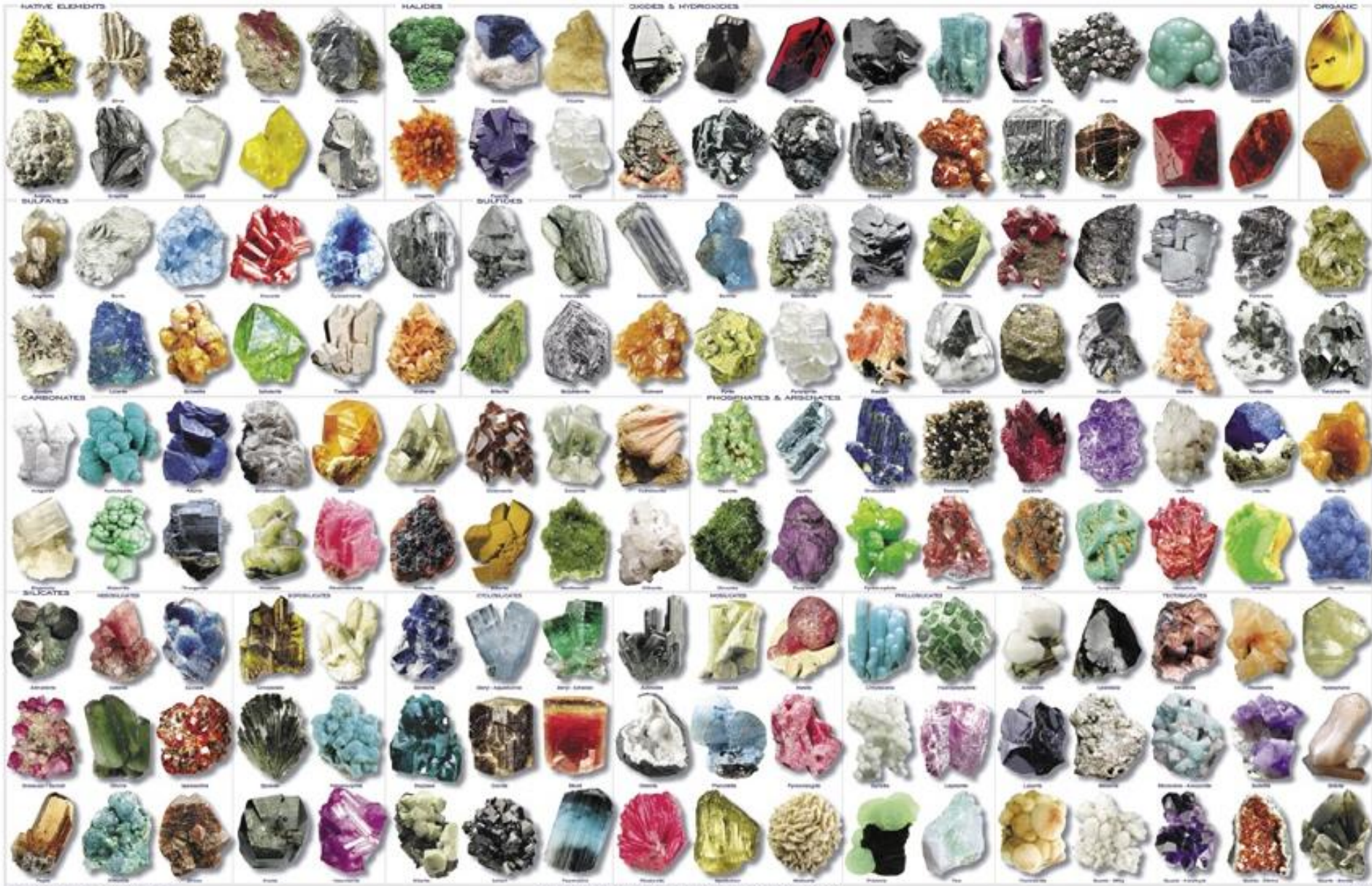


# Minerals

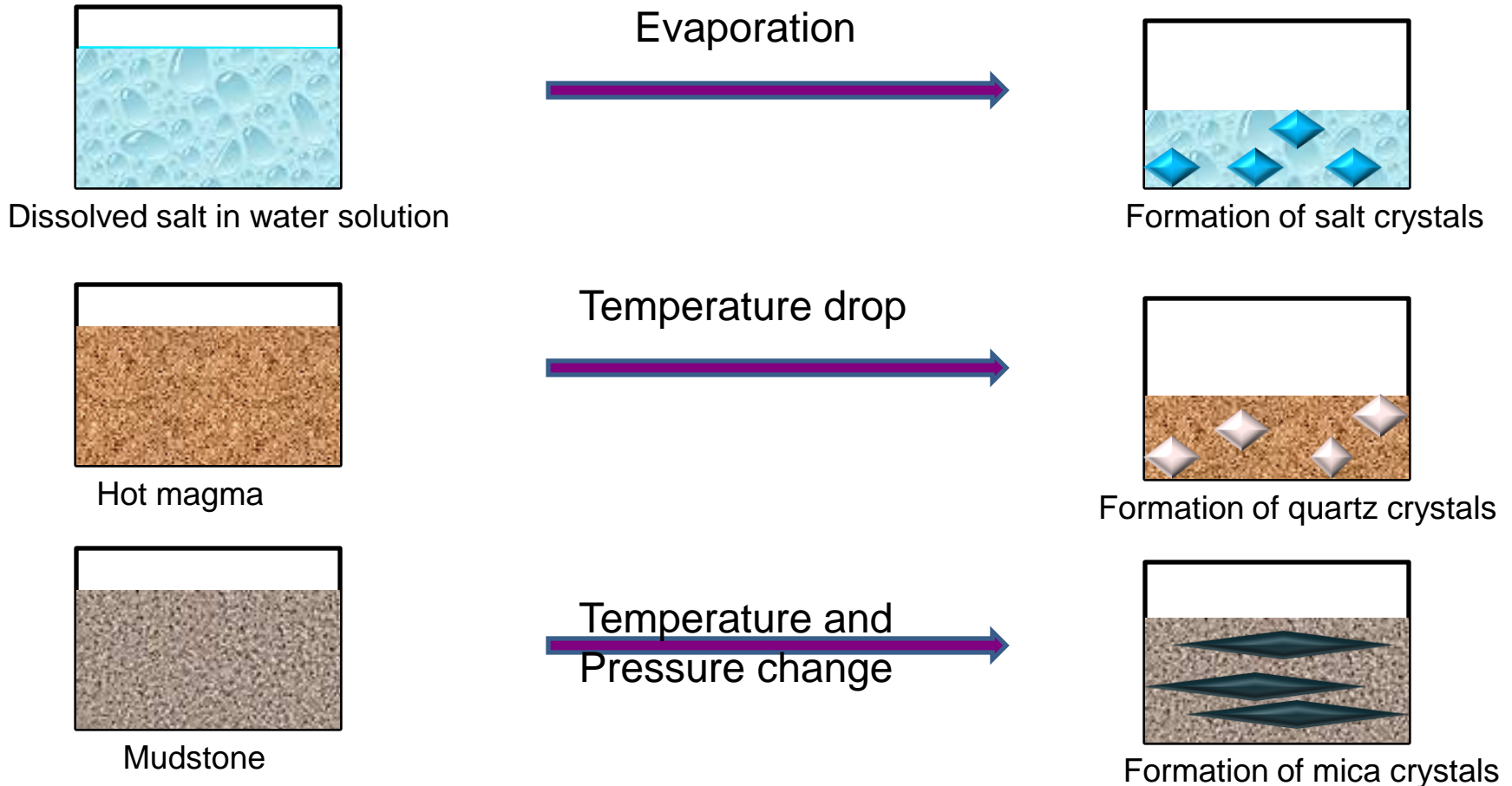


# ***Minerals: Building blocks of rocks***

- **Definition of a mineral:**
  - Naturally occurring
  - Inorganic solid
  - Ordered internal molecular structure
  - Definite chemical composition
- **Definition of a rock:**
  - A solid aggregate or mass of minerals

# How do minerals form

- Crystal is any natural solid with an ordered, repetitive, atomic structure.
- Minerals form through crystallization. The molecules, or ions, chemically bond to form an orderly structure.
- Example:



# Mineral properties

**Hardness:** - How hard a mineral is depends primarily on its crystal structure.

- Example: Diamond & graphite
- Mohs hardness scale

**Habit/ Shape:**

- Characteristic shape
- Determined by crystal structure
