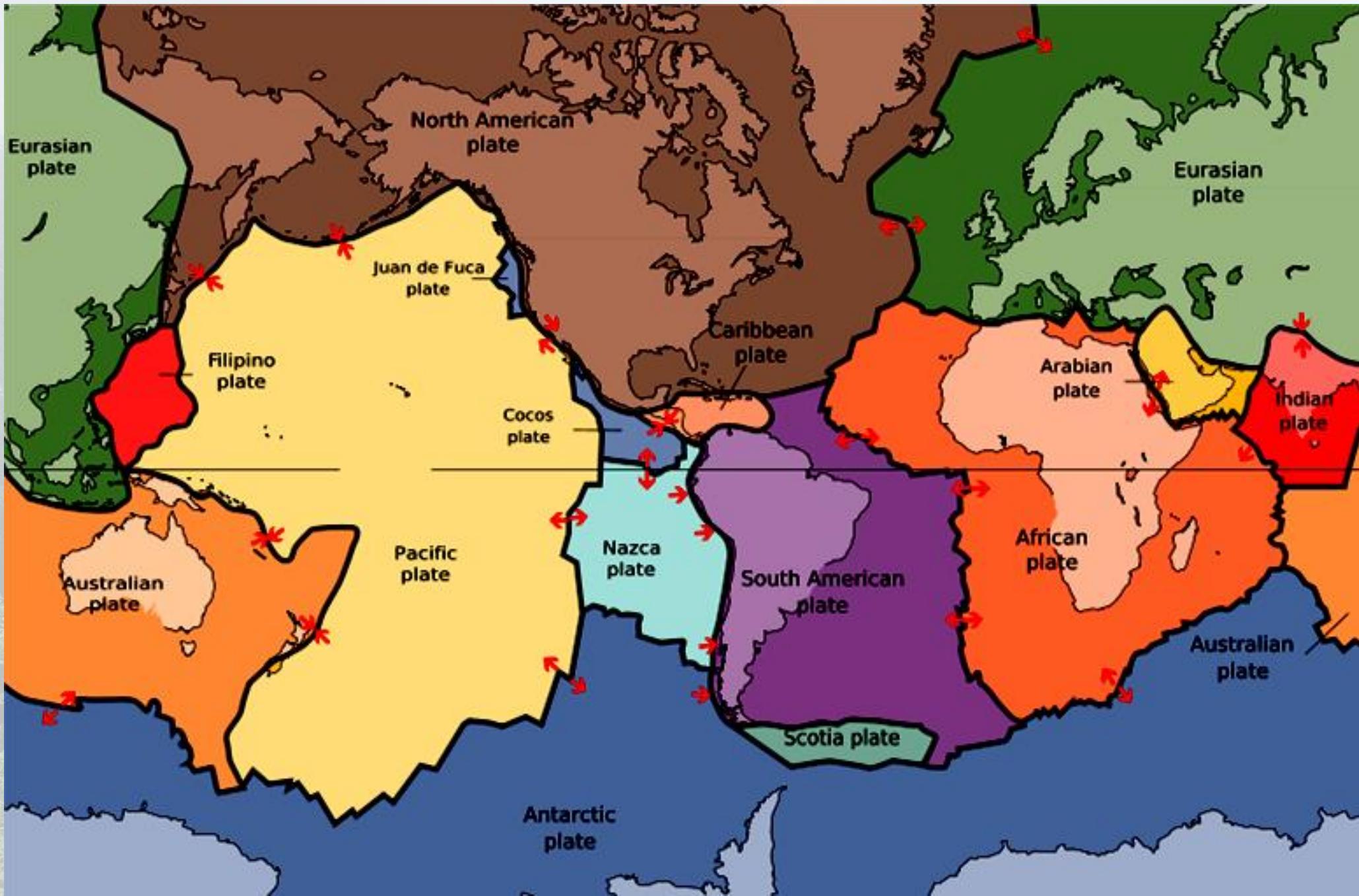


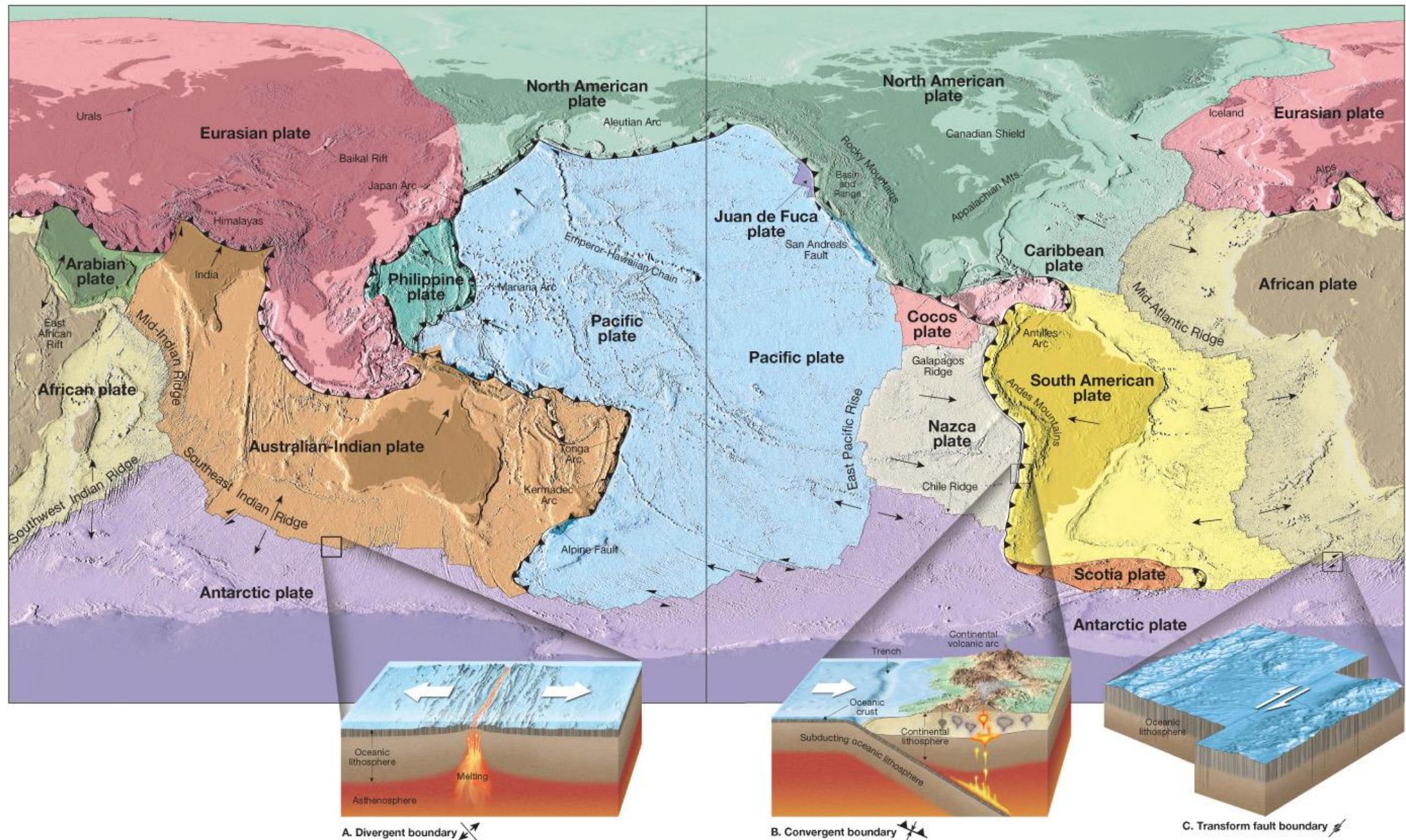


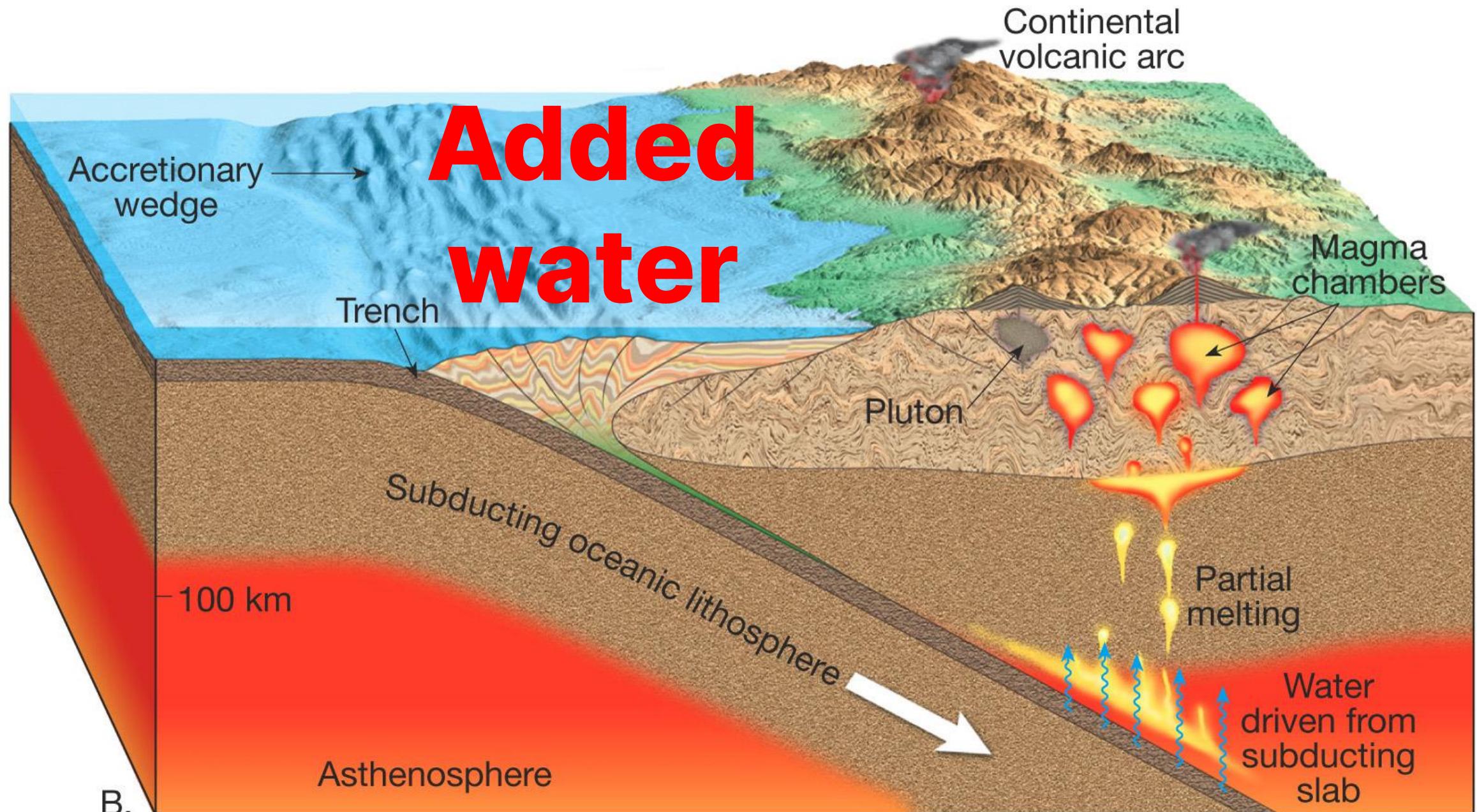
GY4051 Earth Science and Society

Metamorphism

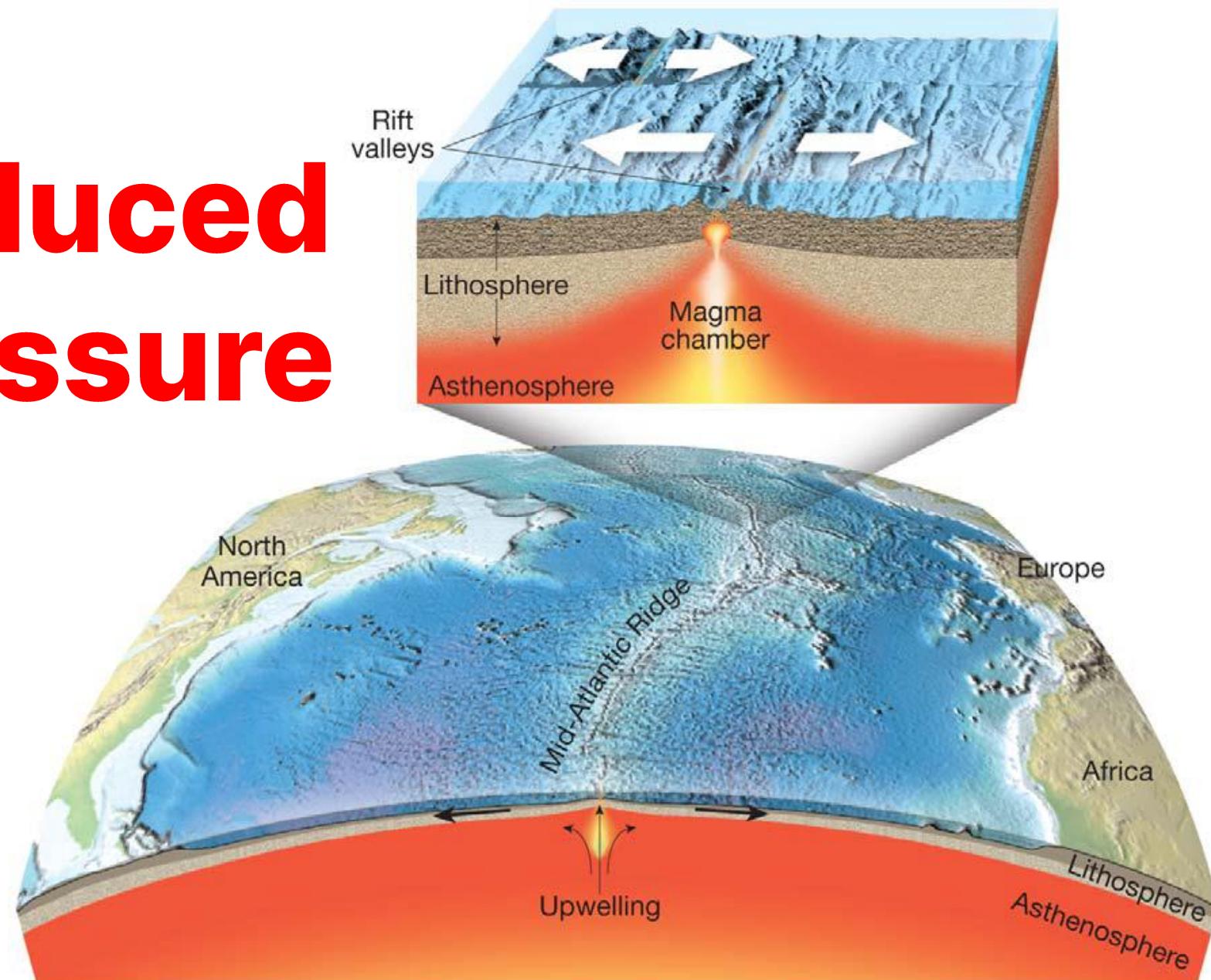




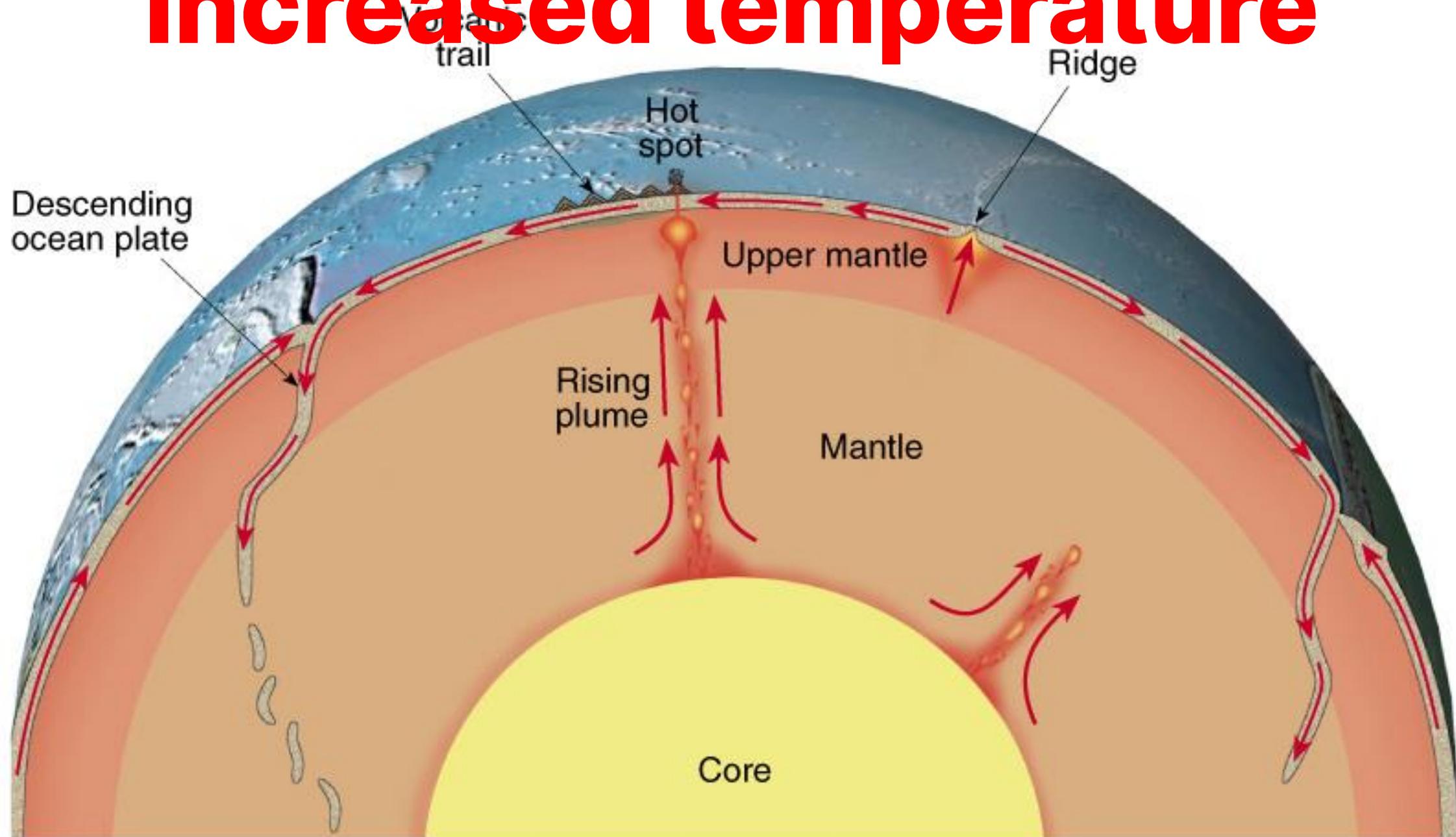




Reduced pressure

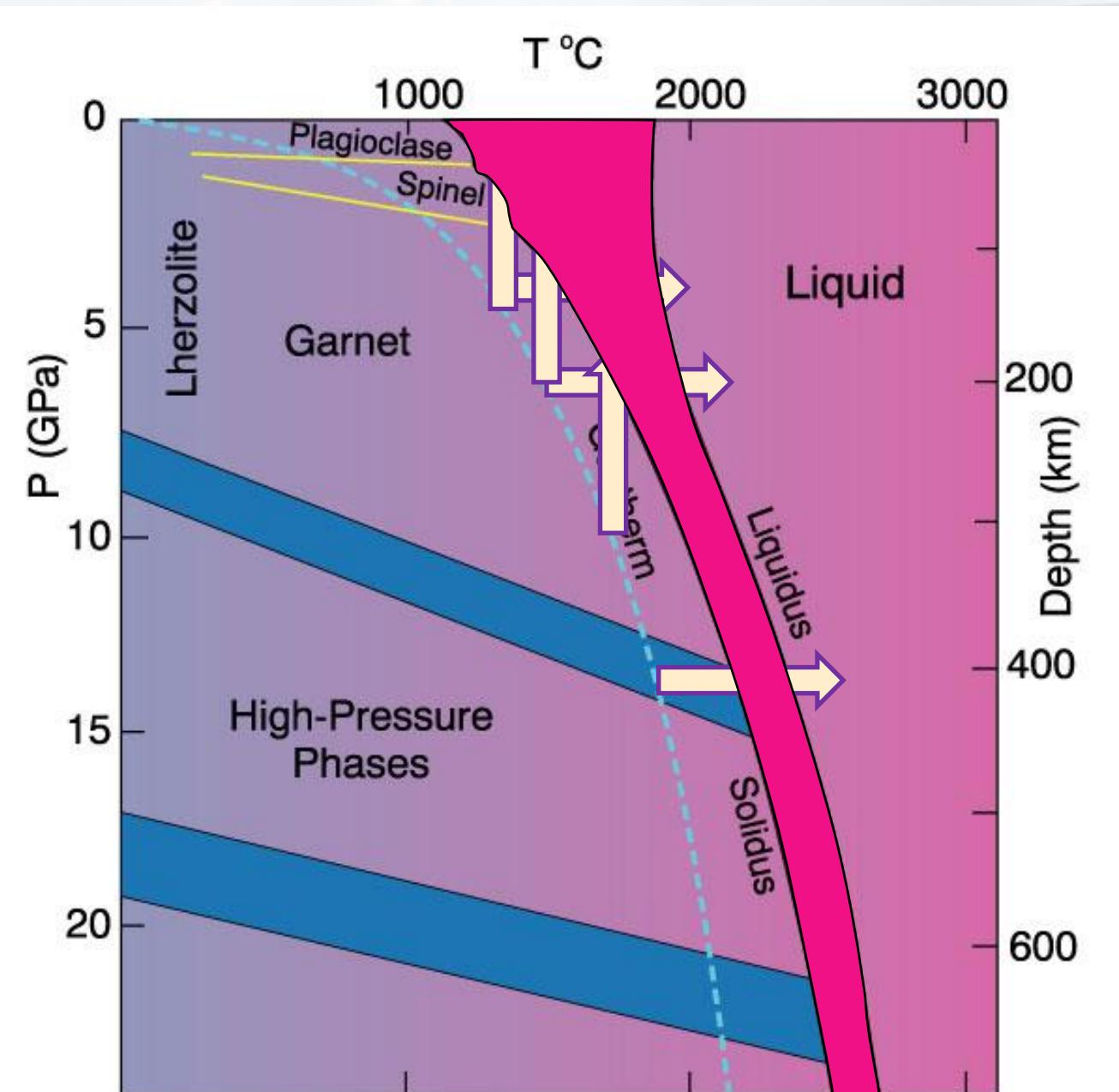


Increased temperature



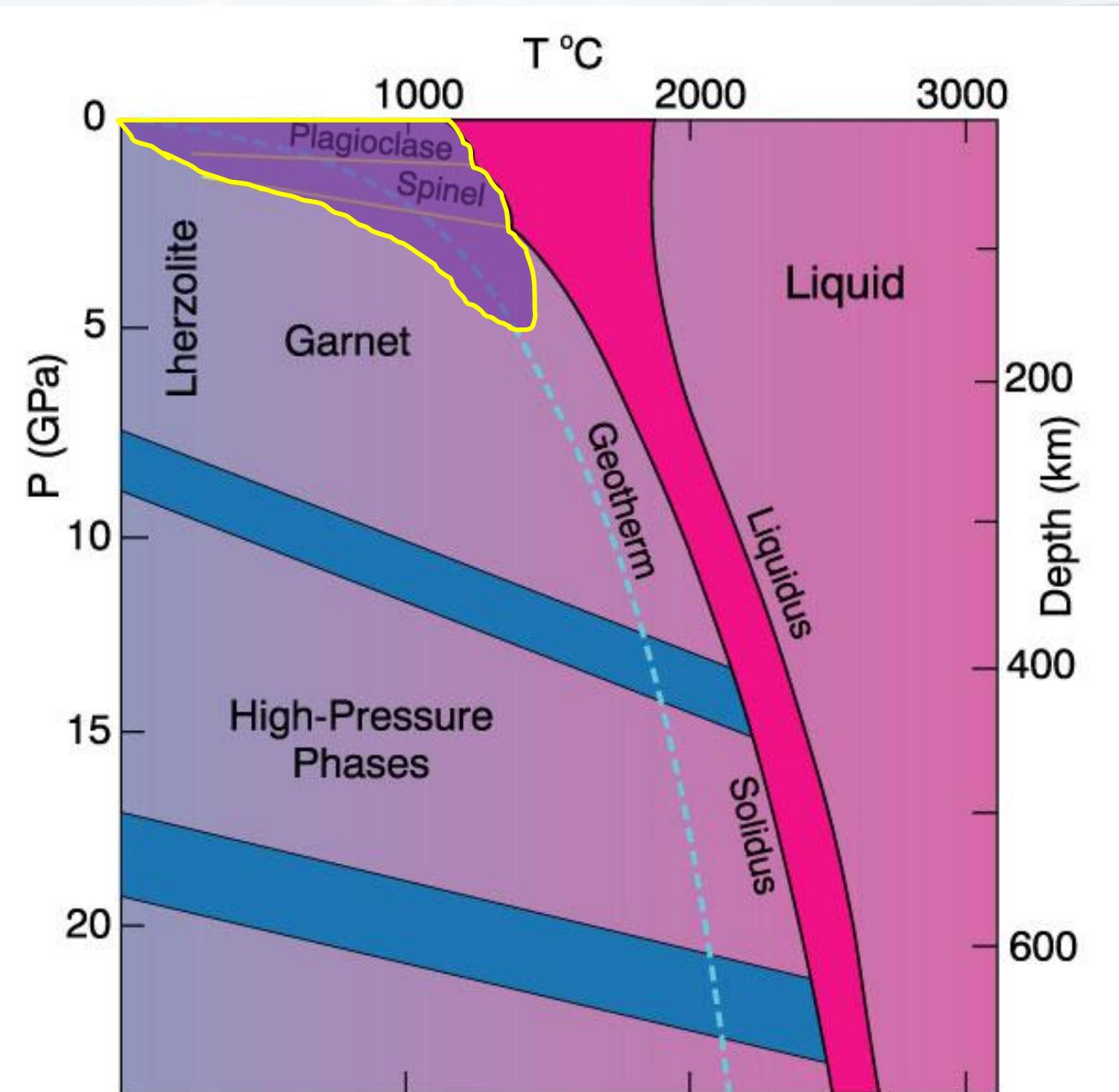
Three ways:

