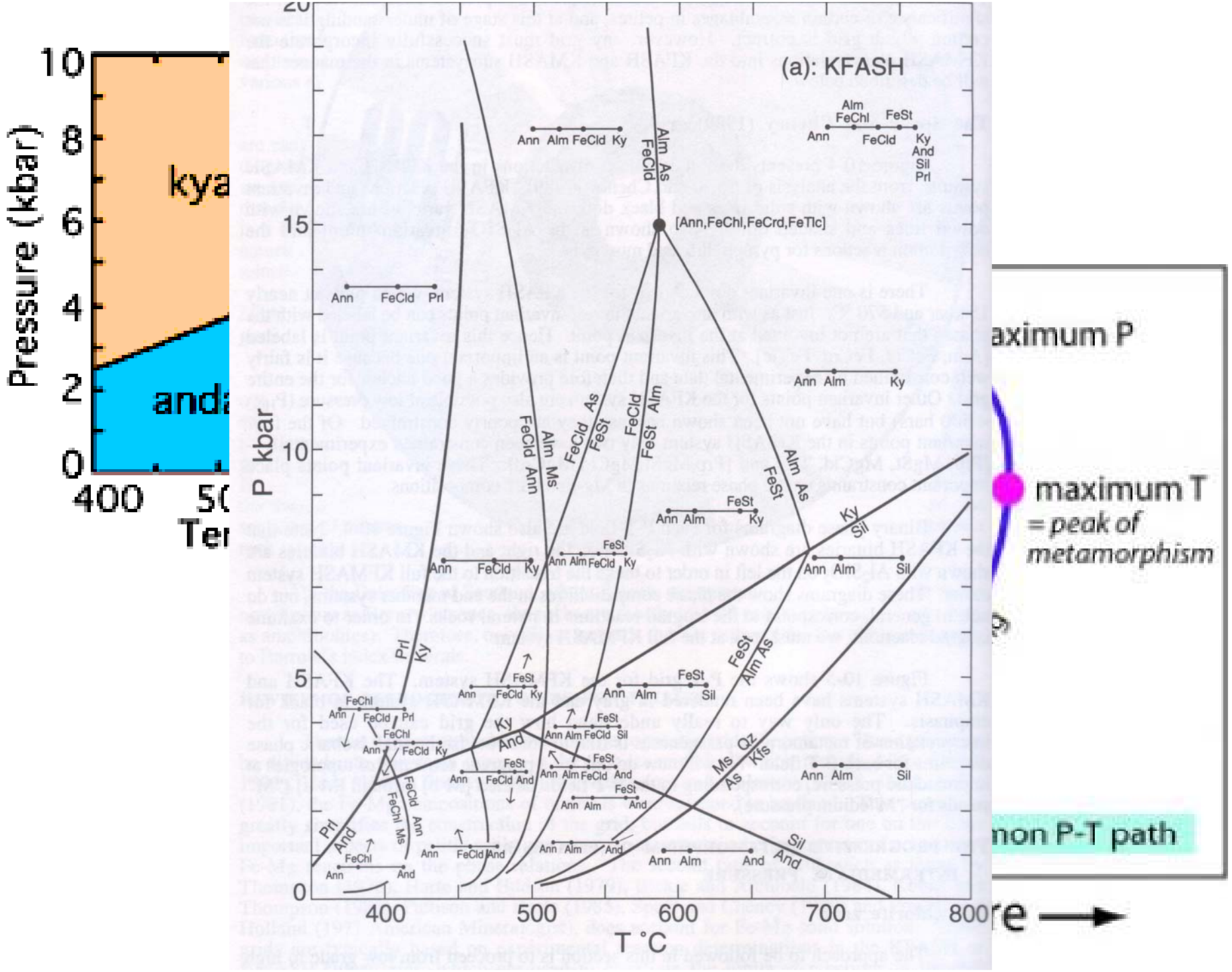
The structure of the mineral consists of chains of AlO_6 octahedra parallel to the c-axis.

Cross linked by AlO_4 and SiO_4 tetrahedra.

Sillimanite is also known as fibrolite, is typically colourless in TS. Has high relief, low BR, good cleavage, a low 2V, and is biaxial positive.

Sillimanite is also known as fibrolite, is typically colourless in TS. Has high relief, low BR, good cleavage, a low 2V, and is biaxial positive.




Pressure (kbar)
10
8
6
4
2
0
400
kya
anda
(a): KFASH
P kbar
T °C
[Ann,FeChl,FeCrd,FeTlc]
maximum P
maximum T
= peak of metamorphism
non P-T path

Industrial and Economic Importance

Like many minerals, when occurring in optically perfect form, it can be cut as a gemstone – particularly kyanite.

This absence of Fe in the aluminosilicates also makes them very good high temperature refractories.

This property is exploited for the production of spark plugs and high refractory porcelains.