- Types: Bladed  
Platy  
Prismatic  
Banded  
Botryoidal

**Cleavage**

**Optical properties:**

- Colour
- Streak
- Luster



---

**TABLE 2.2 Mohs Scale of Hardness**

---

Relative Scale		Mineral	Hardness of Some Common Objects
Hardest	10	Diamond	
	9	Corundum	
	8	Topaz	
	7	Quartz	
	6	Potassium Feldspar	
	5	Apatite	5.5 Glass, Pocketknife
	4	Fluorite	
	3	Calcite	3 Copper Penny
	2	Gypsum	2.5 Fingernail
	1	Talc	
Softest			

---

# Mineral properties: Shape



Bladed kyanite



Botryoidal hematite



Prismatic quartz



Banded agate



Fibrous okenite

Identify the following shapes:

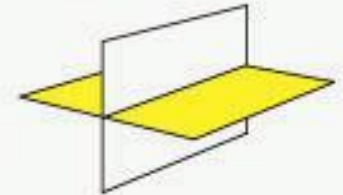


# Mineral properties: cleavage

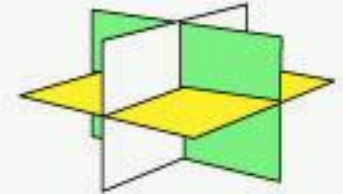
- Preferred plane of breakage.
- Creates a smooth plane.
- Generated by atomic arrangements.