- Increase the temperature
- Lower the pressure
- Add water



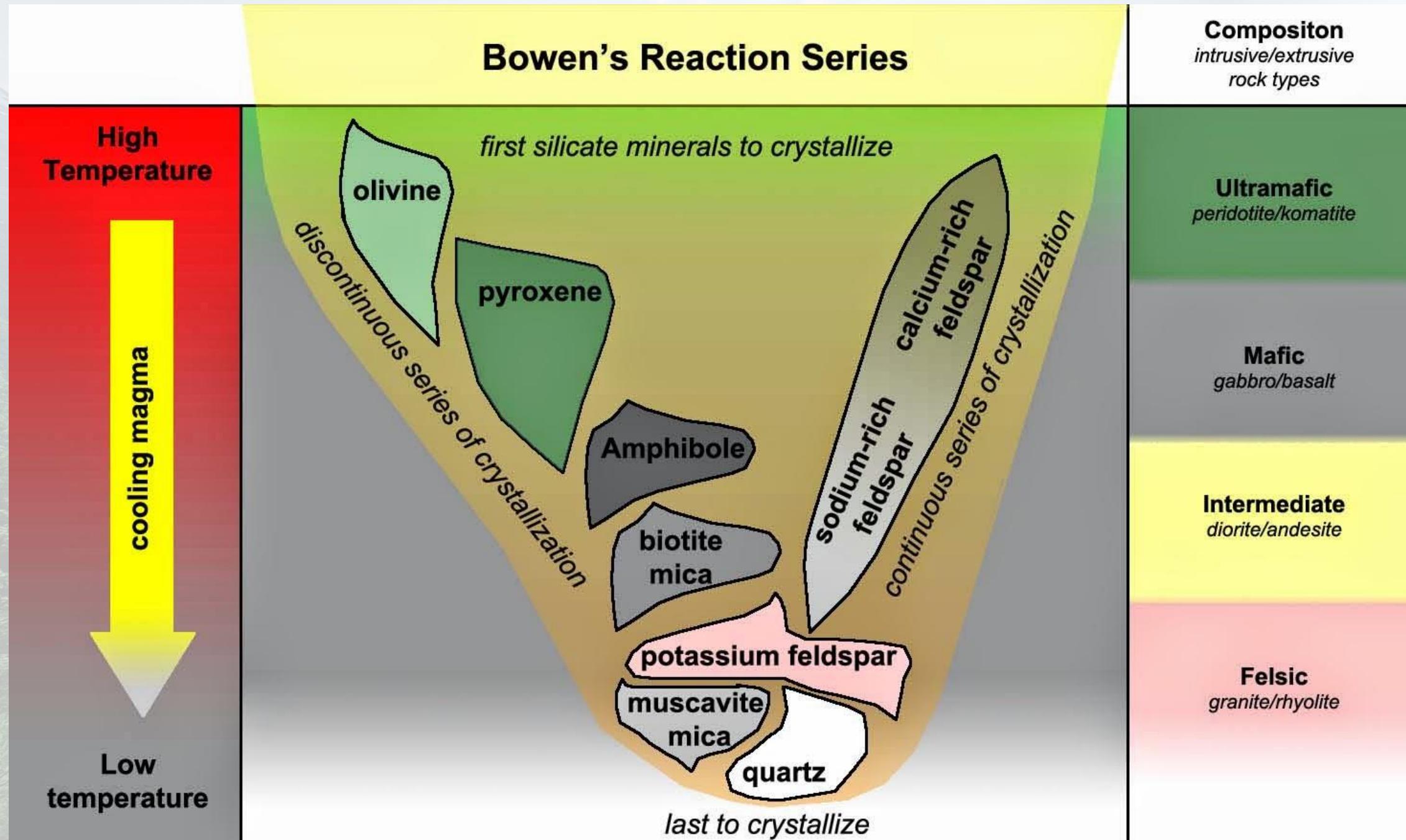
Metamorphic conditions

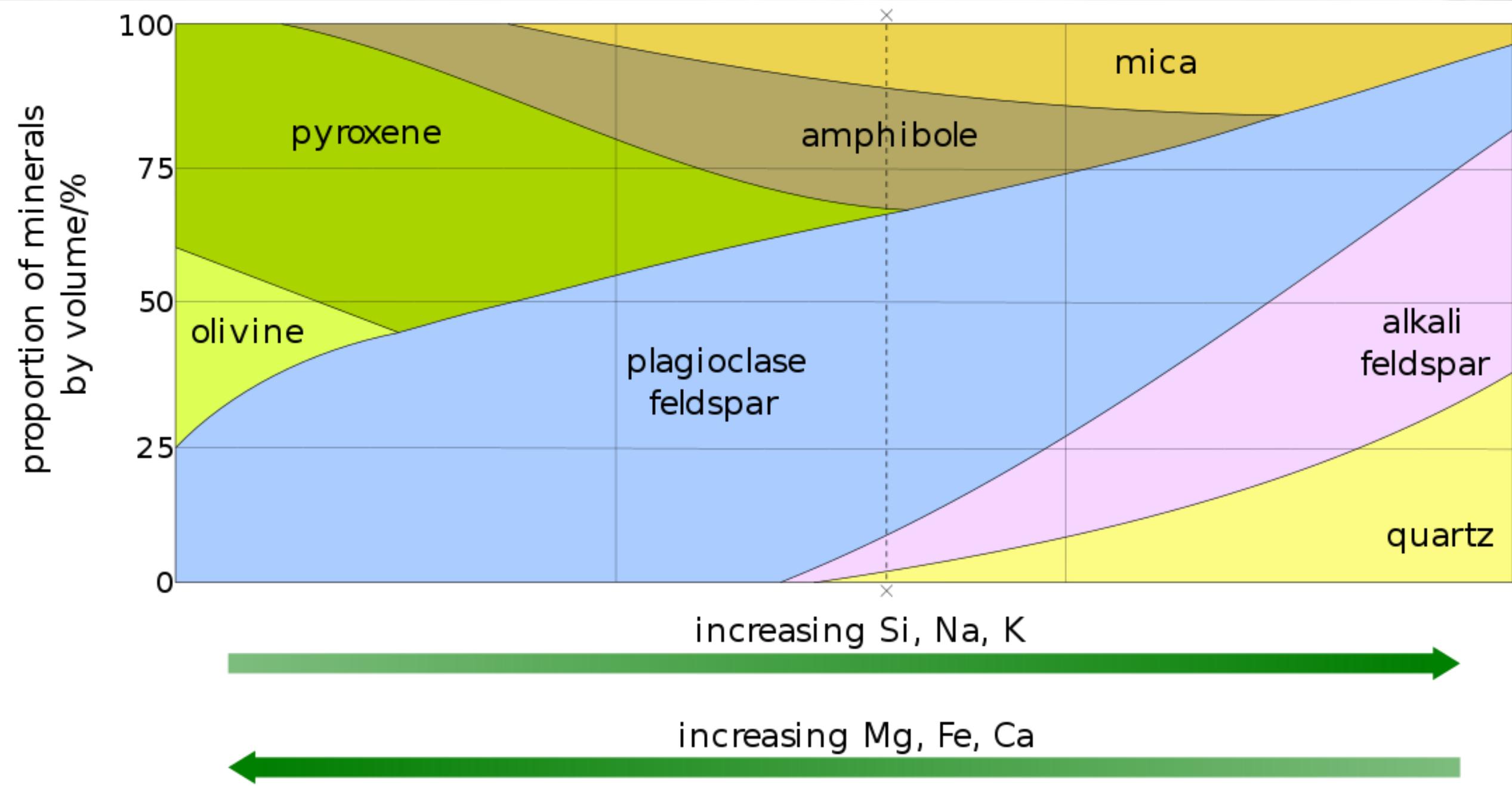
- Higher temperature
- Higher pressure
- But not enough to cause melting

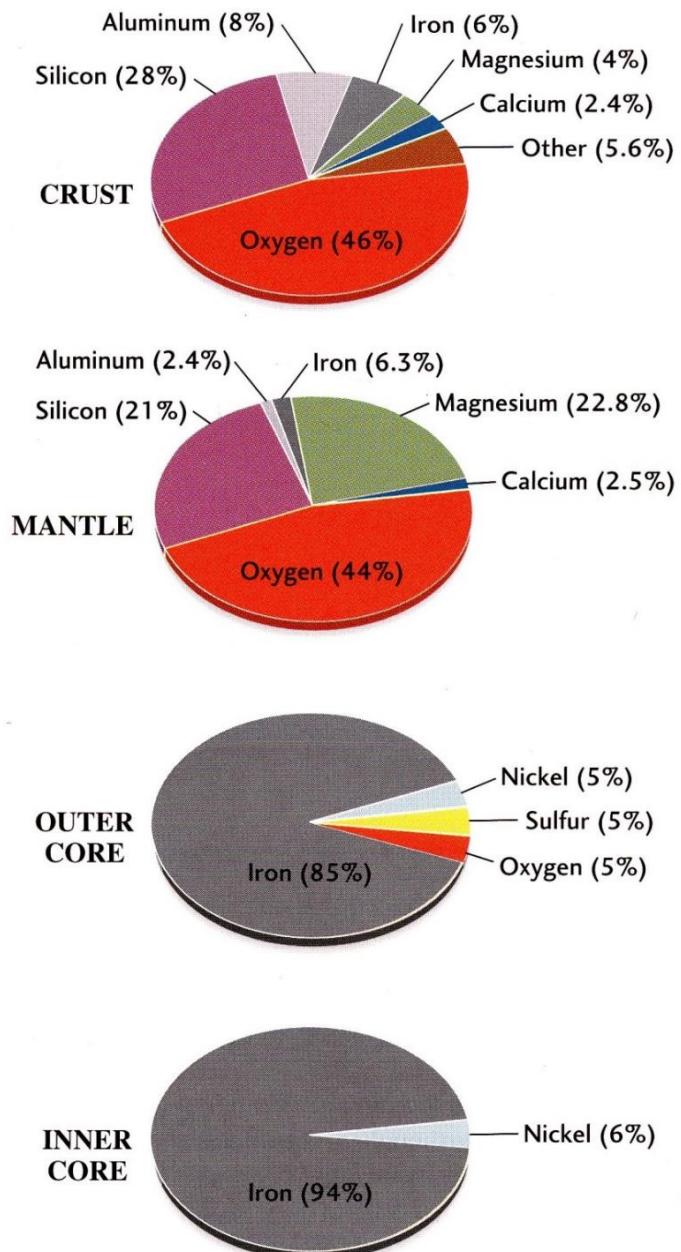
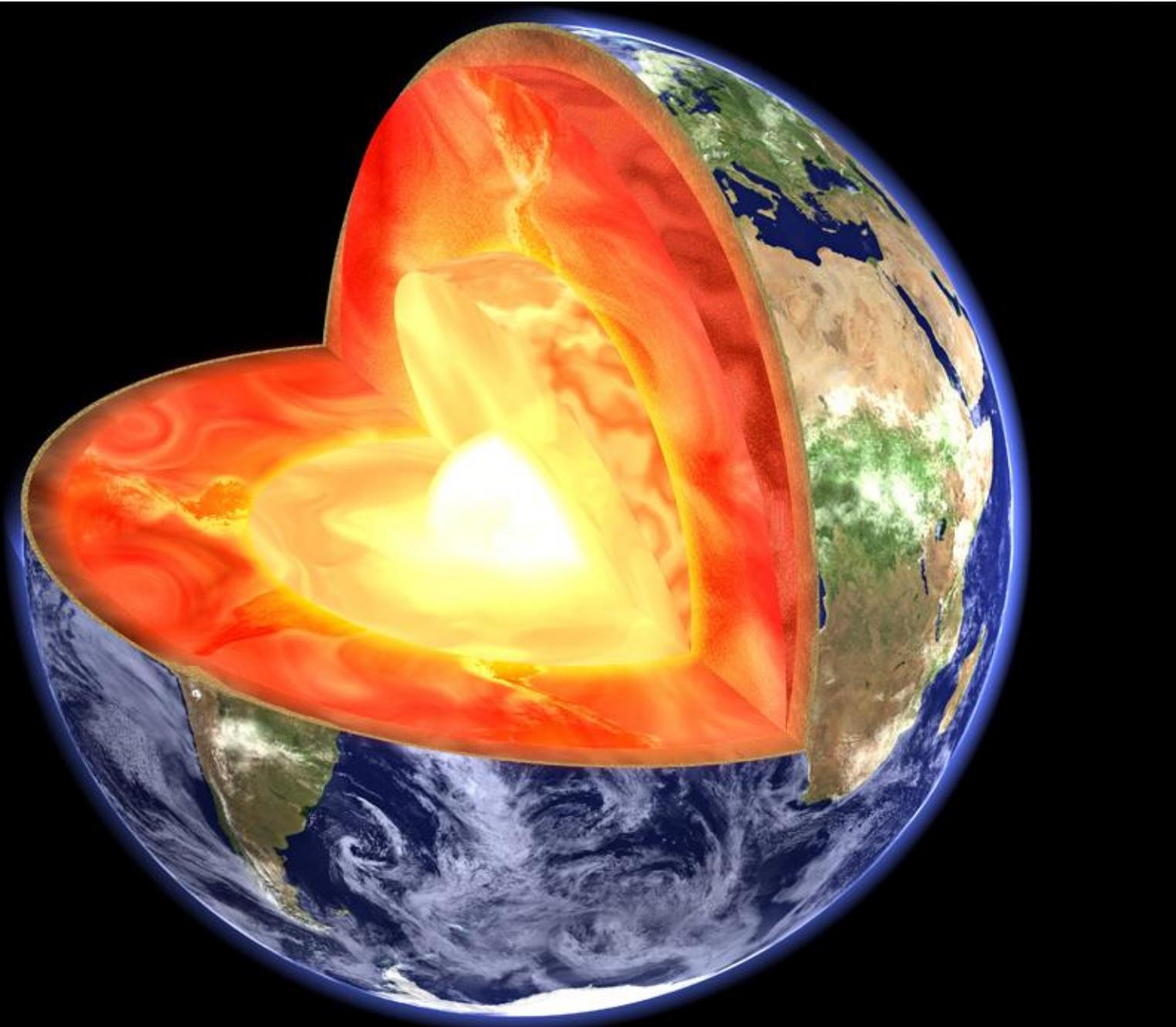


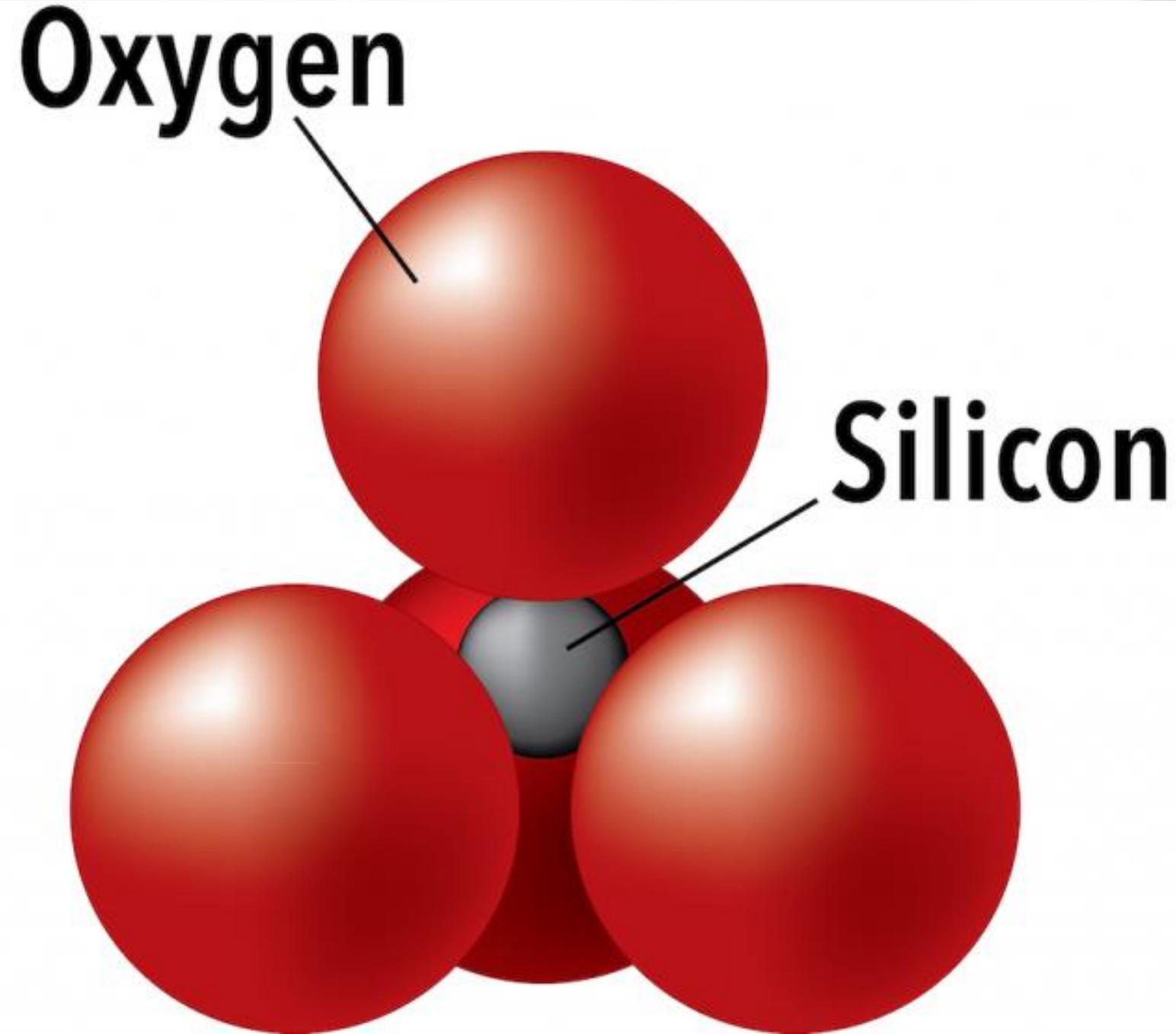
Three things can change with metamorphism

1. Which minerals make up the rock







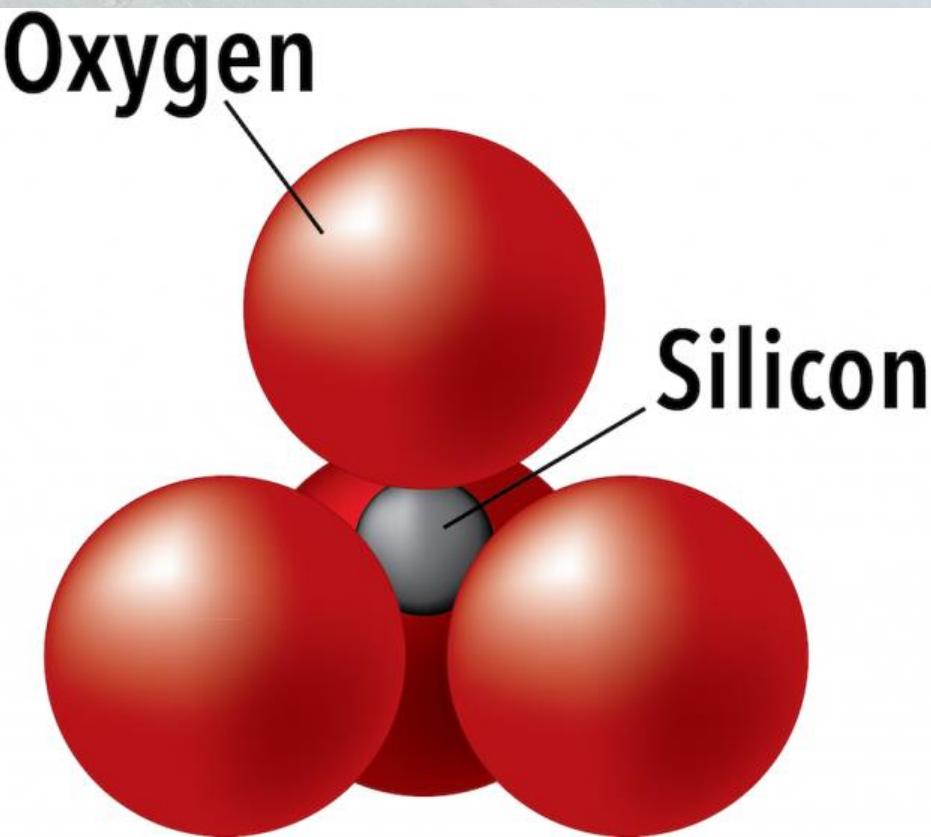


Orthosilicates

Single SiO_4 units

4- balanced by $2 \times \underline{2+}$

e.g. Fe^{2+} , Mg^{2+} , Ca^{2+}

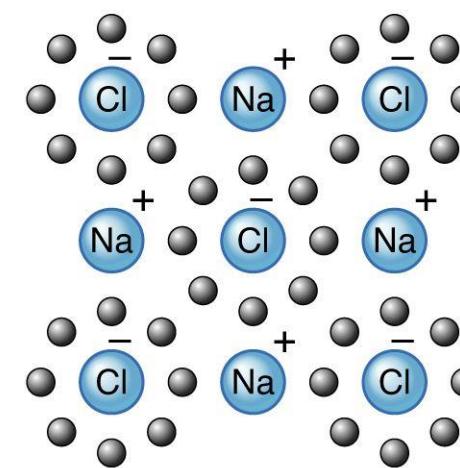
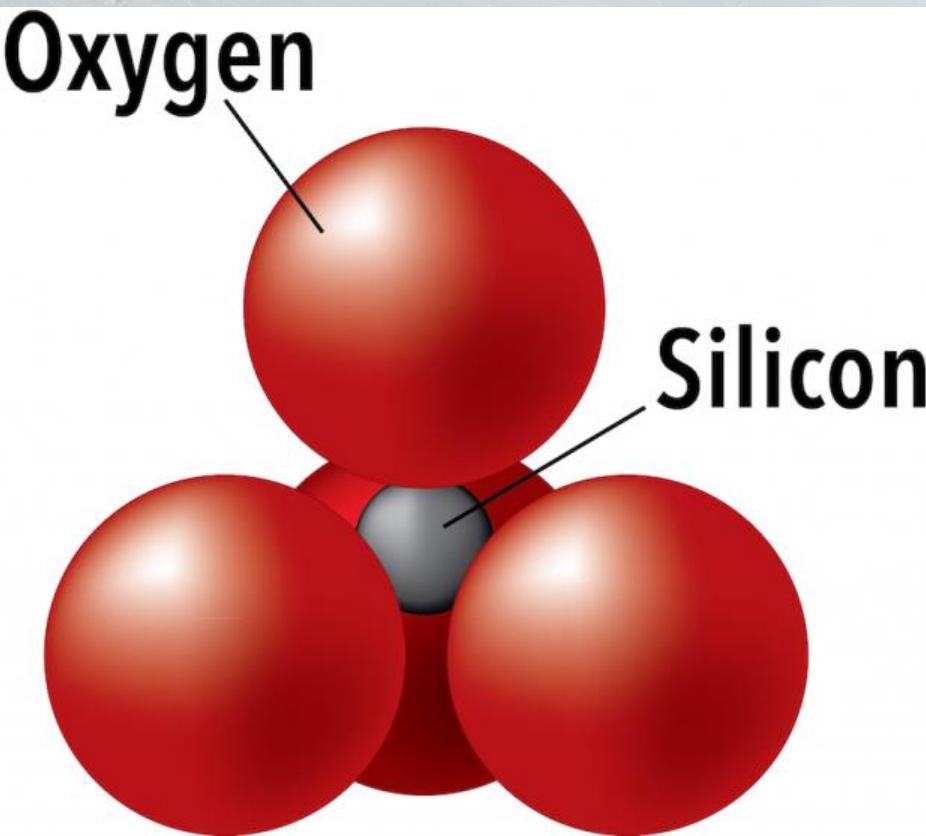


Orthosilicates

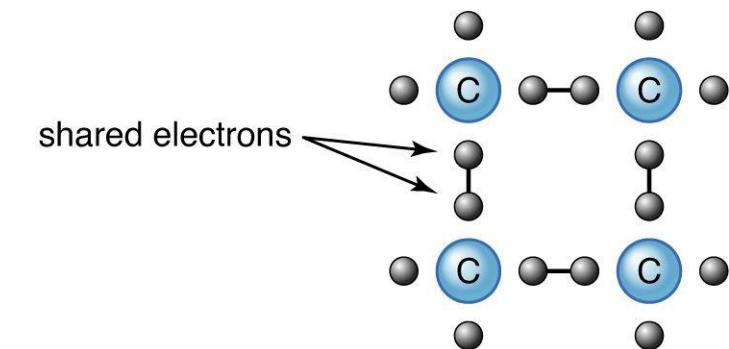
Single SiO_4 units

4- balanced by $2 \times \underline{2+}$

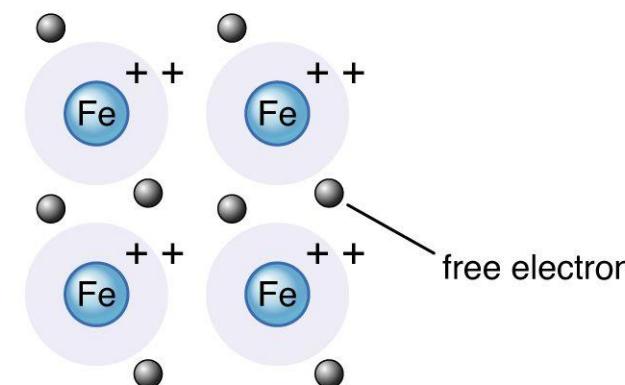
e.g. Fe^{2+} , Mg^{2+} , Ca^{2+}



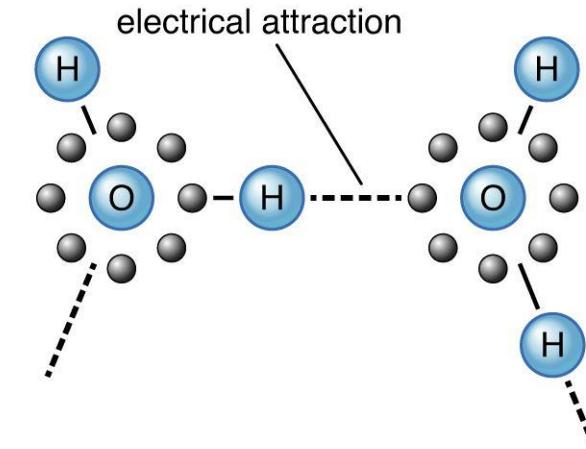
ionic bonding
electron transferred from Na to Cl



covalent bonding
atoms share electrons



metallic bonding
ions surrounded by free electrons



molecular bonding
weak electrical attraction binds molecules

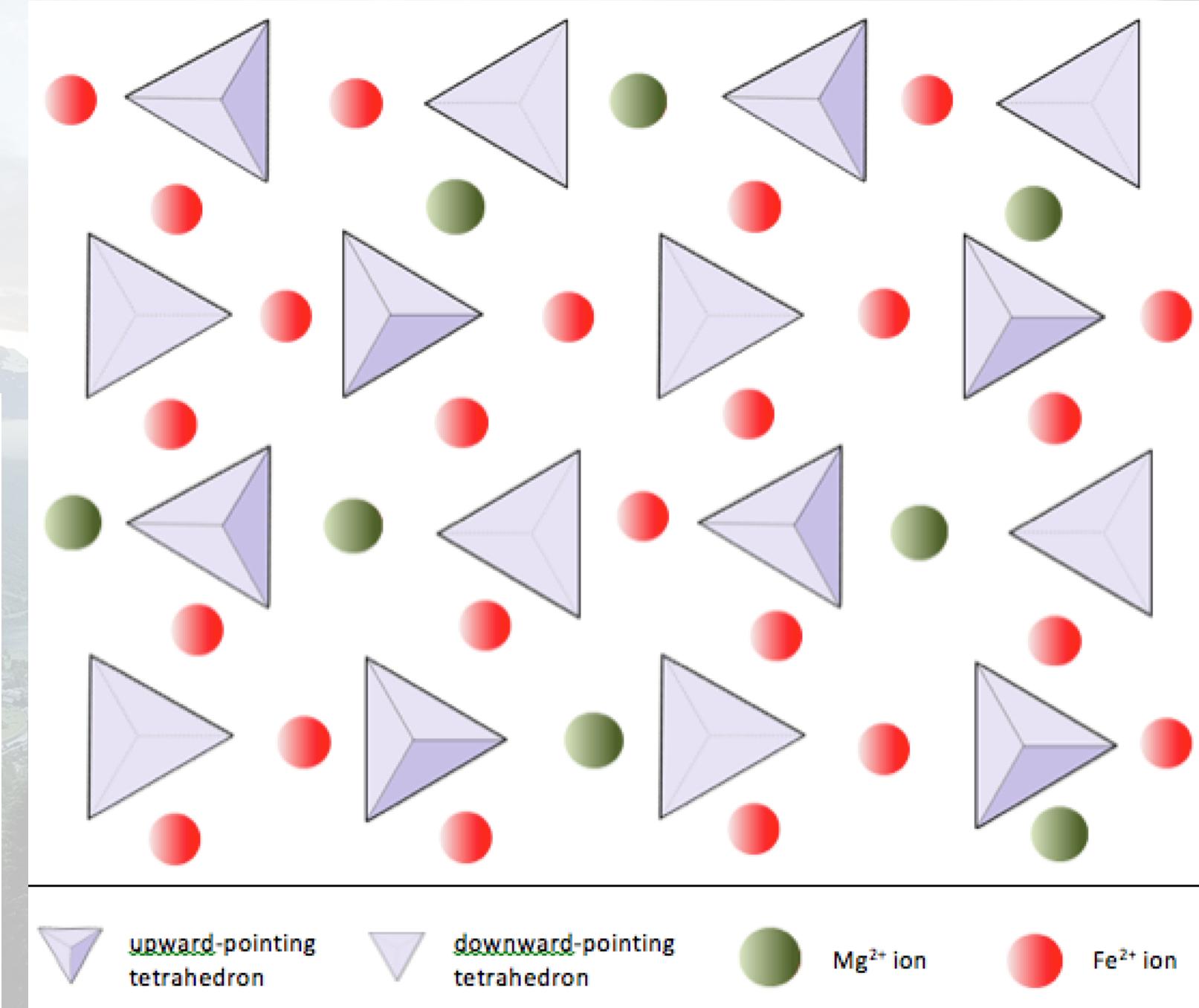
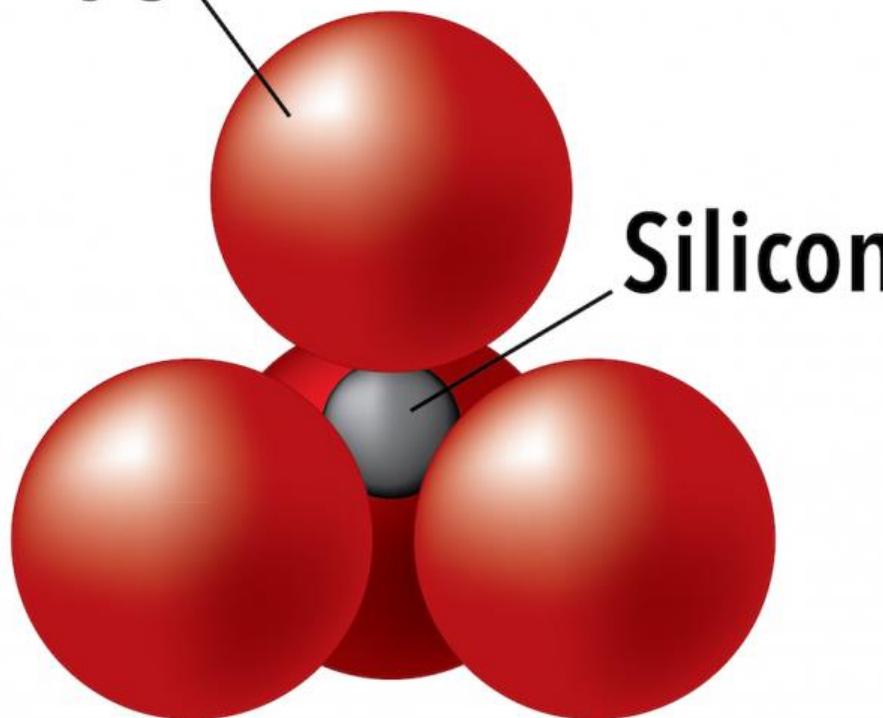
Orthosilicates

Single SiO_4 units

4- balanced by $2 \times \underline{2+}$

e.g. olivine, $(\text{Mg},\text{Fe})_2\text{SiO}_4$

Oxygen

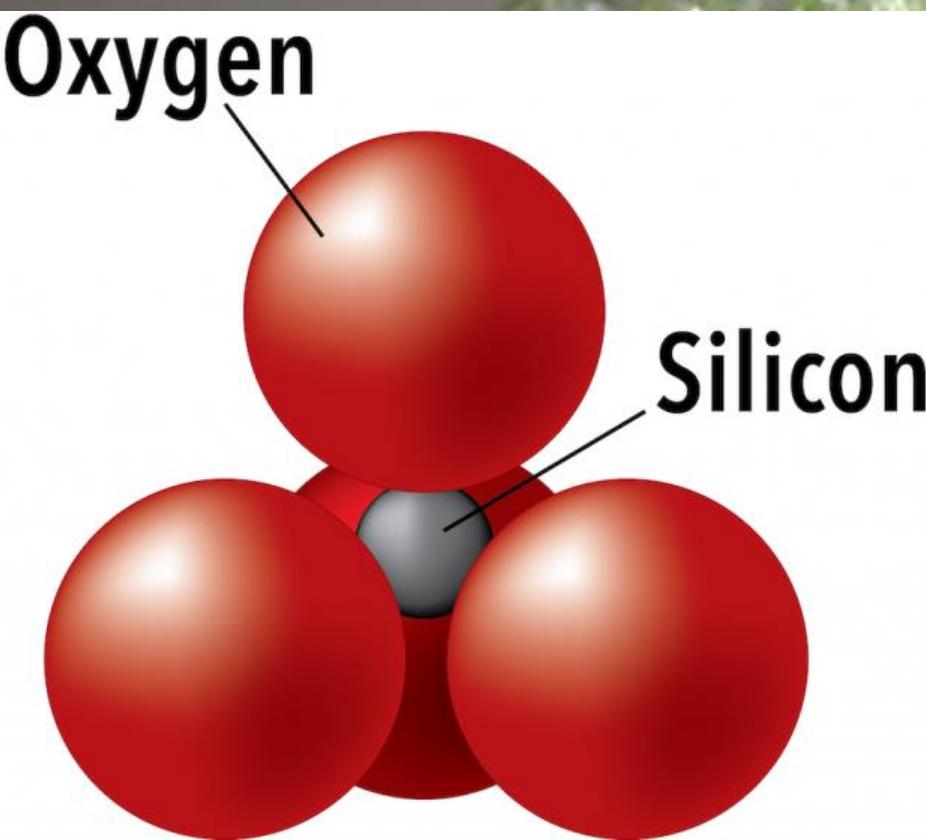


Orthosilicates

Single SiO_4 units

4- balanced by $2 \times \underline{2+}$

e.g. olivine, $(\text{Mg},\text{Fe})_2\text{SiO}_4$



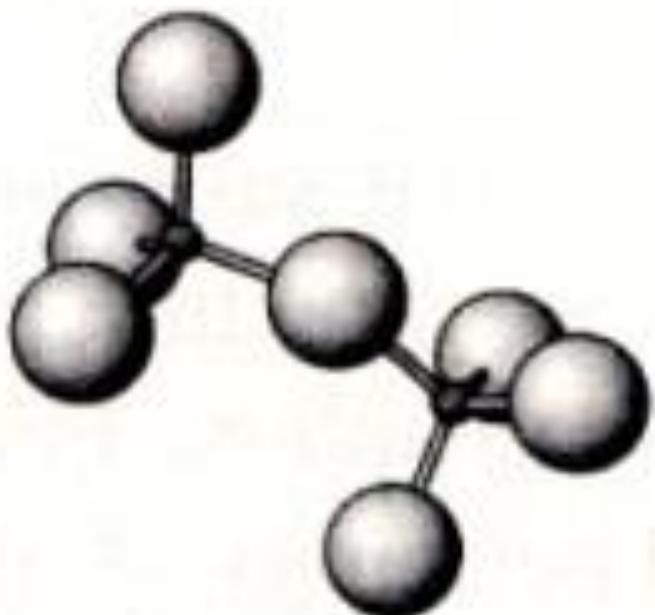


Orthosilicates

Double SiO_4 units sharing one O



e.g. Epidote



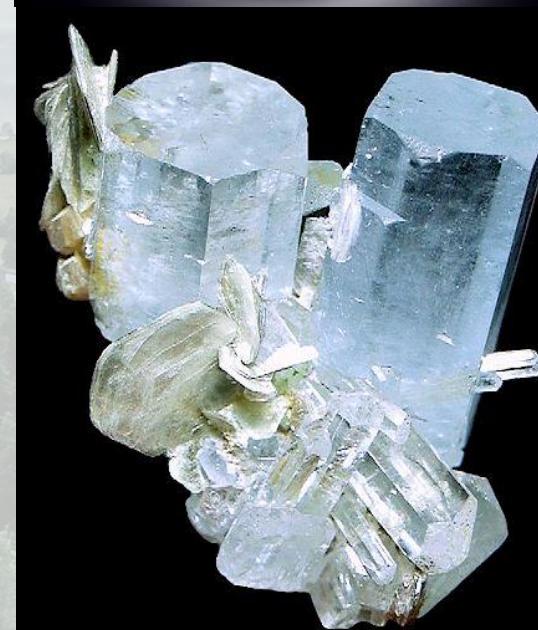
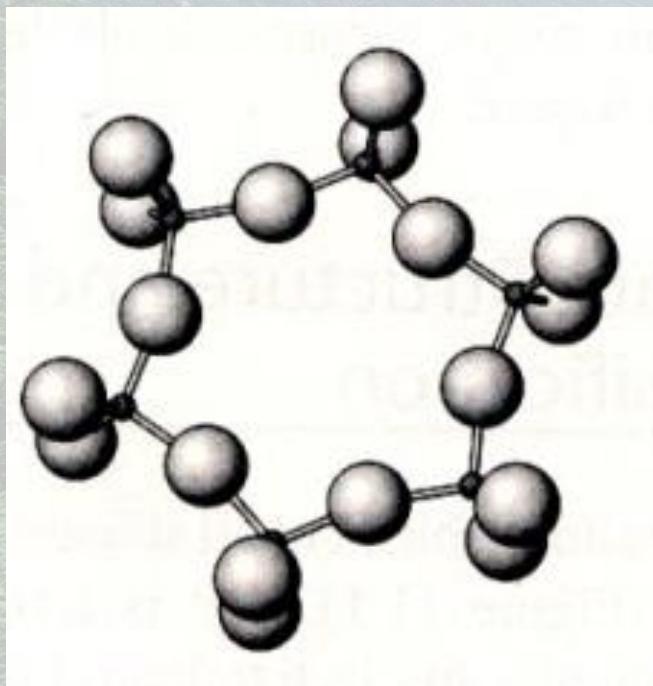
centimetres

Ring silicates

Six SiO_4 units sharing 2 O's each

$$6 \times \text{Si}^{4+} + 18 \times \text{O}^{2-} = \underline{12^-}$$

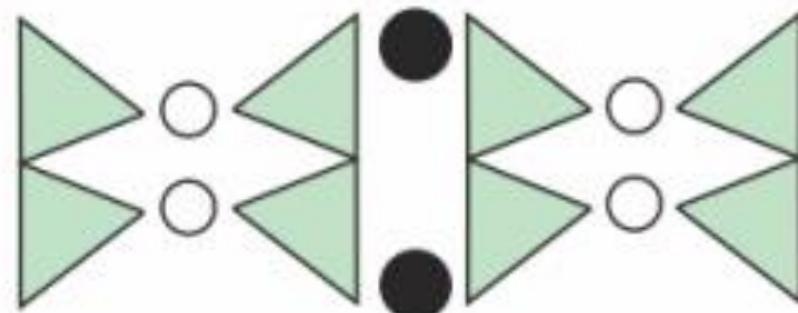
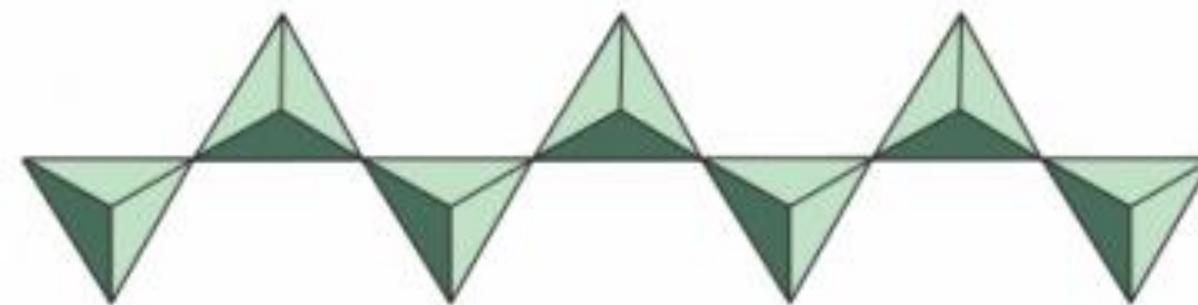
e.g. Beryl (inc. aquamarine, emerald)



Chain silicates

SINGLE CHAIN

View looking down from above



View looking
end-on. This
view shows the
ends of four
chains.