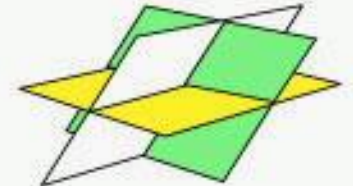
**Cleavage in one direction. Example: MUSCOVITE**



**Cleavage in two directions. Example: FELDSPAR**



**Cleavage in three directions. Example: HALITE**



**Three  
Cleavage in   directions. Example: CALCITE**

# Mineral properties

## Optical property:

**Color:** Rarely a diagnostic property.

**Streak:** -The color of powdered mineral.  
- Diagnostic property.  
- Rub the mineral across unglazed porcelain.

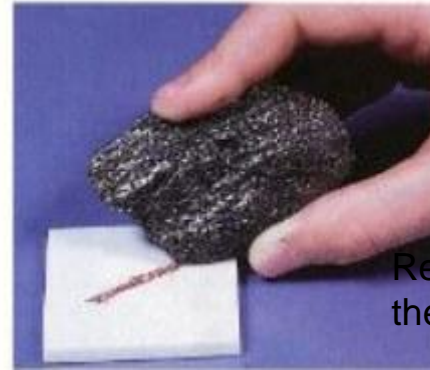
**Luster:** - The appearance of light reflected from mineral surface.

Types: 1. Metallic

2. Non-metallic : Dull/Earthy  
Glassy  
Pearly  
Silky



Varieties of quartz



Red-brown streak of the mineral hematite.



# Different types of luster



Metallic luster of pyrite



Glassy luster of quartz



Earthy luster of limonite



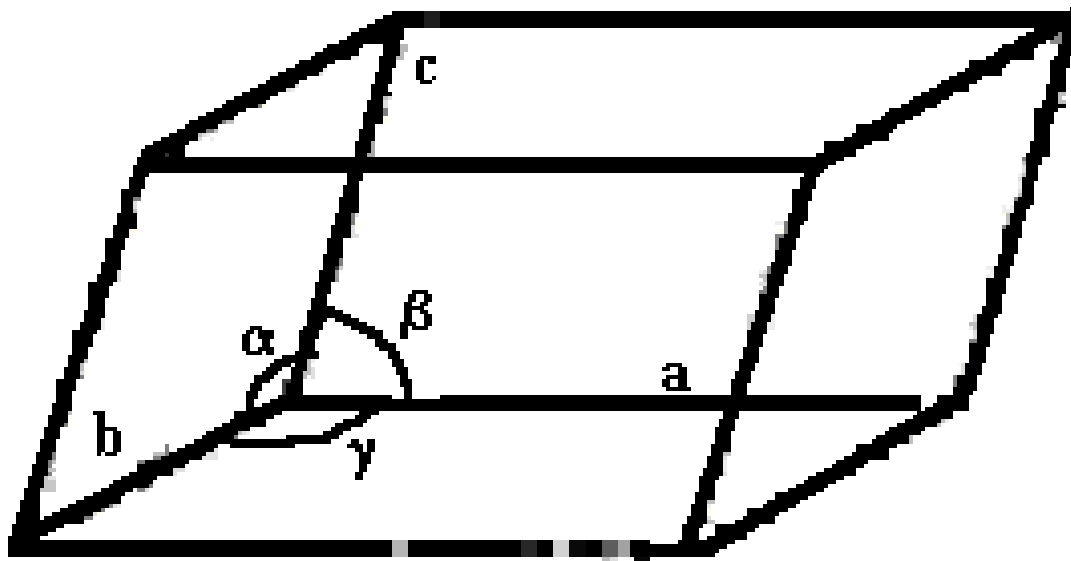
Pearly luster of talc



Silky luster of siderite

# Crystals are made of infinite number of unit cells

Unit cell is the smallest unit of a crystal, which, if repeated, could generate the whole crystal.



A crystal's unit cell dimensions are defined by six numbers, the lengths of the 3 axes,  $a$ ,  $b$ , and  $c$ , and the three interaxial angles,  $\alpha$ ,  $\beta$  and  $\gamma$ .