Tetrahedron
points up

Tetrahedron
points down

Cations
(type varies)



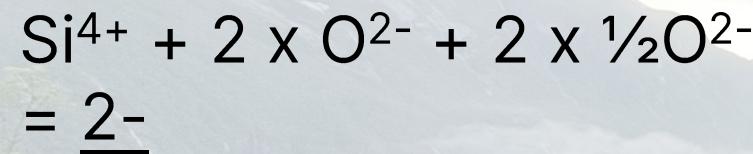
Aegirine variety



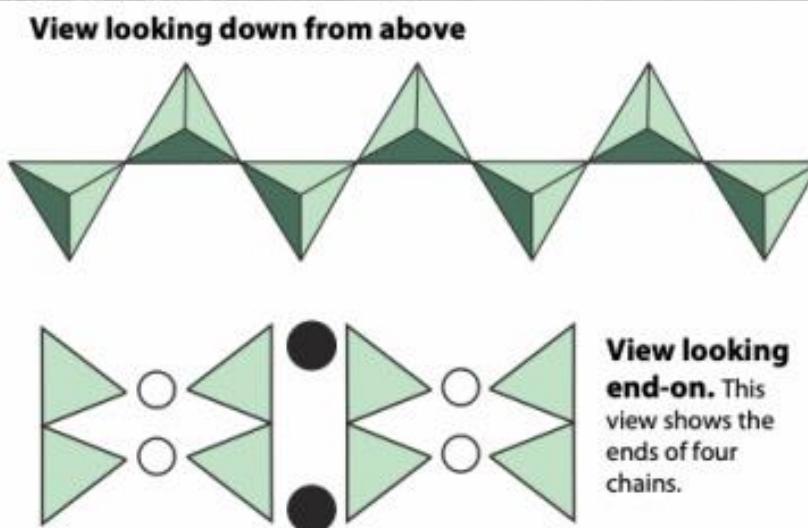
R. Weller/ Cochise College

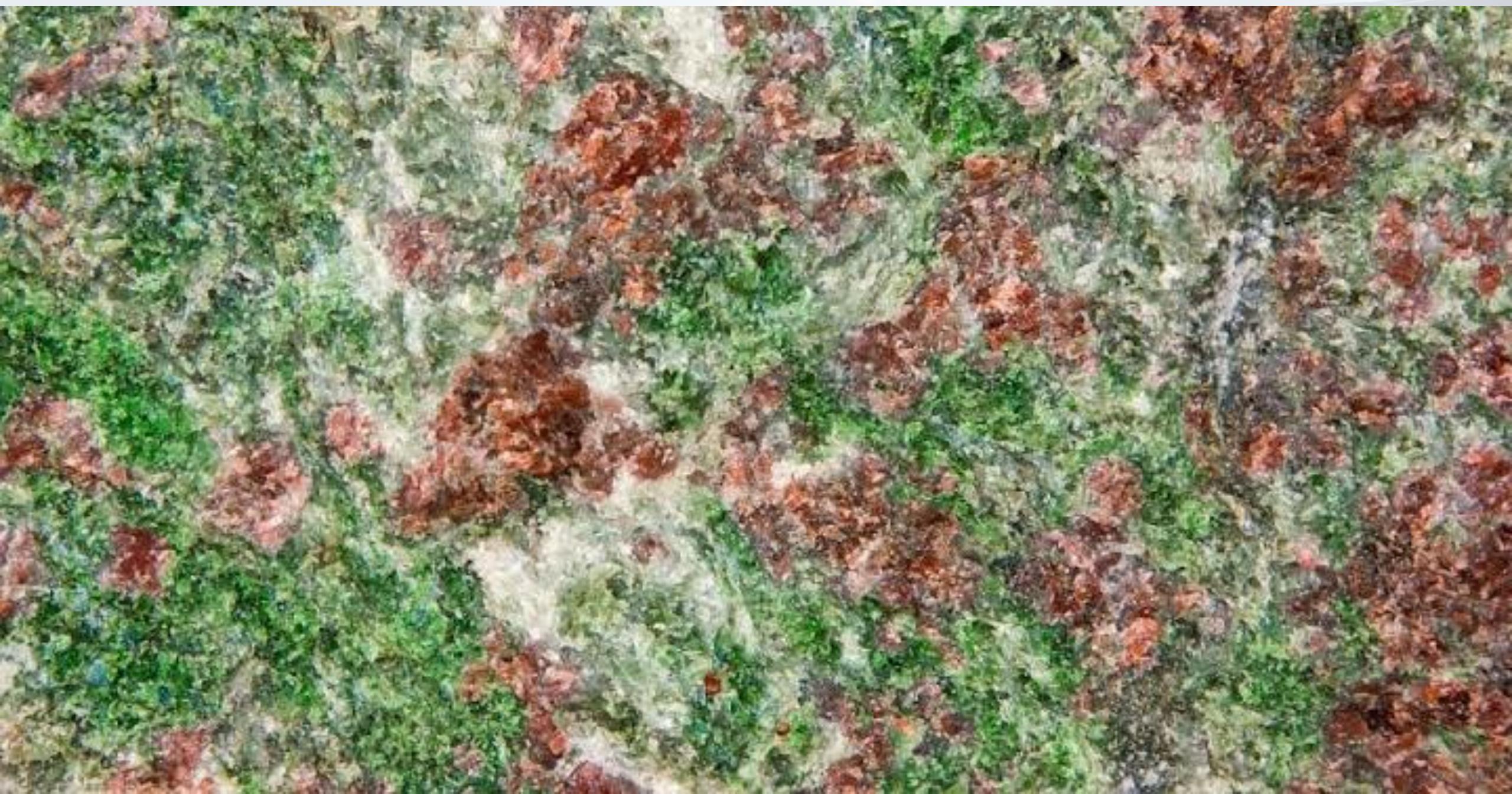
Chain silicates

Continuous chains of SiO_4 units sharing $2 \times \text{O}$



e.g. Pyroxene



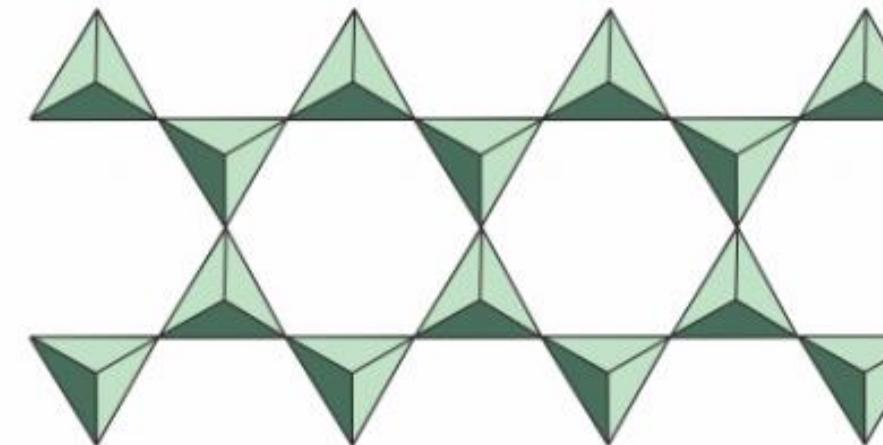


Double Chain silicates

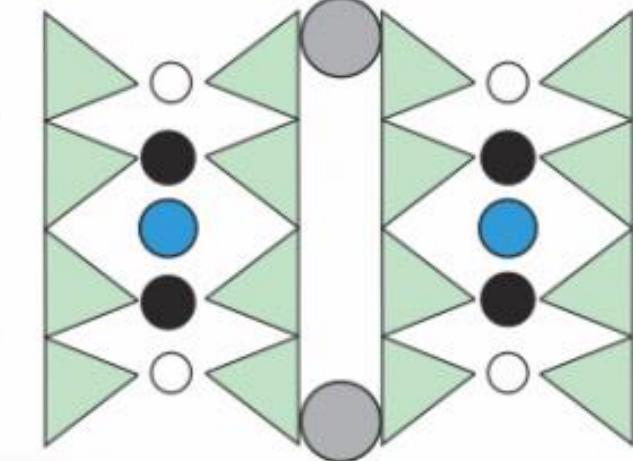
Continuous double chains of SiO_4 units

DOUBLE CHAIN

View looking down from above



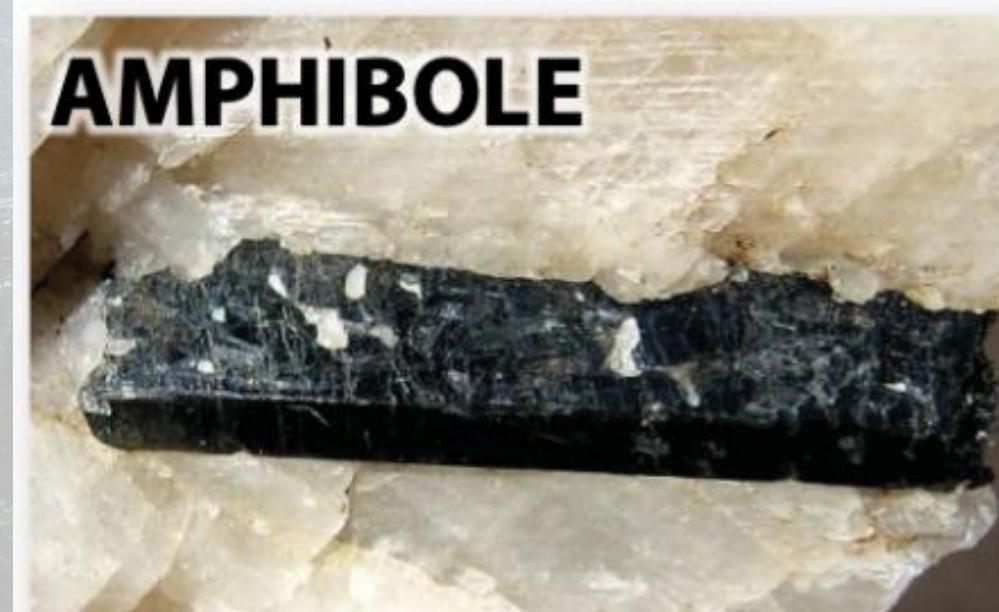
View looking end-on. This view shows the ends of four chains.



Tetrahedron points up

Tetrahedron points down

Cation sites
(type of cation varies)



$\text{Ca}_2(\text{Mg},\text{Fe},\text{Al})_5(\text{Al},\text{Si})_8\text{O}_{22}(\text{OH})_2$
Hornblende variety

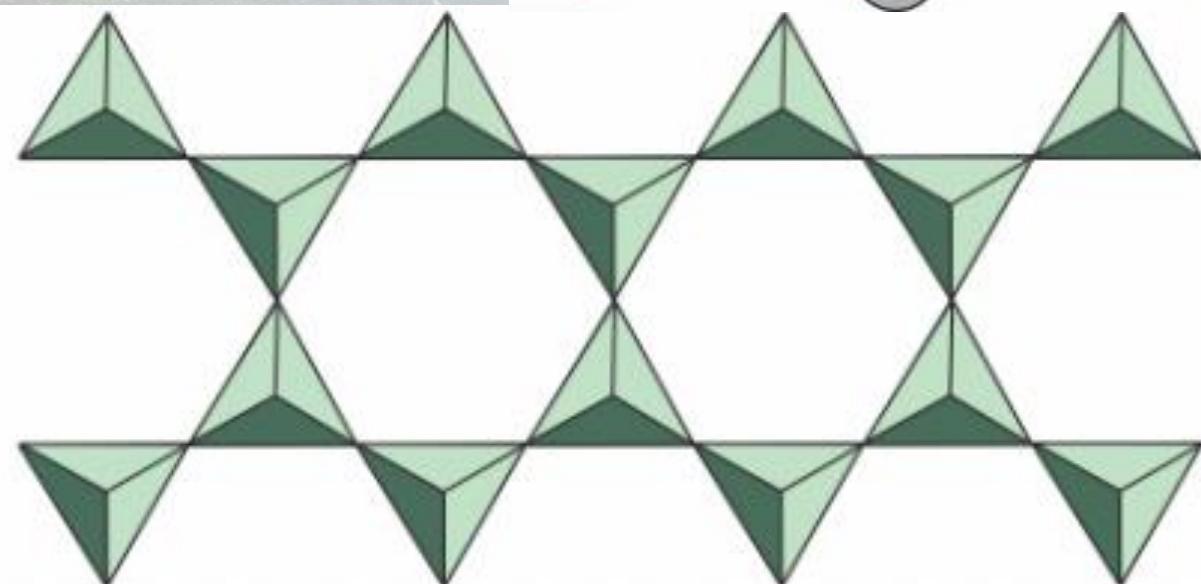


R. Weller/ Cochise College

Double Chain silicates

Continuous double chains of SiO_4 units

e.g. Amphibole

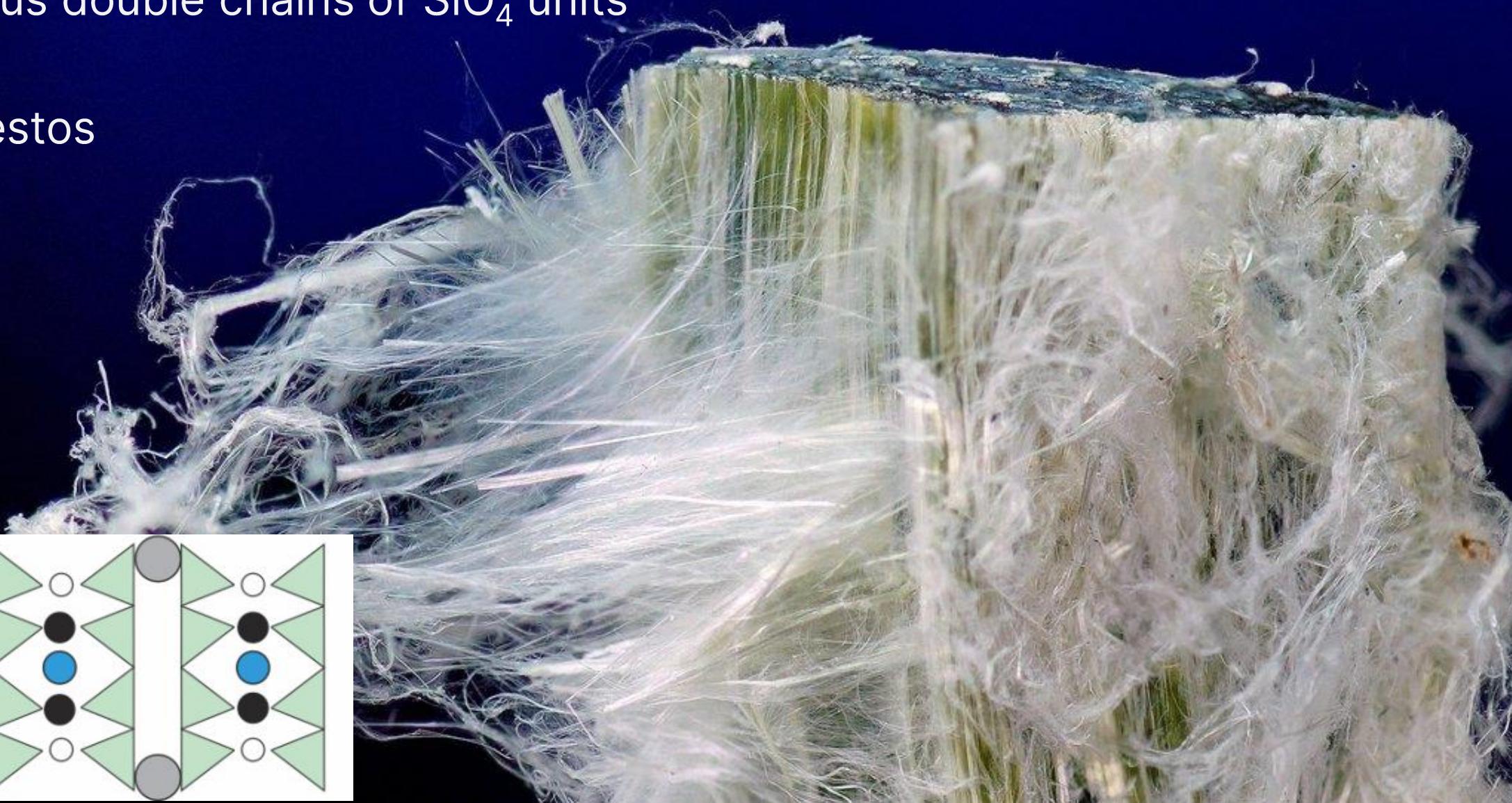
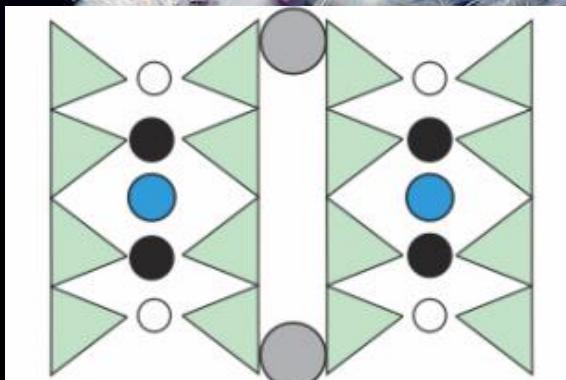
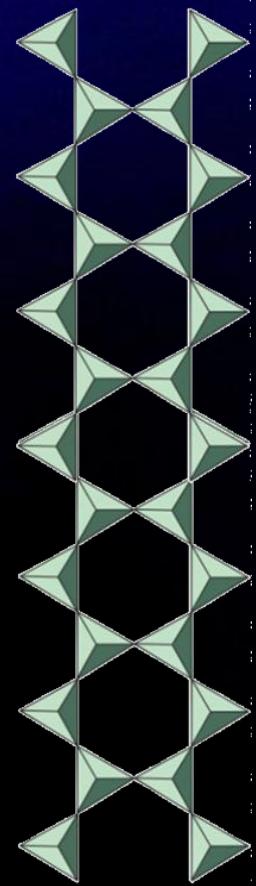


centimetres

Double Chain silicates

Continuous double chains of SiO_4 units

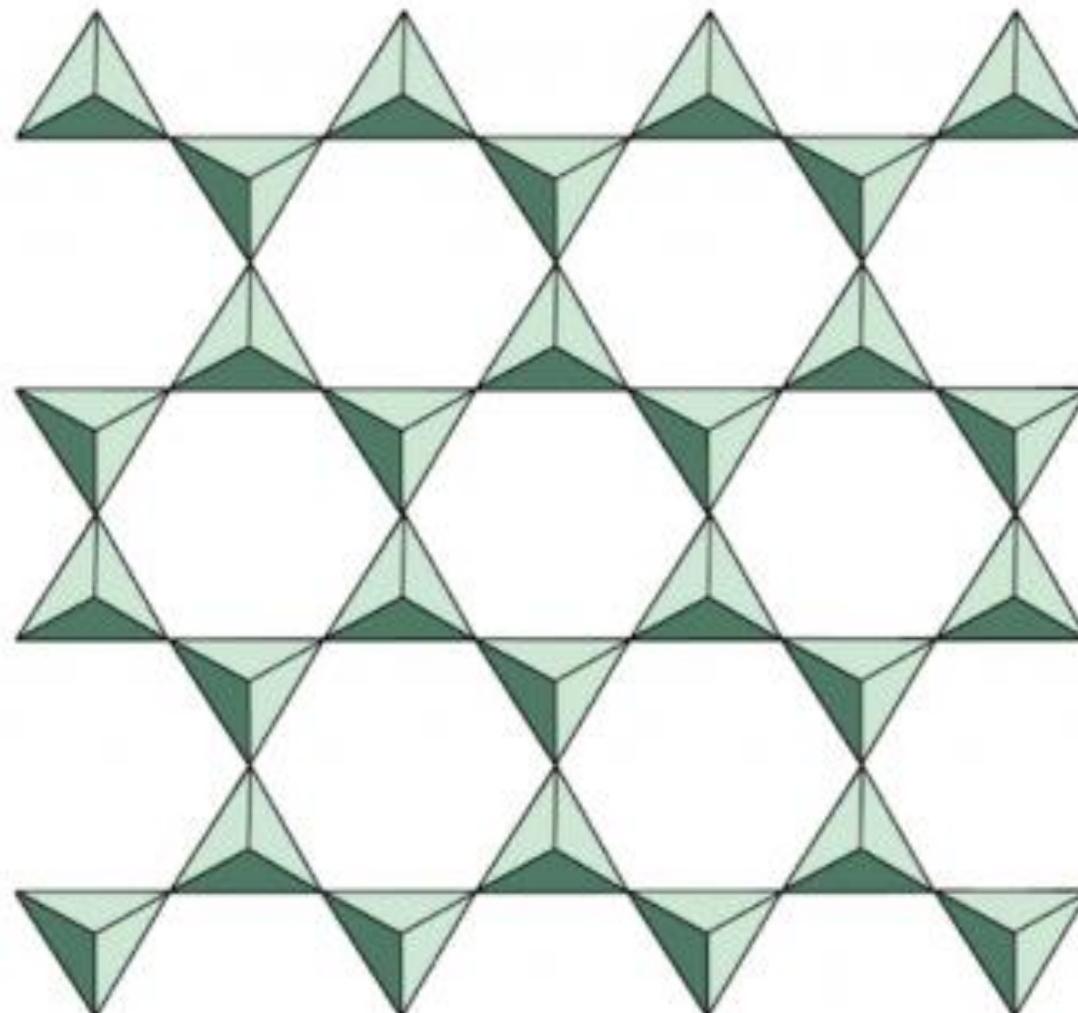
e.g. Asbestos



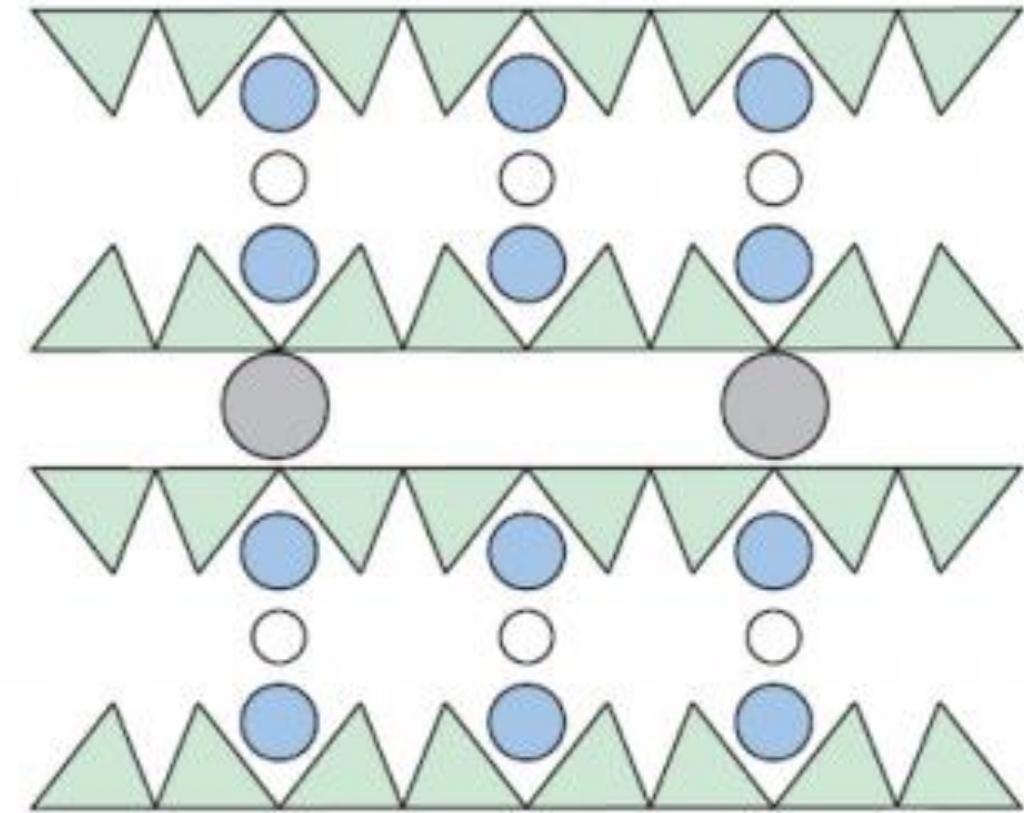
Sheet Silicates

Continuous sheets of SiO_4 units sharing 3 O's each, e.g. mica

View looking down on the sheet of tetrahedra



View looking end-on at sheets of tetrahedra



Top view of tetrahedron

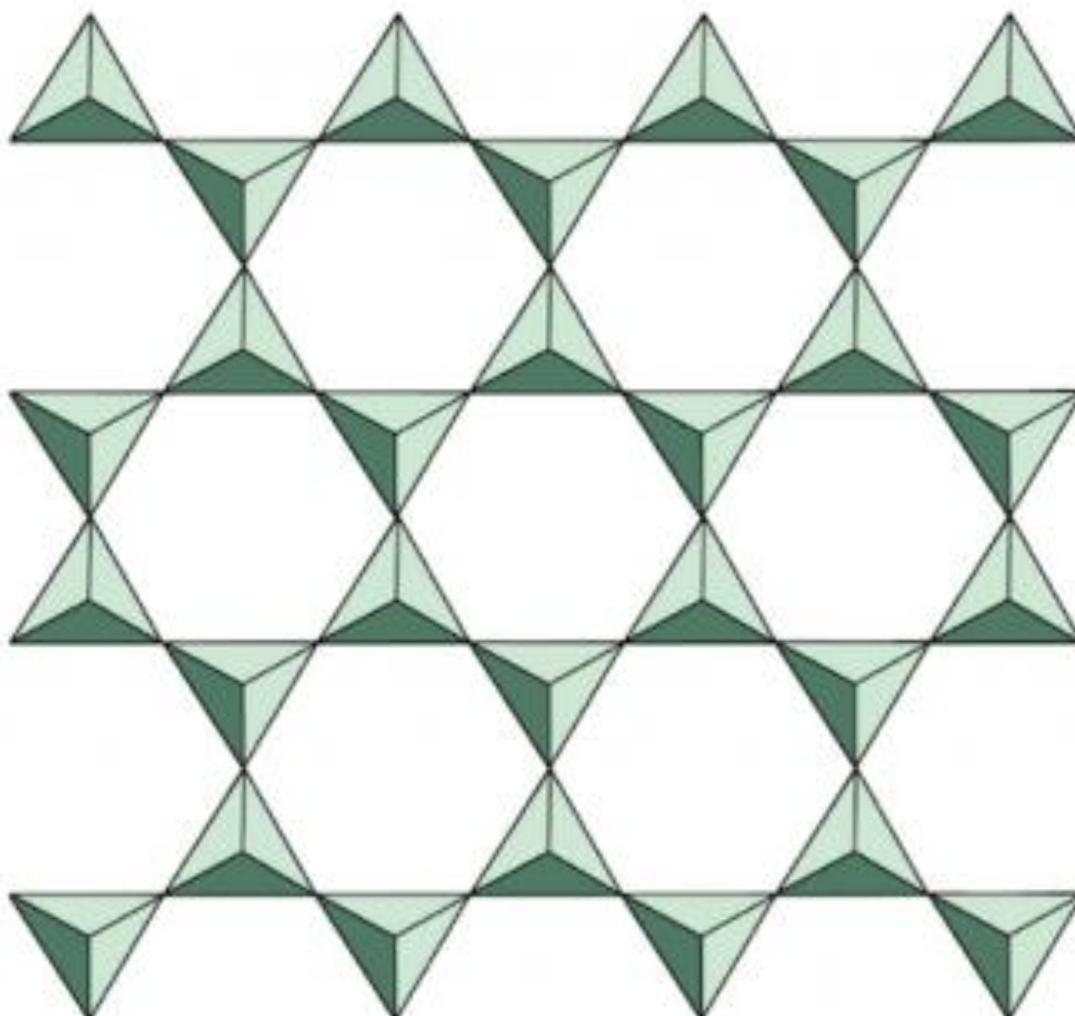
End-on view of tetrahedron

Cation sites
 OH^- anion

Sheet Silicates

Continuous sheets of SiO_4 units sharing 3 O's each, e.g. mica

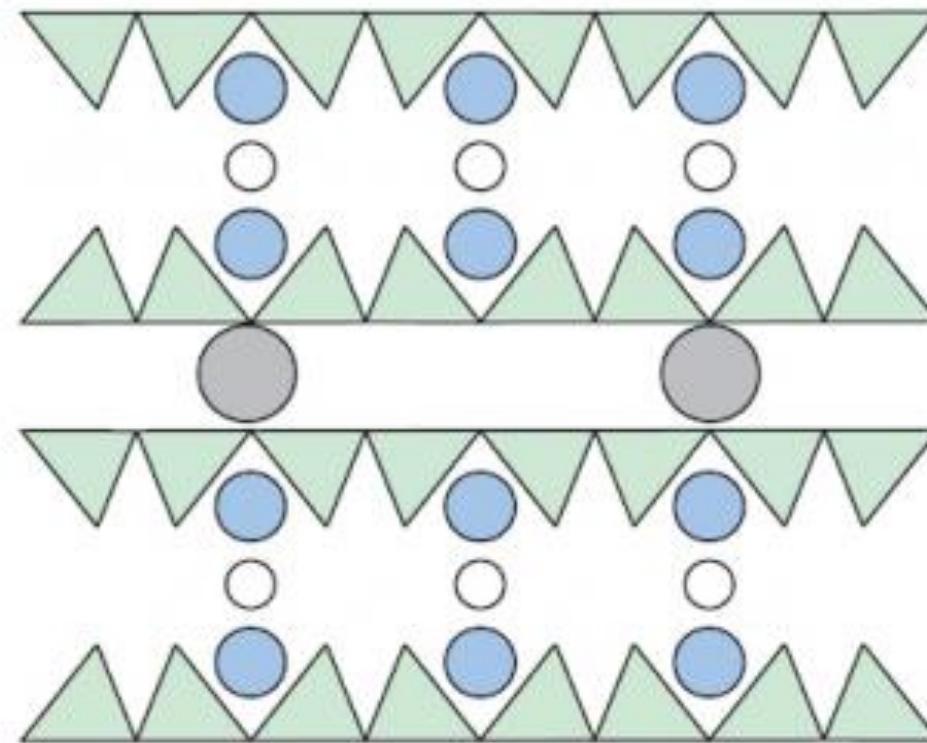
View looking down on the sheet of tetrahedra



Sheet Silicates

Continuous sheets of SiO_4 units sharing 3 O's each, e.g. mica

View looking end-on at sheets of tetrahedra



Top view of tetrahedron

End-on view of tetrahedron

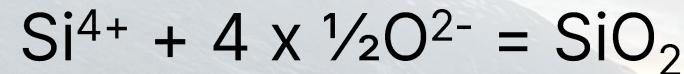
Cation sites
 OH^- anion



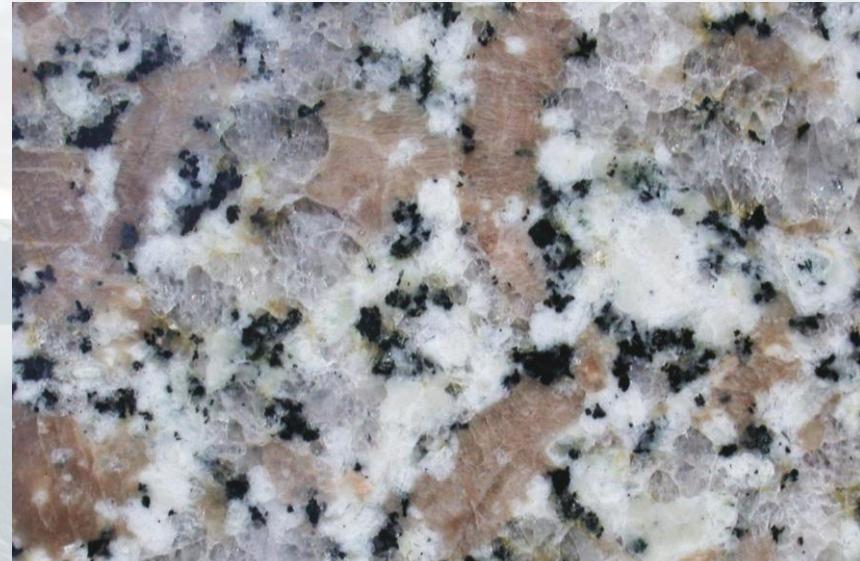
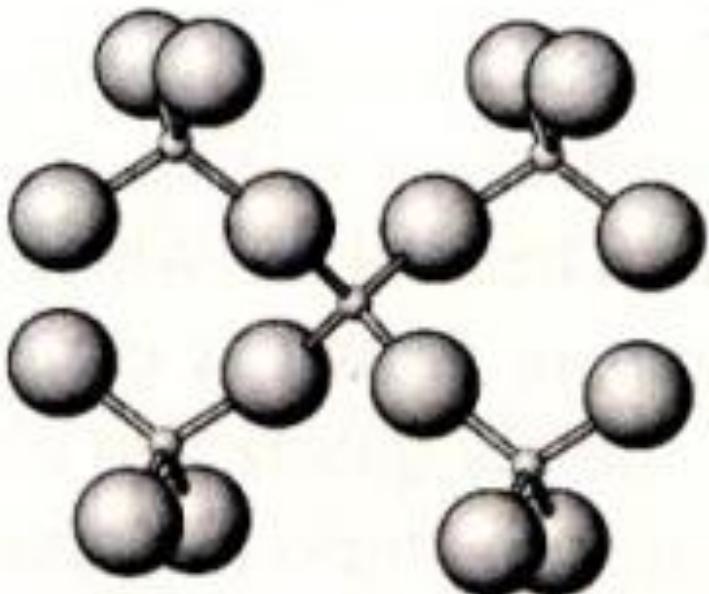


Framework silicates

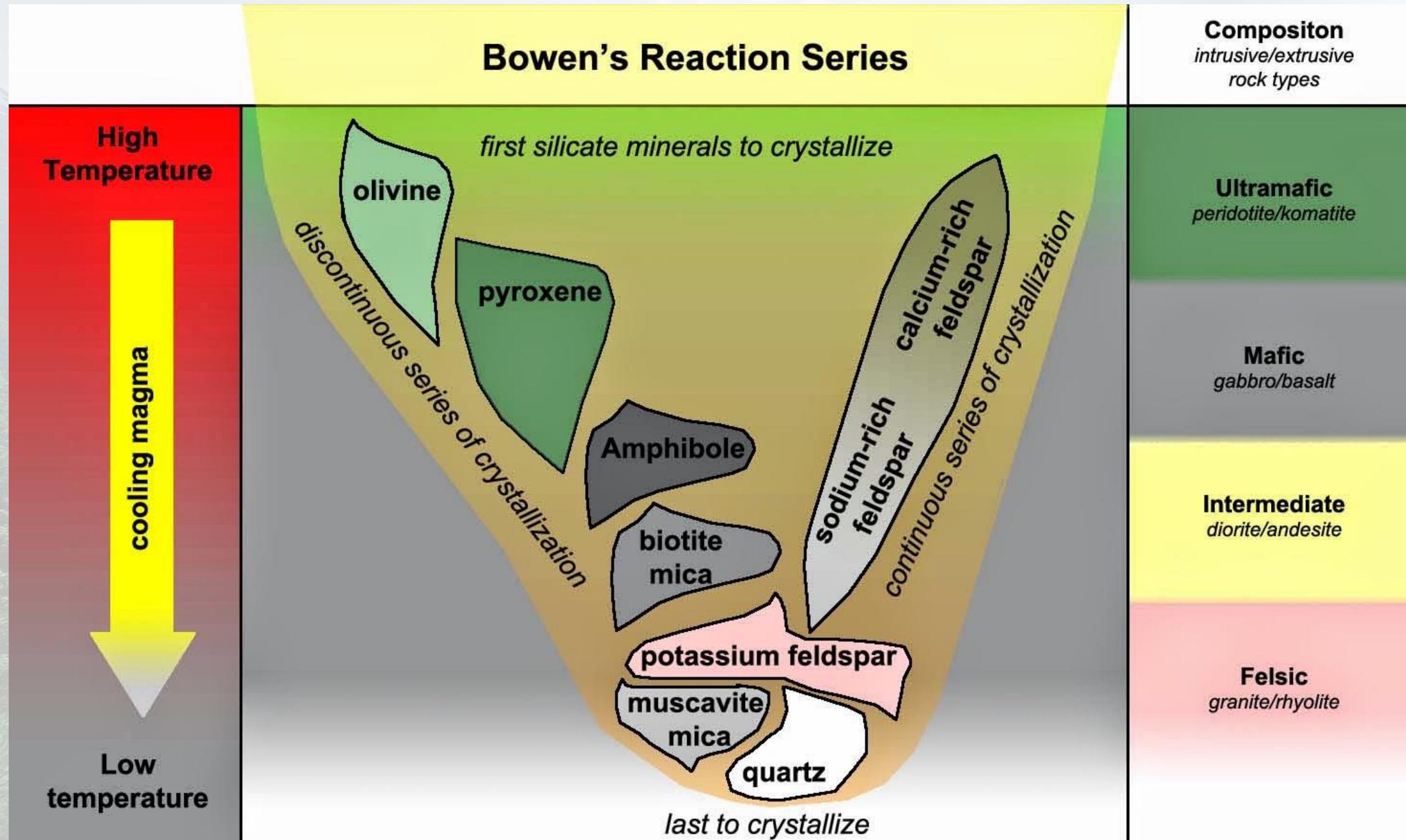
Continuous 3D framework of SiO_4 units sharing all 4 O's