## Cubic



garnet



spinel



halite



pyrite

## Tetragonal



apophyllite



rutile

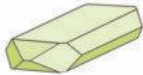


zircon



wulfenite

## Orthorhombic



barite



olivine



topaz



sulfur

## Hexagonal



corundum



quartz



ilmenite



calcite

## Rhombohedral

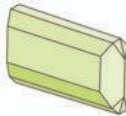
## Monoclinic



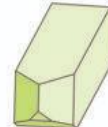
diopside



gypsum

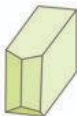


epidote



orthoclase

## Triclinic



albite



wollastonite



kyanite



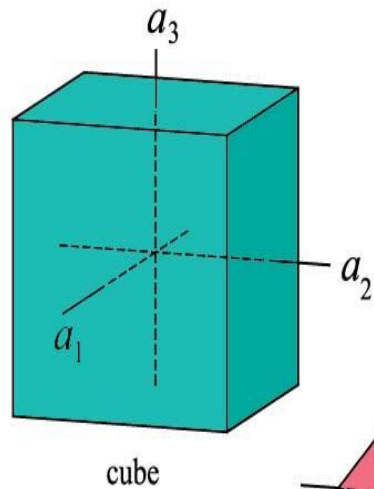
rhodonite

# Representative Minerals in Crystal Systems

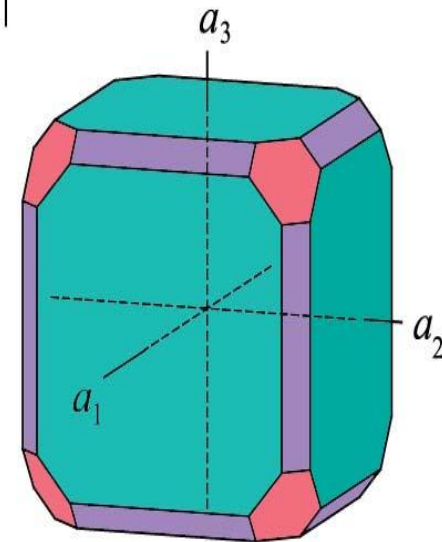
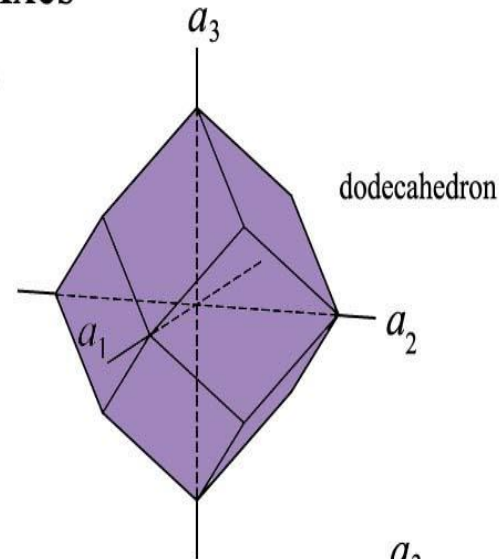
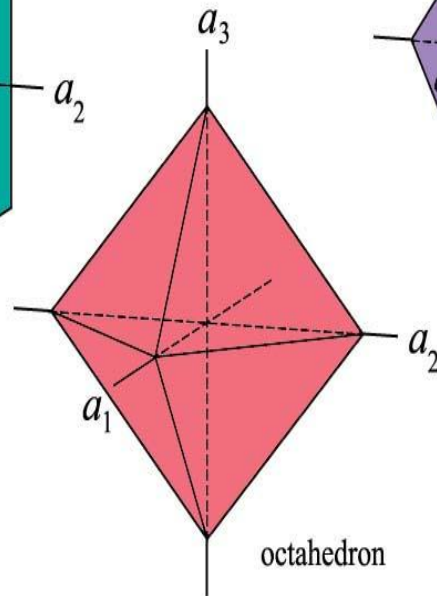
# 3-D Symmetry