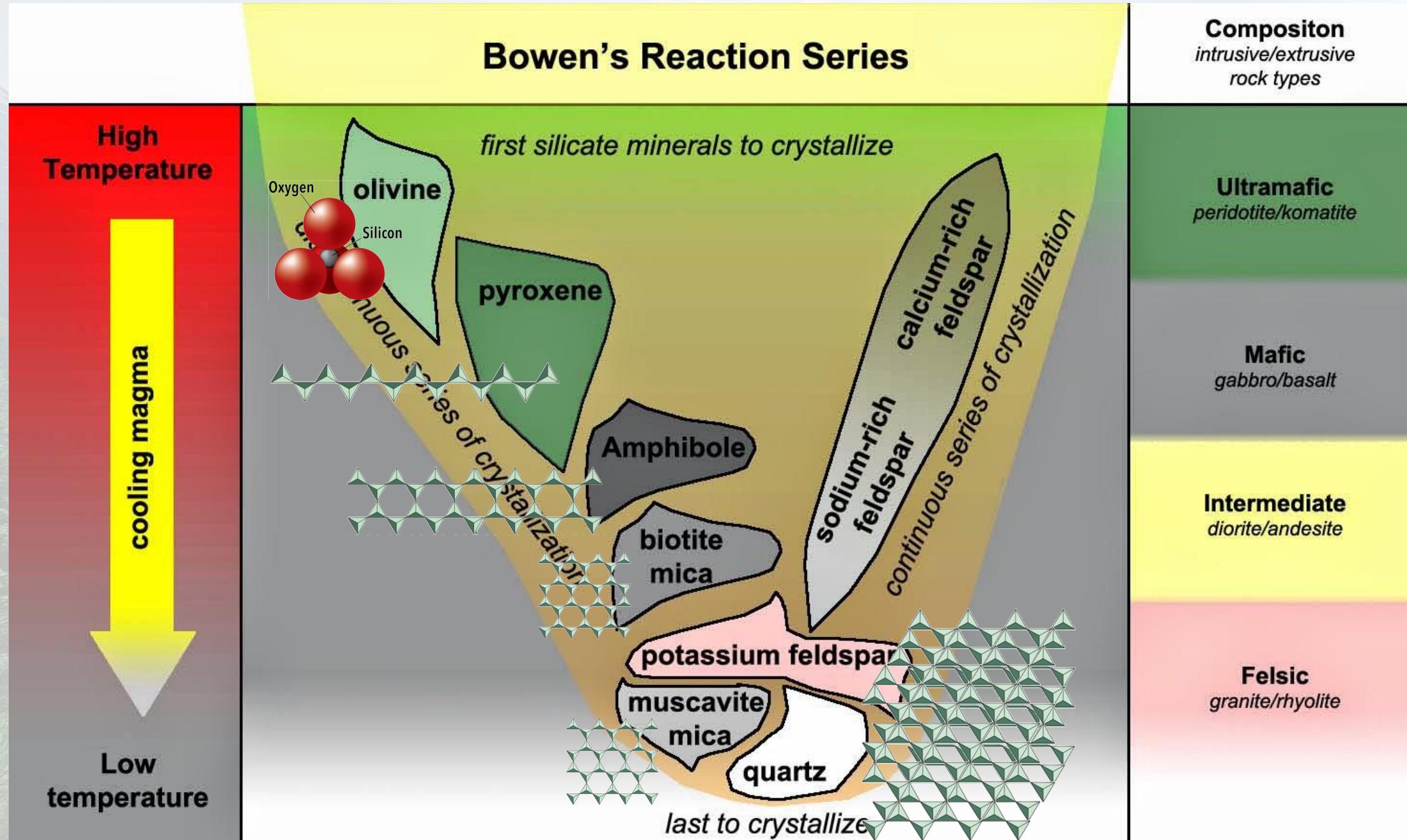


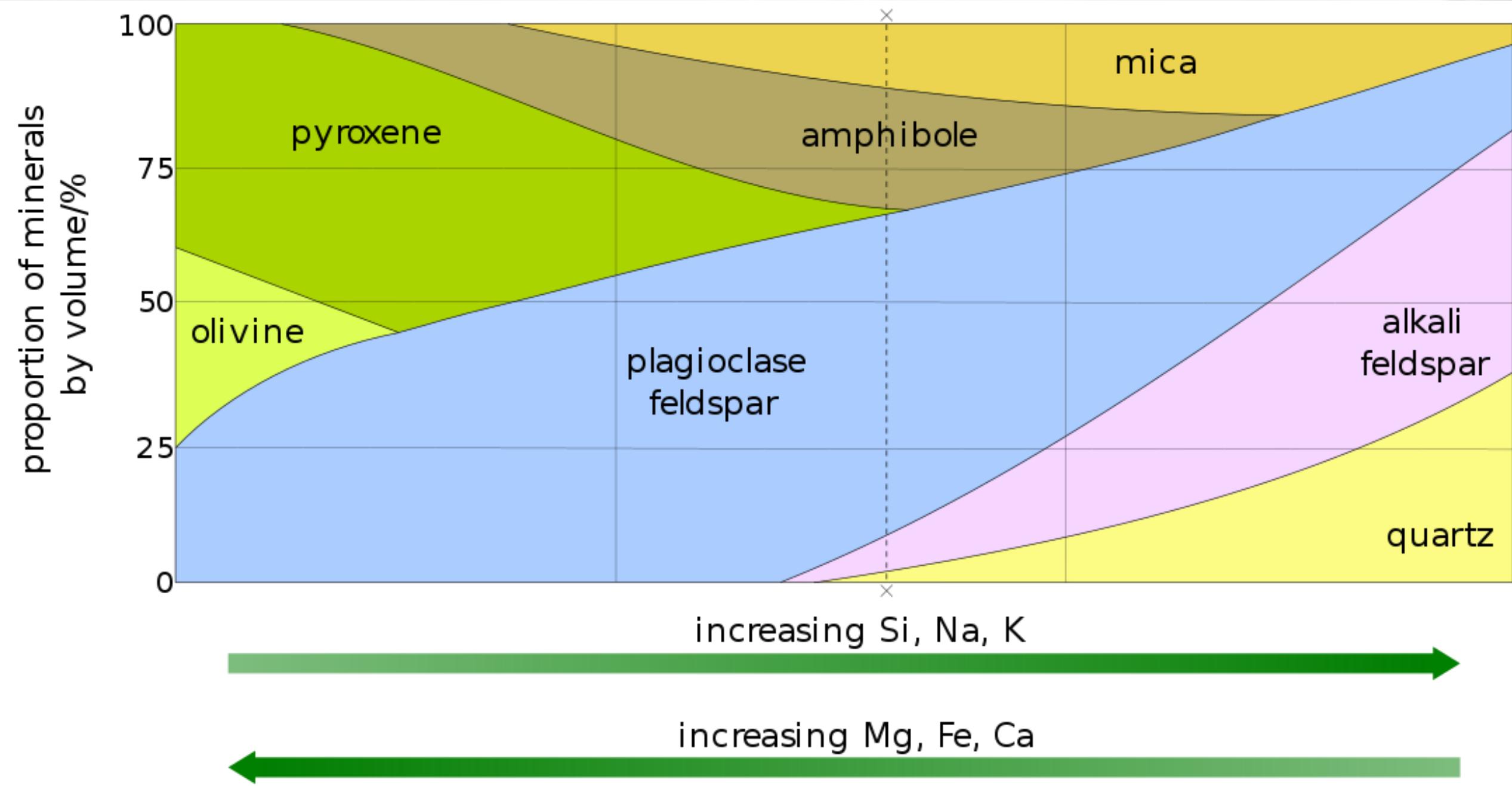
e.g. Quartz, feldspar

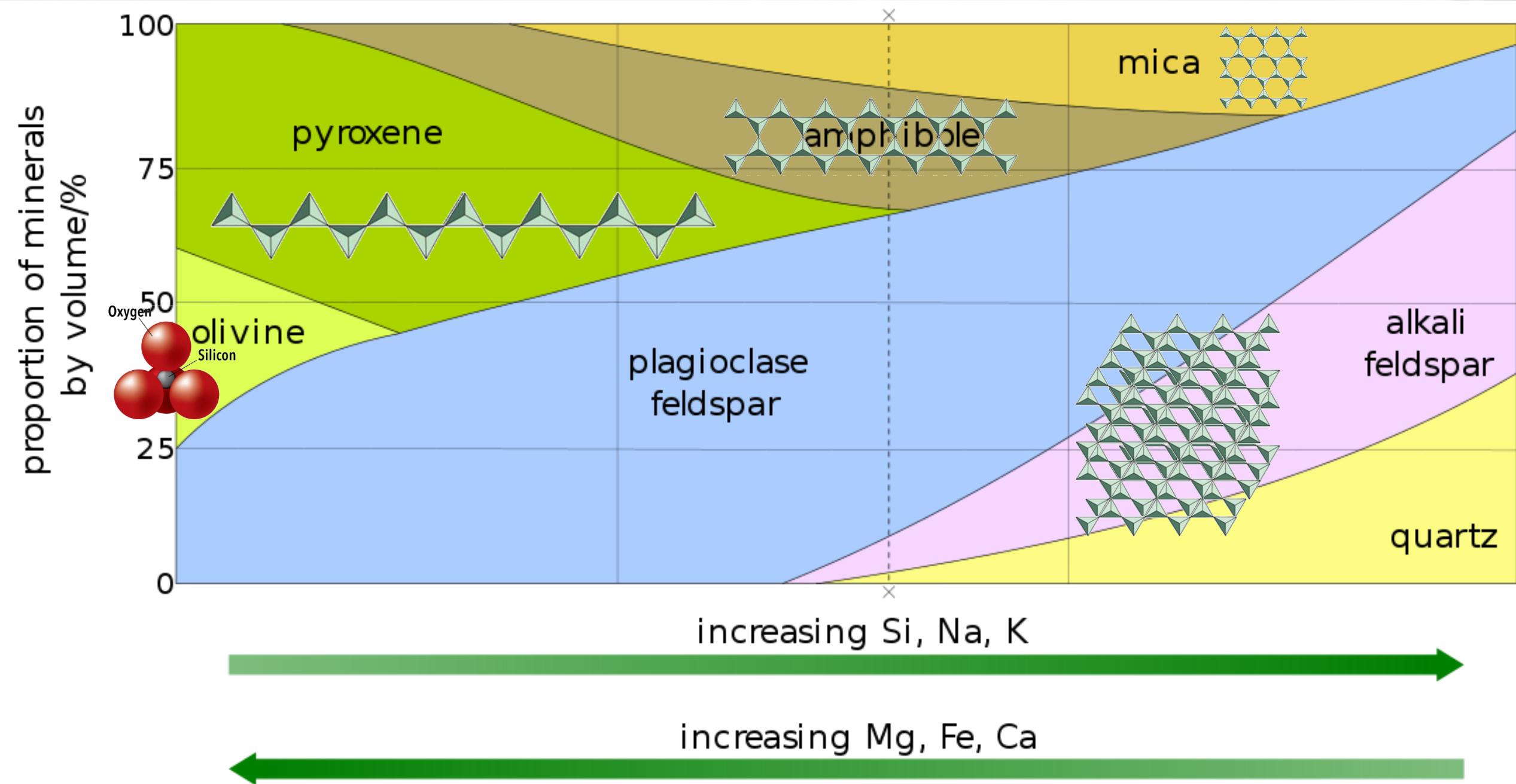


centimetres

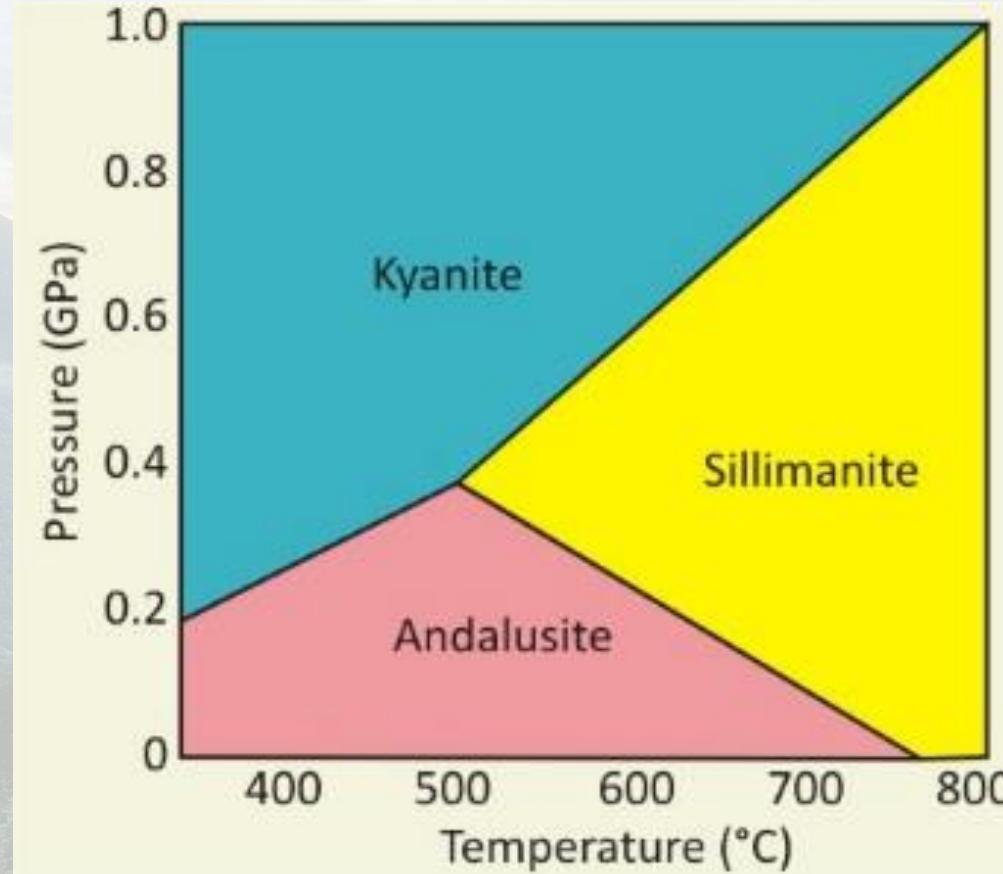








Al₂SiO₅



Al₂SiO₅

Al₂SiO₅

On the Earth's surface, this is called **chemical weathering**



Obviously not at
mantle P/T conditions

Metastable at
Earth surface

Piece of mantle



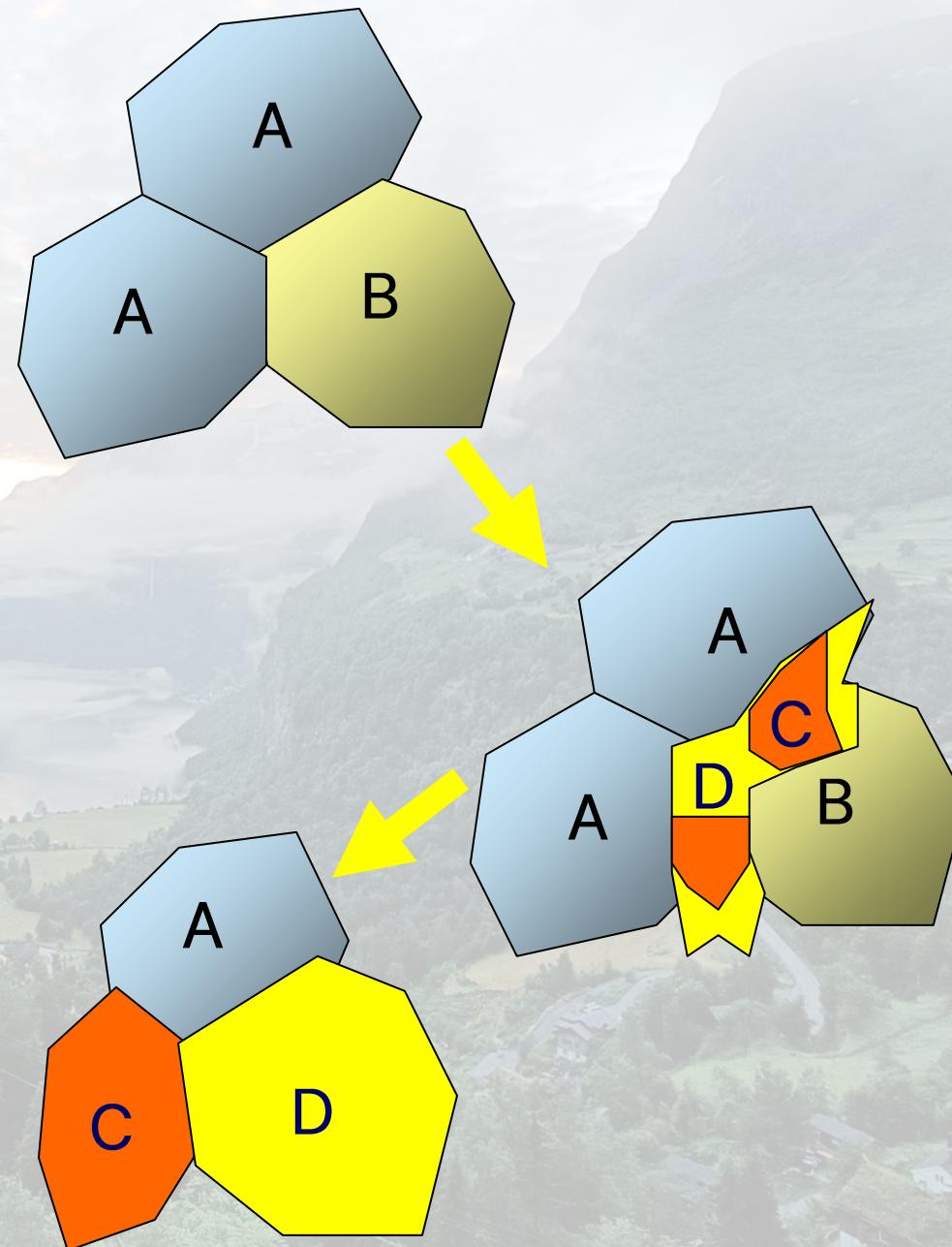
Set of minerals A + B **stable** at initial pressure and temperature

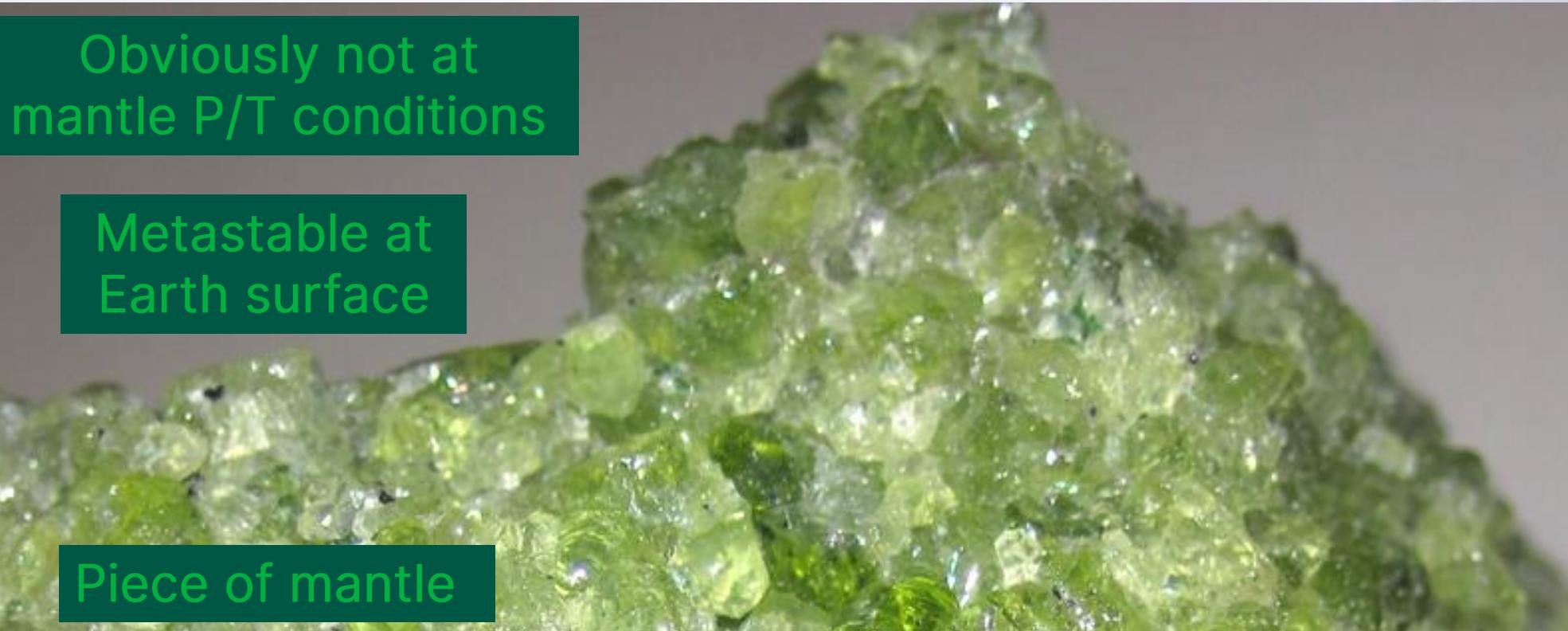
Pressure and temperature change – A + B are now **unstable**

Minerals A + B start to recrystallize, bit by bit

New minerals start to grow which *are* stable at this pressure and temperature: C + D