## Crystal Axes

### Isometric



$$a_1 = a_2 = a_3$$
$$\alpha = \beta = \gamma = 90$$



all three forms combined

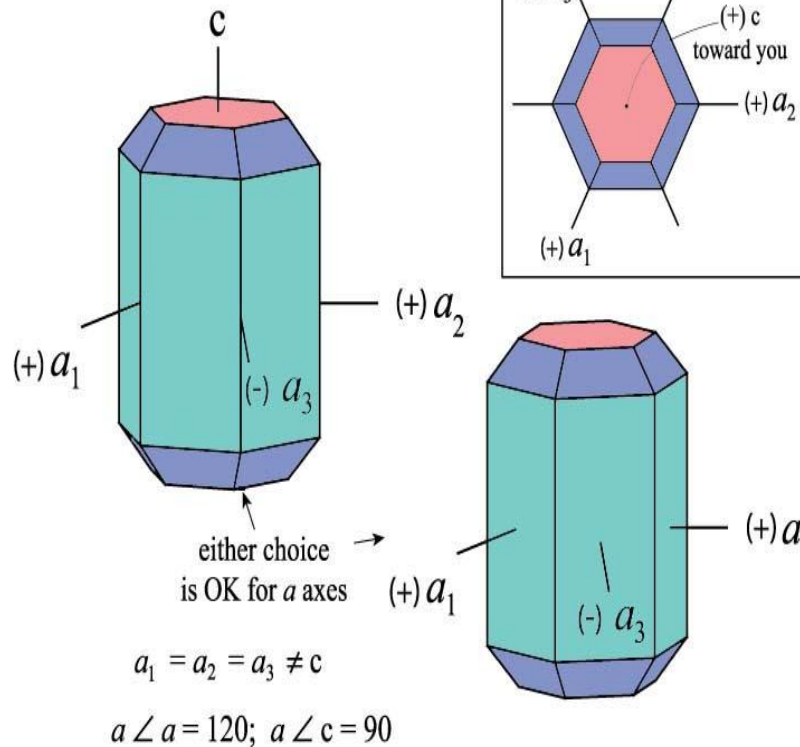
All three axes are mutually perpendicular and of equal length. They are set  $\parallel$  to the 4-fold axes (if present), otherwise  $\parallel$  to the 2-fold axes.



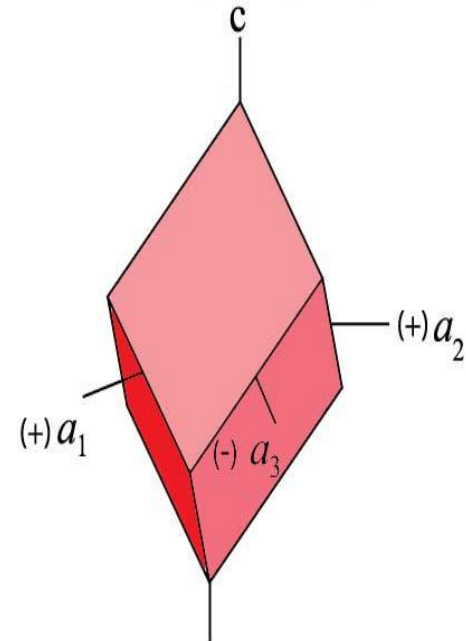
# 3-D Symmetry

## Crystal Axes

### Hexagonal



### Trigonal (also considered as the rhombohedral division of the Hexagonal system)

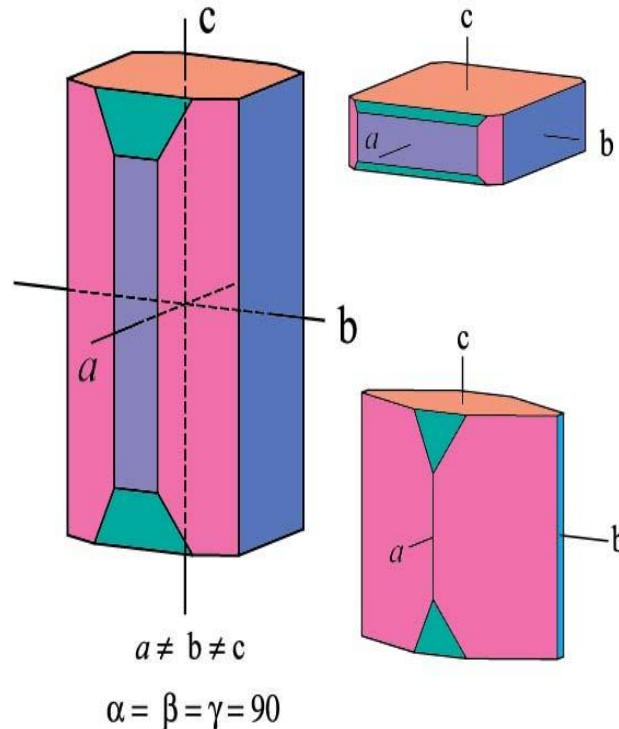


The Hexagonal system (and Trigonal sub-system) typically has four axes, three are of equal length at  $120^\circ$  to one another, and all  $\perp$  to  $c$ , which is  $\parallel$  to either the 3-fold or 6-fold rotation. The conventional choice of the three  $a$  axes is shown in the inset.