New minerals will eventually replace most or all of the earlier ones

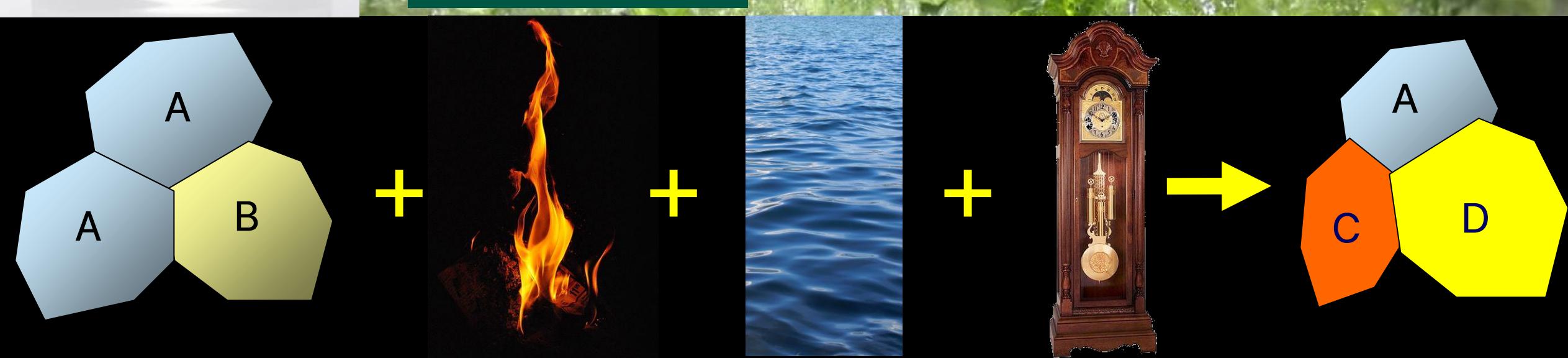


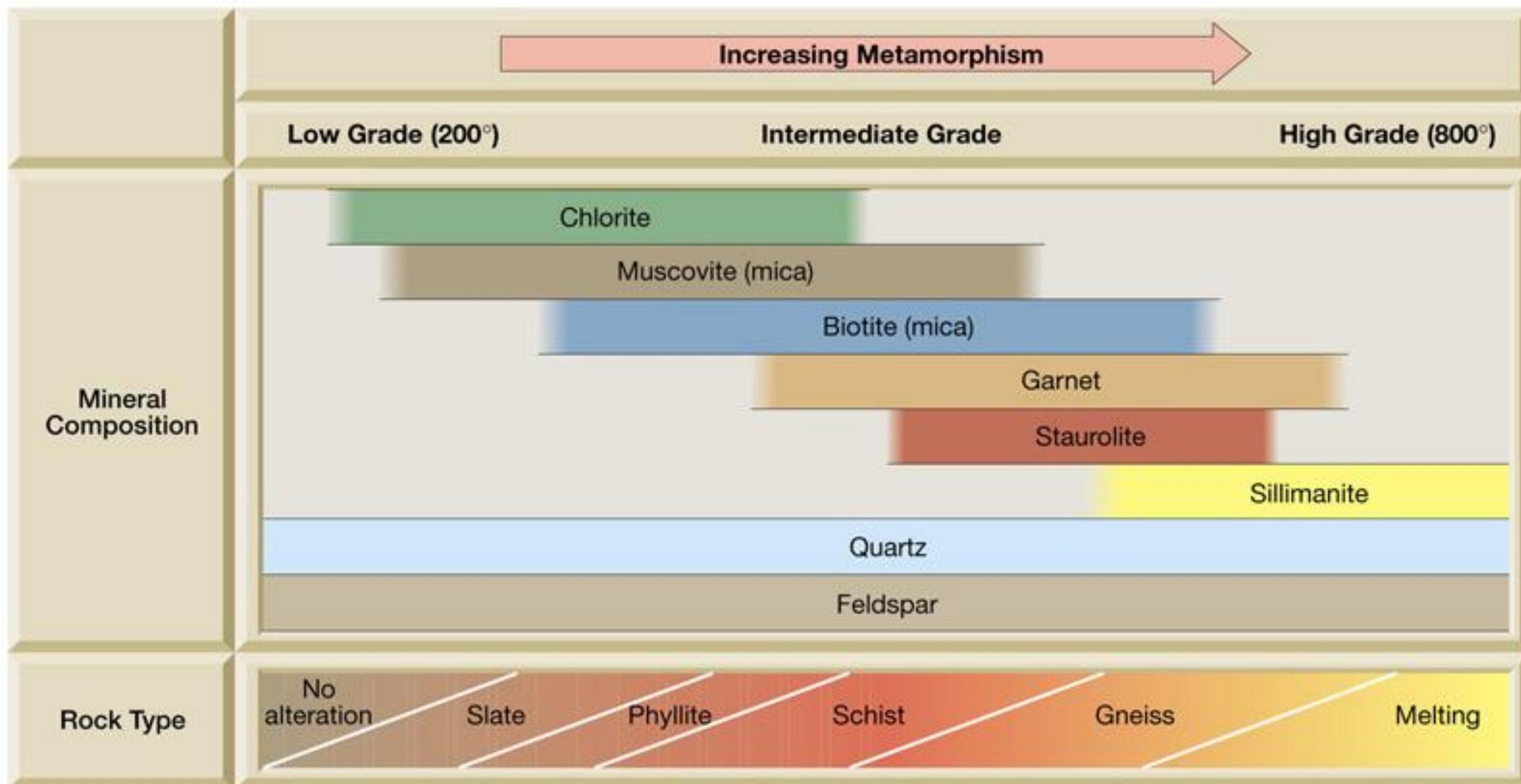


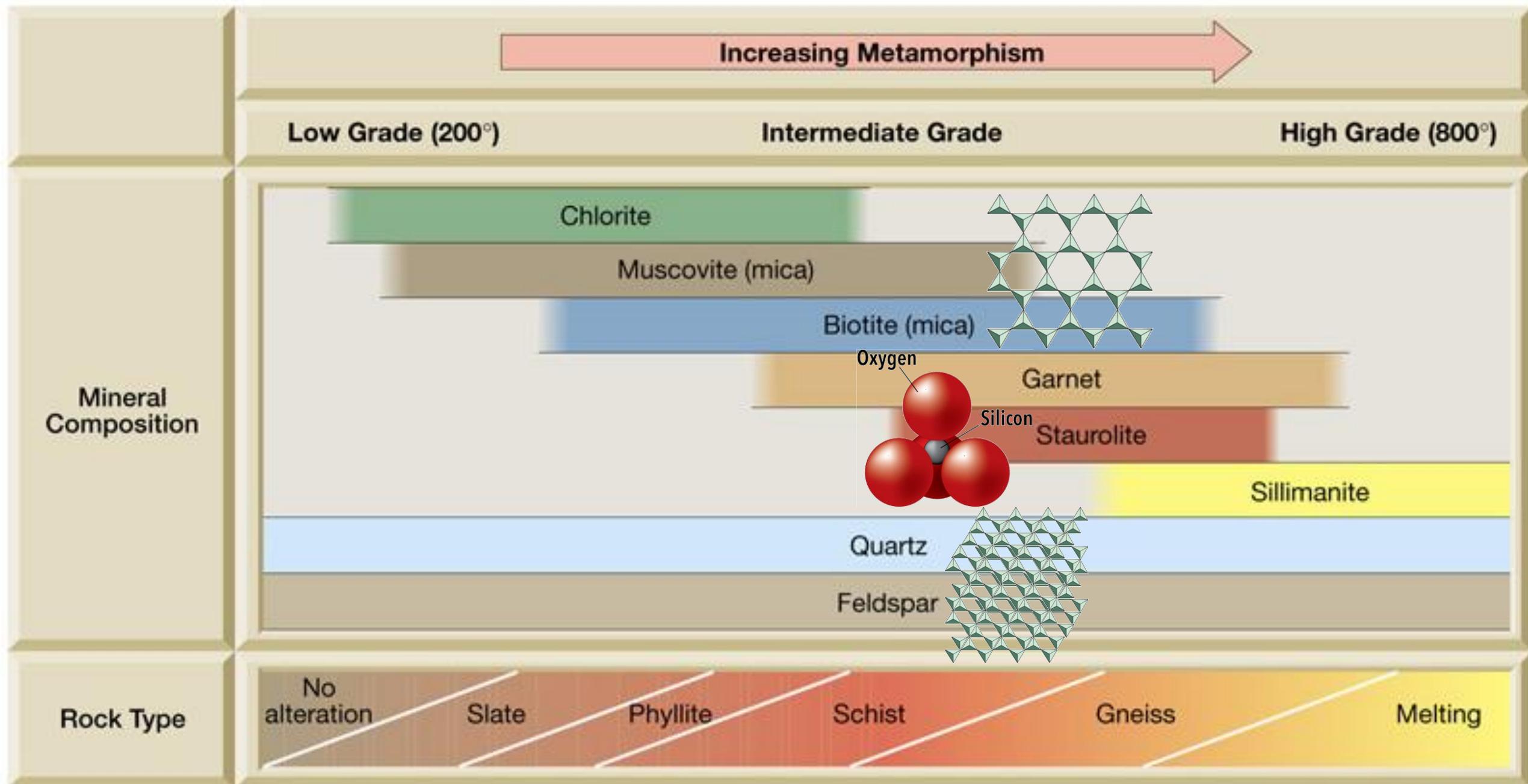
Obviously not at
mantle P/T conditions

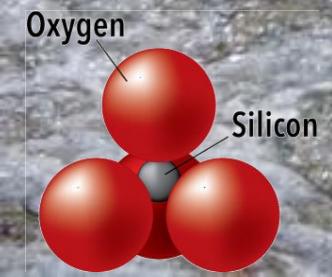
Metastable at
Earth surface

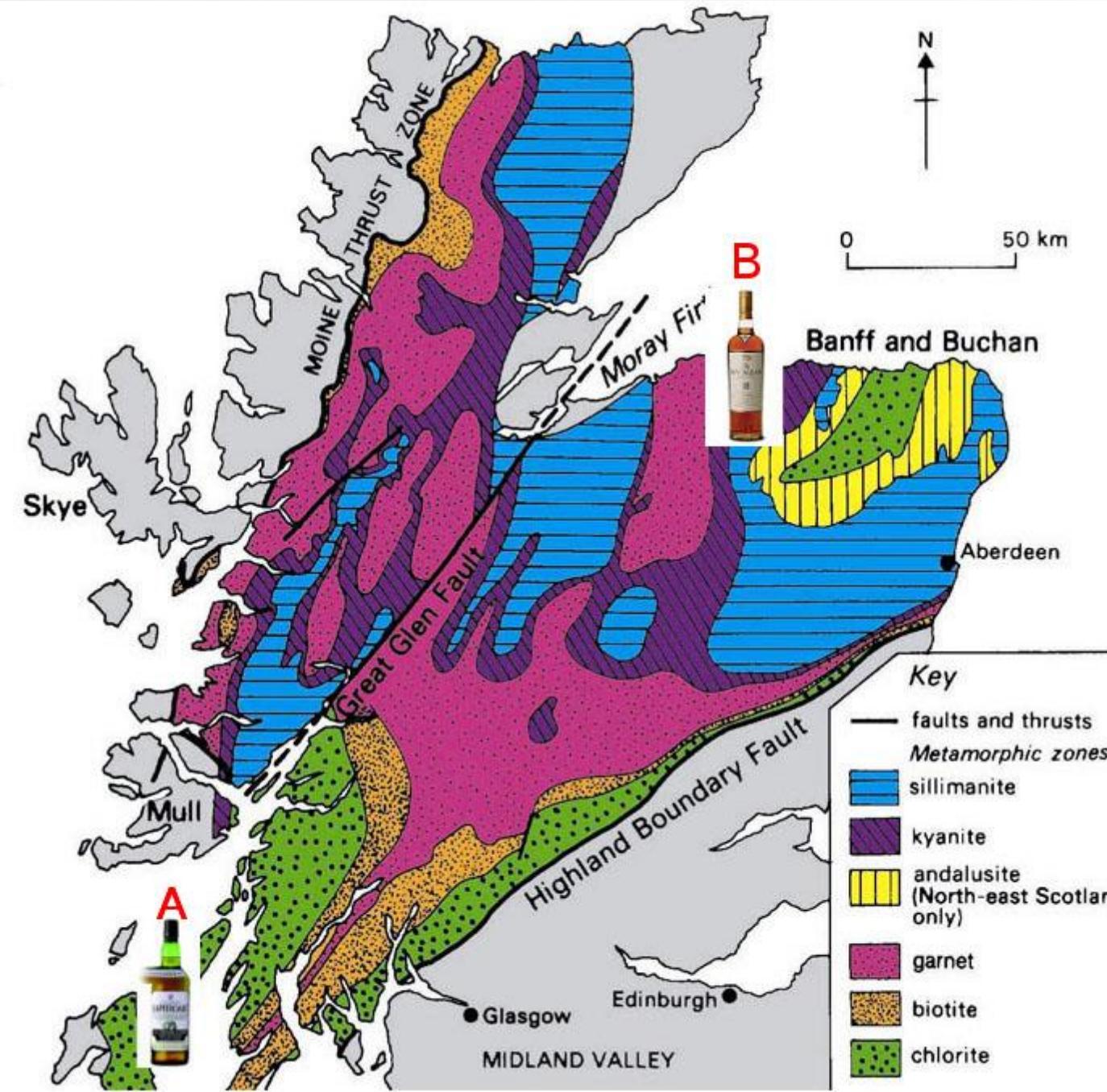
Piece of mantle











Three things can change with metamorphism

1. Which minerals make up the rock
2. What crystal size the minerals are

Crystal size grows with higher pressure and temperature



Shale
(parent rock)



Slate



Phyllite



Schist



Gneiss



Migmatite

Three things can change with metamorphism

1. Which minerals make up the rock
2. What crystal size the minerals are
3. How thick the layers are



Slate
Cleavage



Phyllite
Foliation



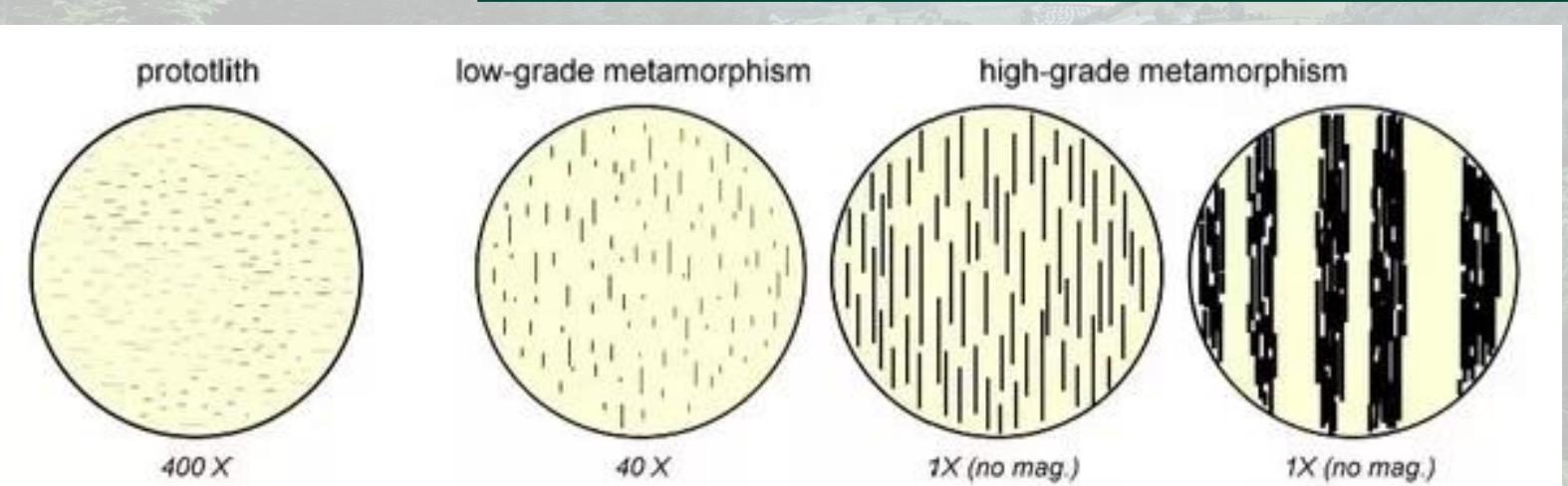
Schist
Schistosity



Gneiss
Banding

++ layer thickness

++ mineral size

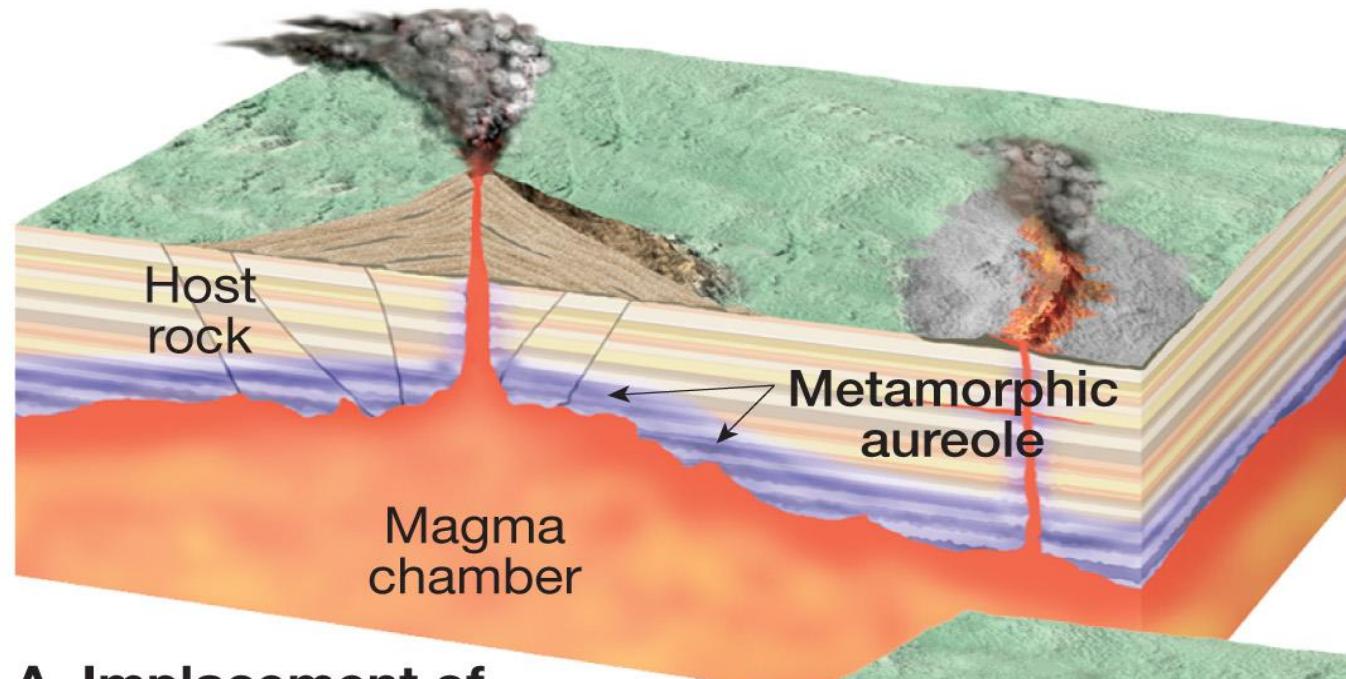




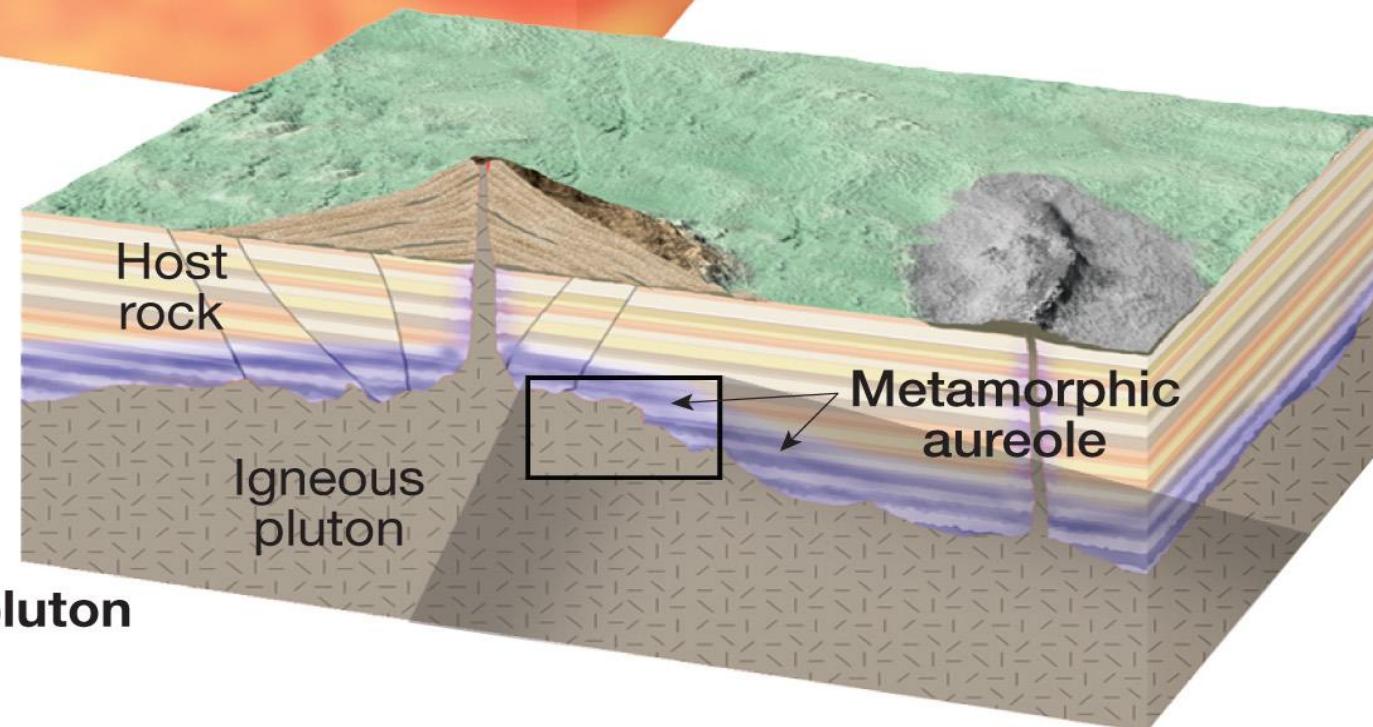
So, how does metamorphism happen?