# 3-D Symmetry

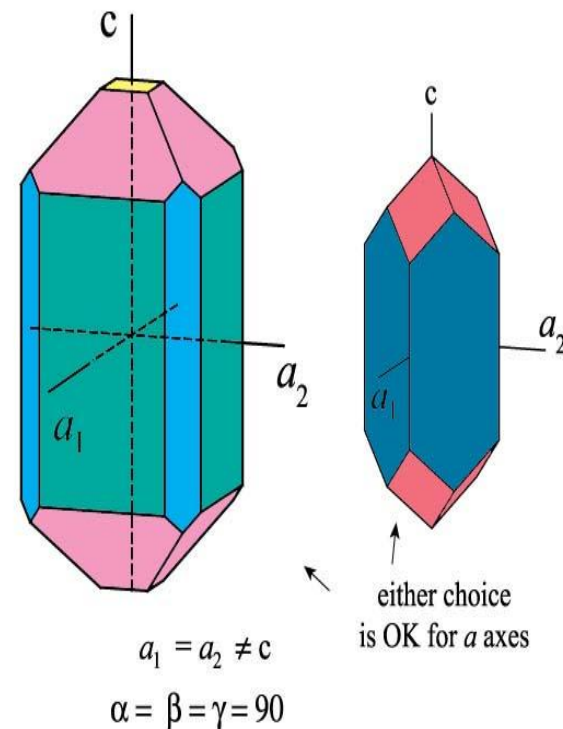
## Crystal Axes

Orthorhombic



The axes are mutually perpendicular and  $\parallel$  to 2-fold axes (conventionally  $c < a < b$ ). When crystals are elongated (as above left)  $c$  is chosen as the direction of elongation. When crystals are flattened (top insert),  $c$  is chosen as normal to the predominant plane.

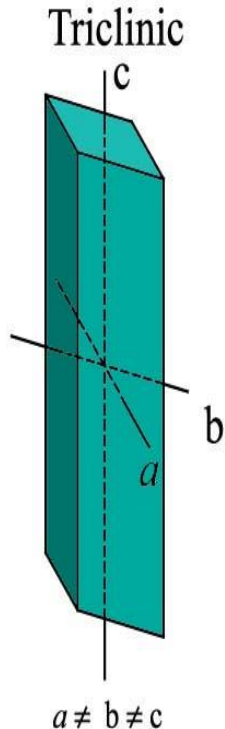
Tetragonal



The axes are mutually perpendicular and  $c$  is chosen  $\parallel$  to the 4-fold axis. Due to the 4-fold symmetry, the other two axes are equal.  $a_1$  is oriented toward the front and  $a_2$  to the right.

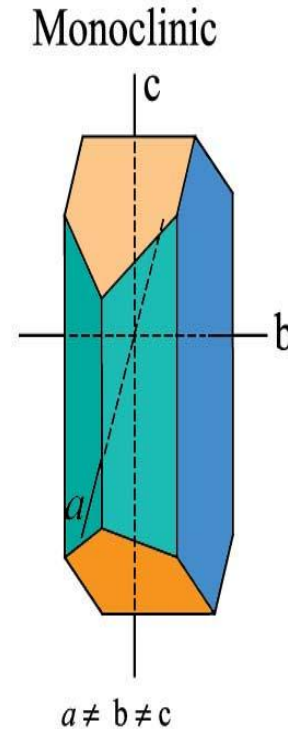
# Crystallographic Axes & Crystal Systems

## Crystal Axes



$$\alpha \neq \beta \neq \gamma \neq 90$$

The axes are chosen as parallel to the principal face intersections. There are no symmetric restrictions to the choice of **a**, **b**, and **c**, but, by convention, the most pronounced zone is oriented vertically and the zone axis is **c**.



$$\alpha = \gamma = 90, \beta \neq 90$$


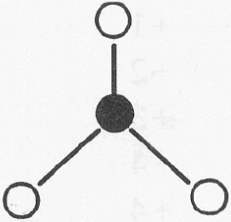
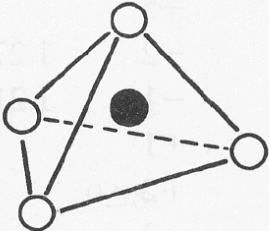
The axes are chosen as parallel to the principal face intersections. **b** is selected as  $\parallel$  to the 2-fold axis or  $\perp$  to the mirror. The most pronounced zone is oriented vertically and the zone axis is **c**. **a** slopes down and forward so that  $\beta$  is typically  $> 90$ .

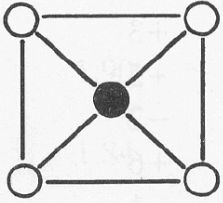
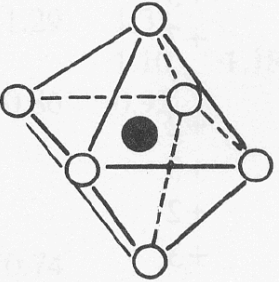
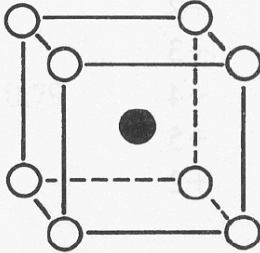
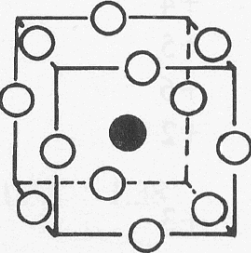
# ***Classification of Minerals***