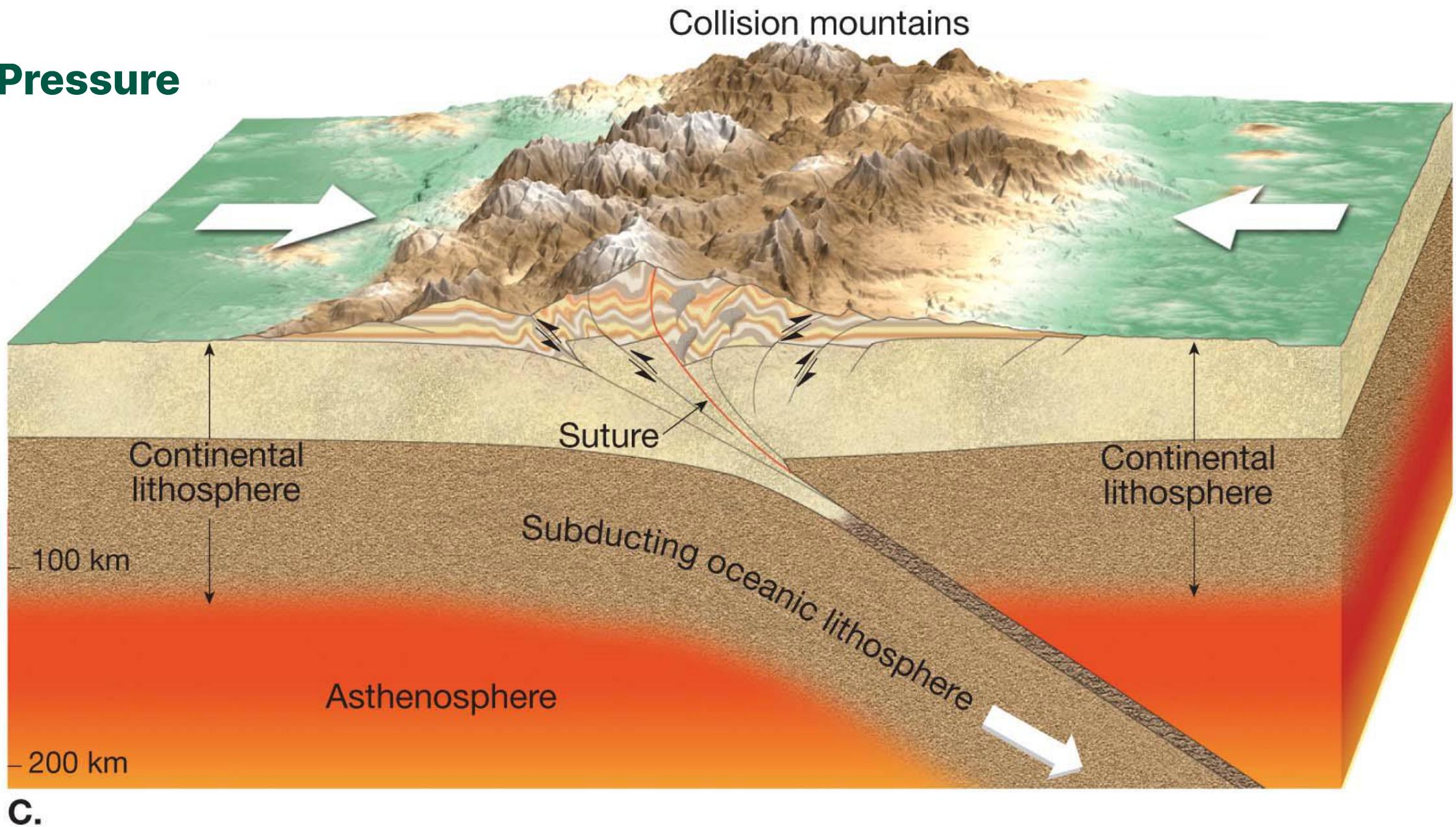
Heat

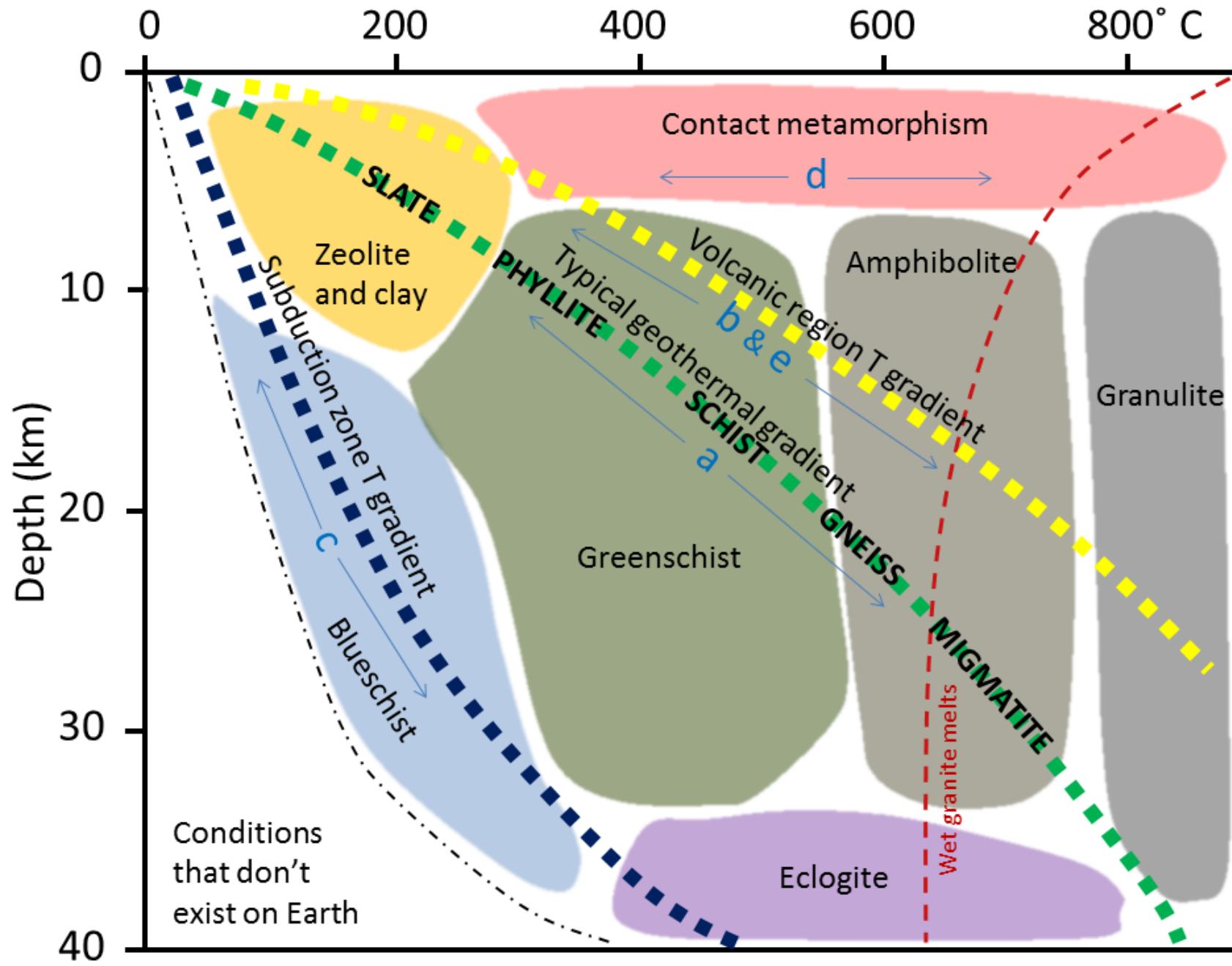


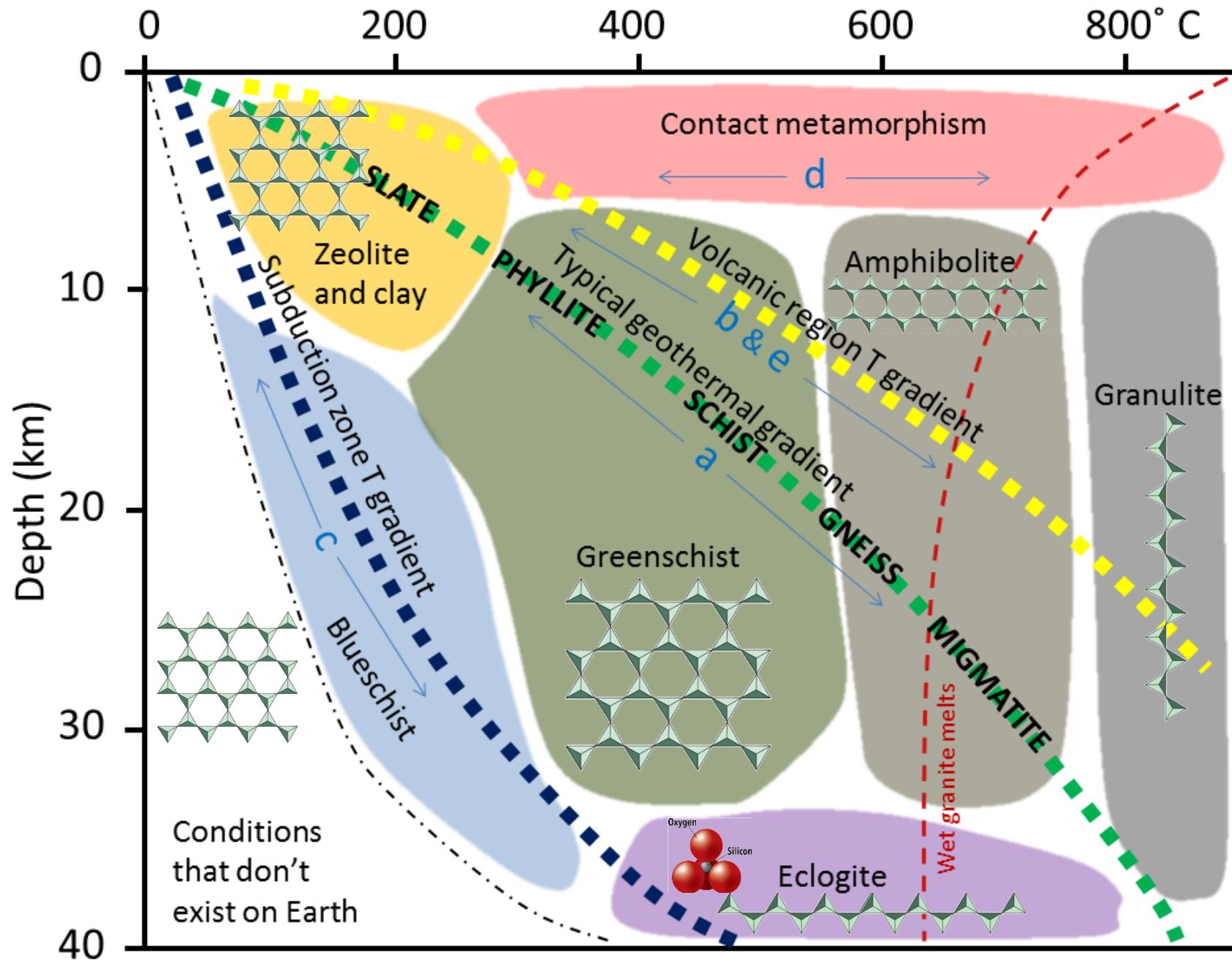
A. Implacement of igneous body and metamorphism



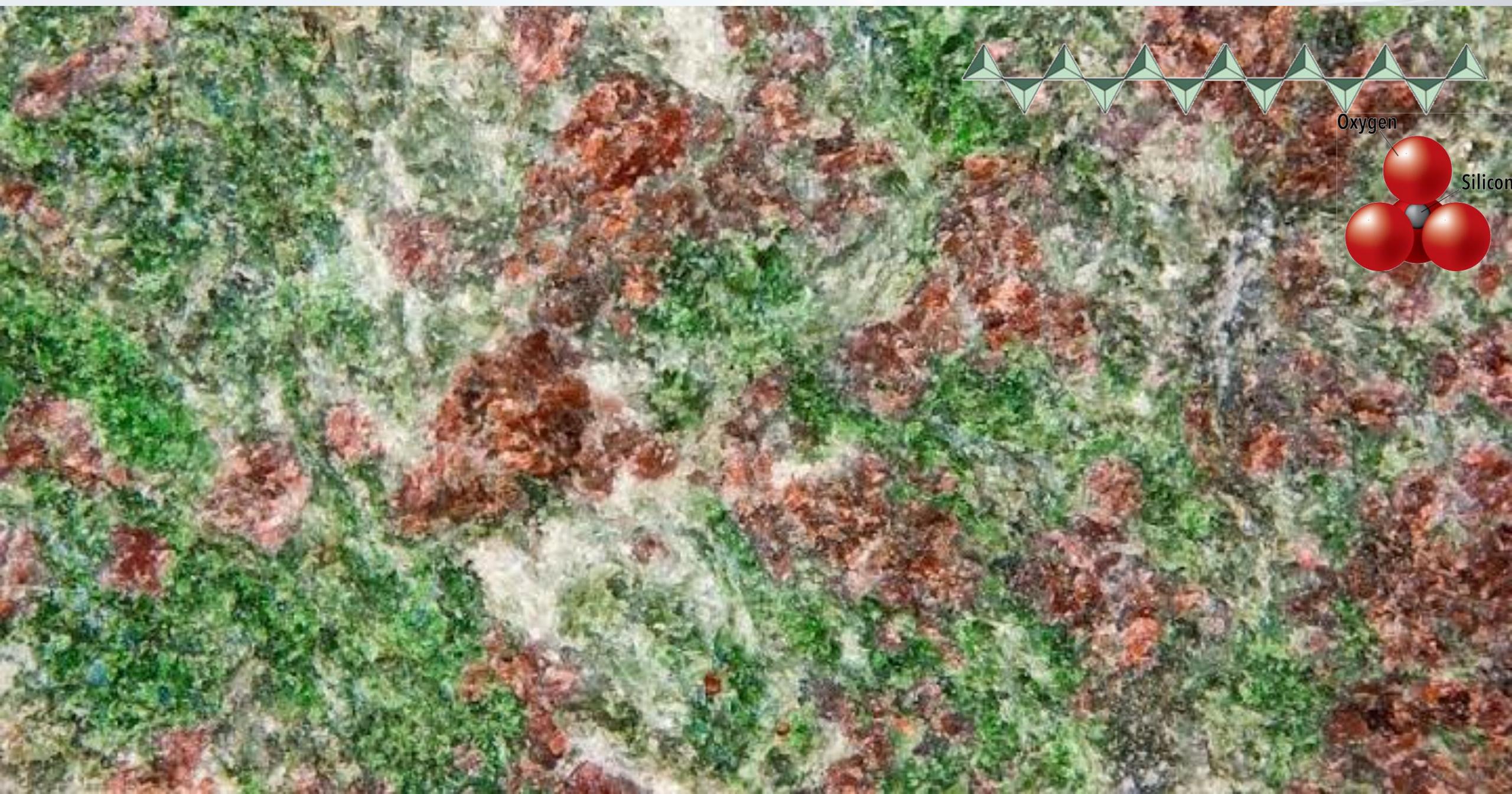
B. Crystallization of pluton

Pressure**C.**







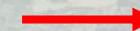
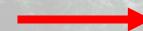




Shale
(parent rock)

Slate

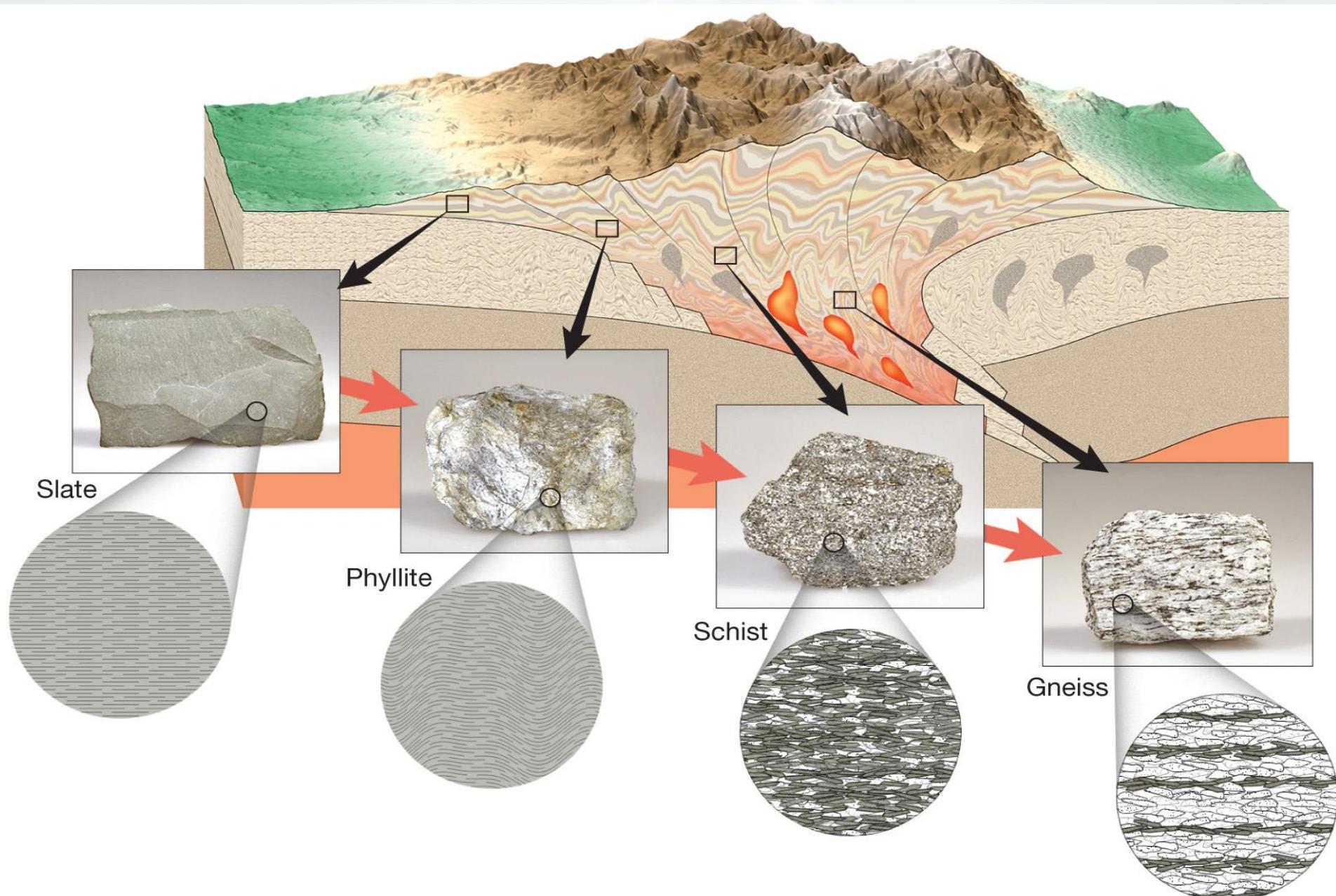
Phyllite

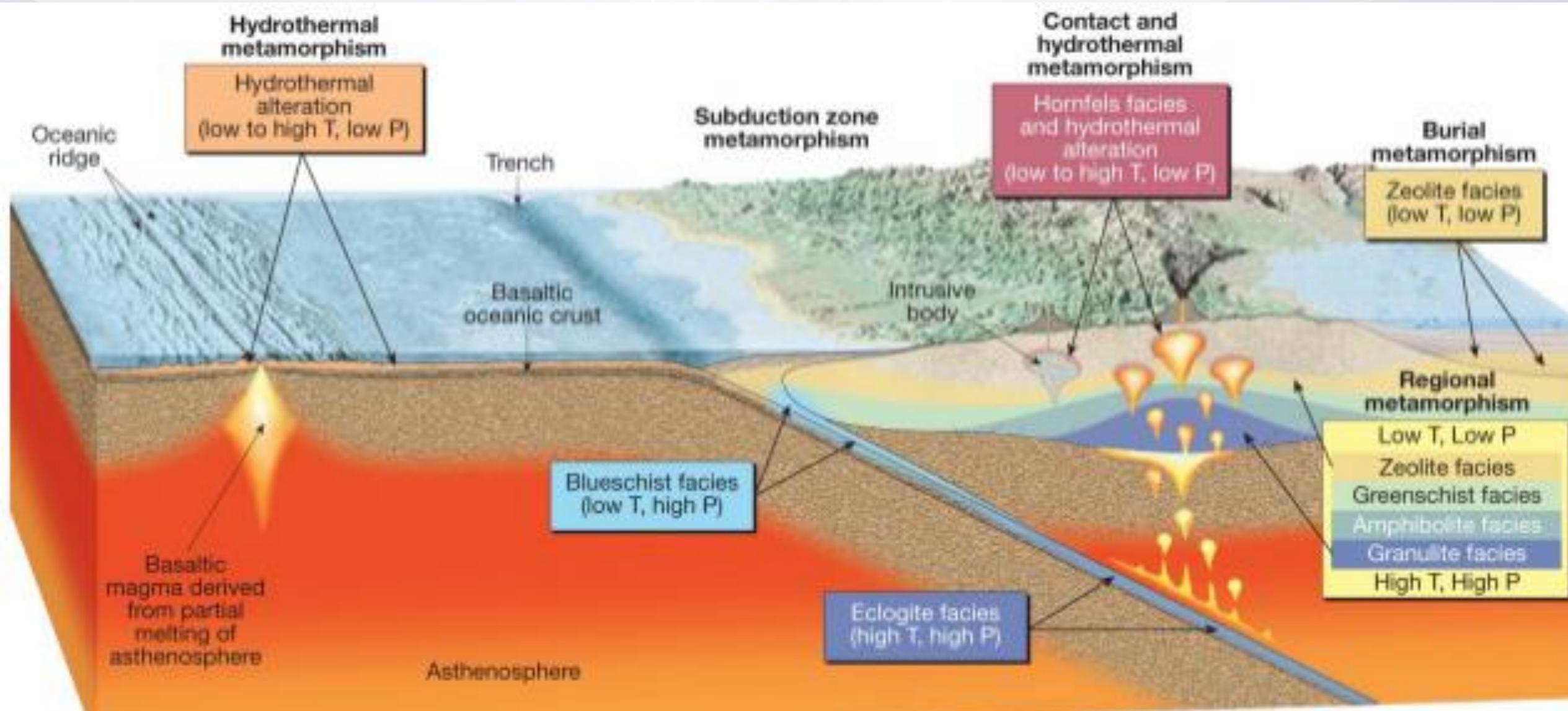


Schist

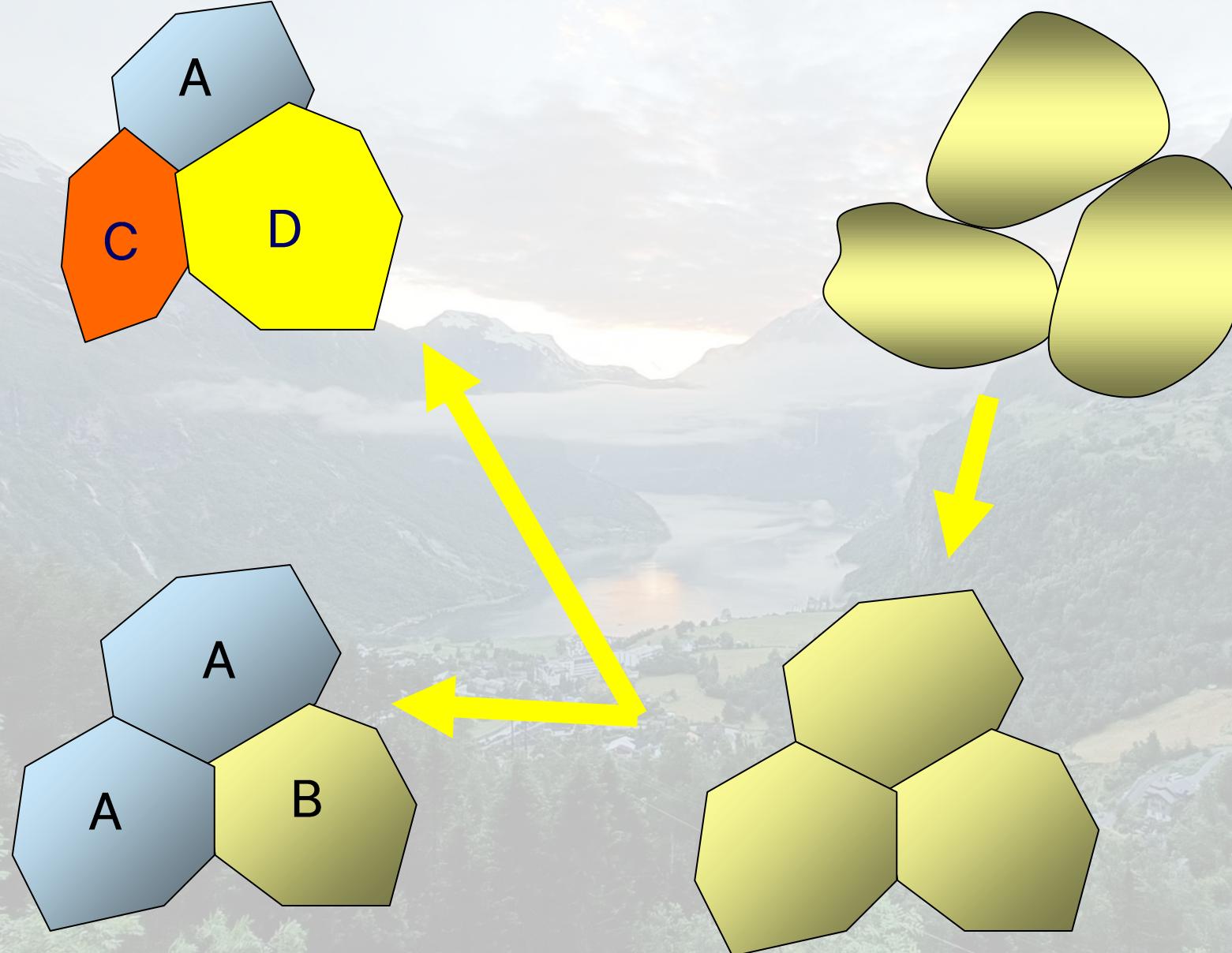
Gneiss

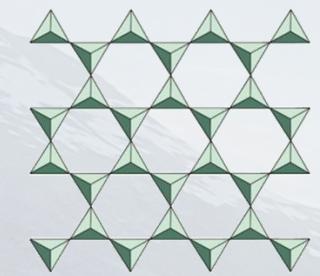
Migmatite











Slate Mine, Llanberis, Wales



Assynt, Scotland



Connemara, Galway



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'Lazy Beds' – old pre-'famine'
potato farms on metamorphic
rocks of Tully Mountain,
Galway

(ridges in
the grass)