- **Nearly 4000 minerals have been identified on Earth (most of which we don't really worry about).**
- **Rock-forming minerals**
  - **Common minerals that make up most of the rocks of Earth's crust**
  - **Only a few dozen members**
  - **Composed mainly of the 8 elements that make up 98% of the continental crust**



# Structure of minerals: Basic considerations are radius ratio and co-ordination number

Radius ratio	Coordination	Arrangement of ions	
$<0.155$	2		Linear
$0.155-0.225$	3		Trigonal planar
$0.225-0.414$	4		Tetrahedral

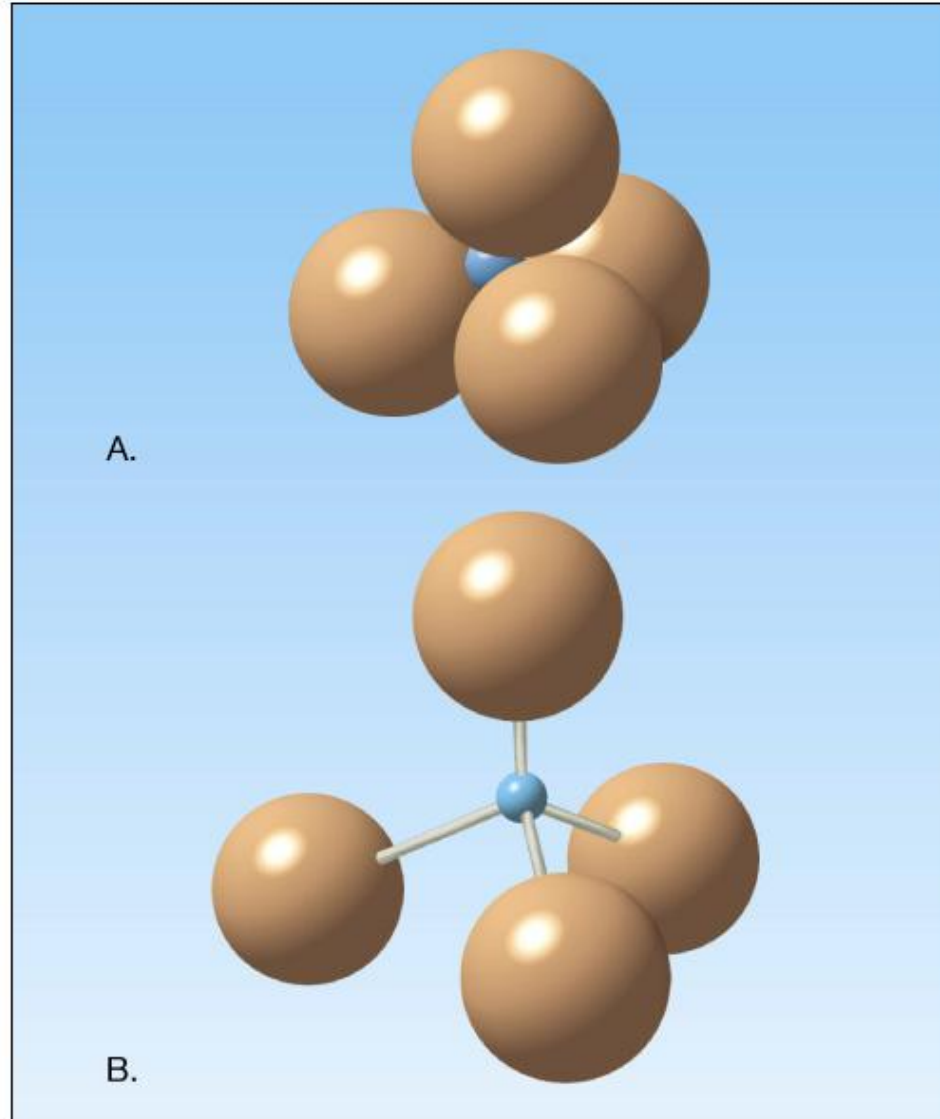
$0.414-0.732$	4		Square planar
$0.414-0.732$	6		Octahedral
$0.732-1.00$	8		Body-centered cubic
$>1.00$	12		Edge-centered cubic

● Cation, ○ Anion






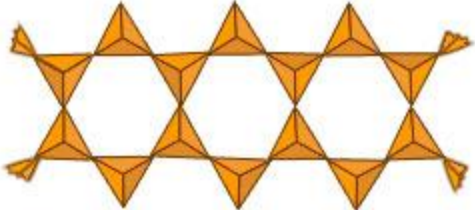
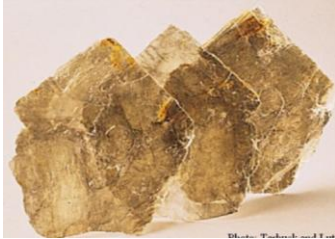
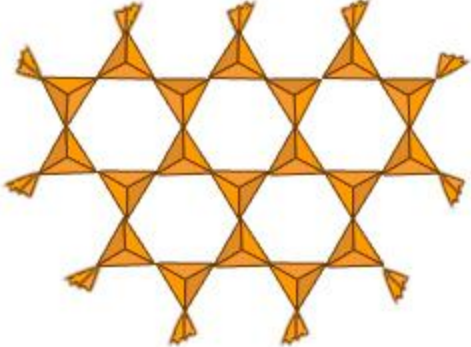


- **Silicates**

- **Most important mineral group**
  - **Comprise most of the rock-forming minerals**
  - **Very abundant due to large amounts of silicon and oxygen in Earth's crust**
- **Basic building block is the silicon-oxygen tetrahedron molecule**
  - **Four oxygen ions surrounding a much smaller silicon ion**

# Silica Tetrahedra (1 Si, 4 O's)

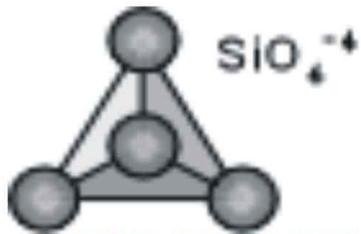


# Silica tetrahedron

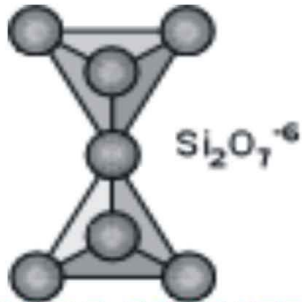
Independent	Olivine		
Single chain	Pyroxene		
Double chain	Amphibole		
Sheet structure	Mica		
Three dimensional network	Quartz, Feldspar		



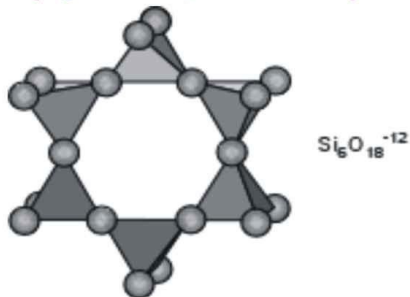
## Linking of $\text{SiO}_4$ Tetrahedra



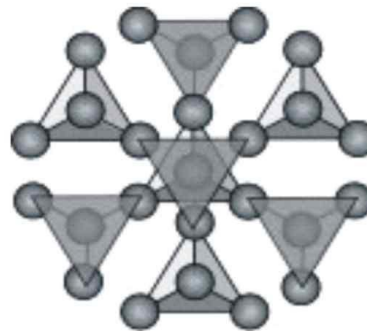
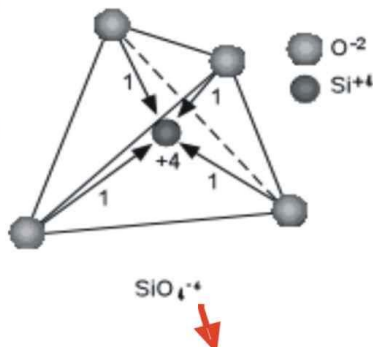
**NESO SILICATE**  
(Olivine, garnet)



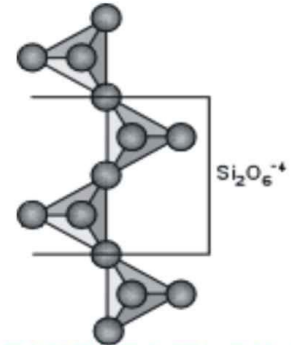
**SORO SILICATE**  
(epidote, melilite)



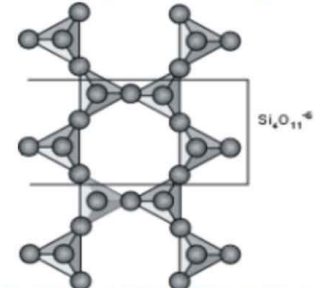
**CYCLO/RING SILICATE**  
(Tourmaline, beryl, cordierite)



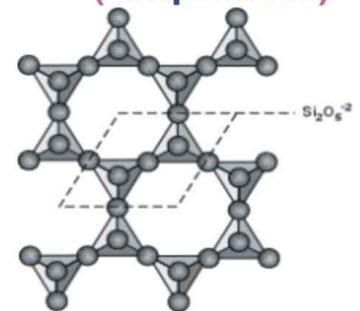
**TECTO(FRAME WORK) SILICATE** (Feldspar, quartz)



**INO(SINGLE) SILICATE**  
(pyroxene)

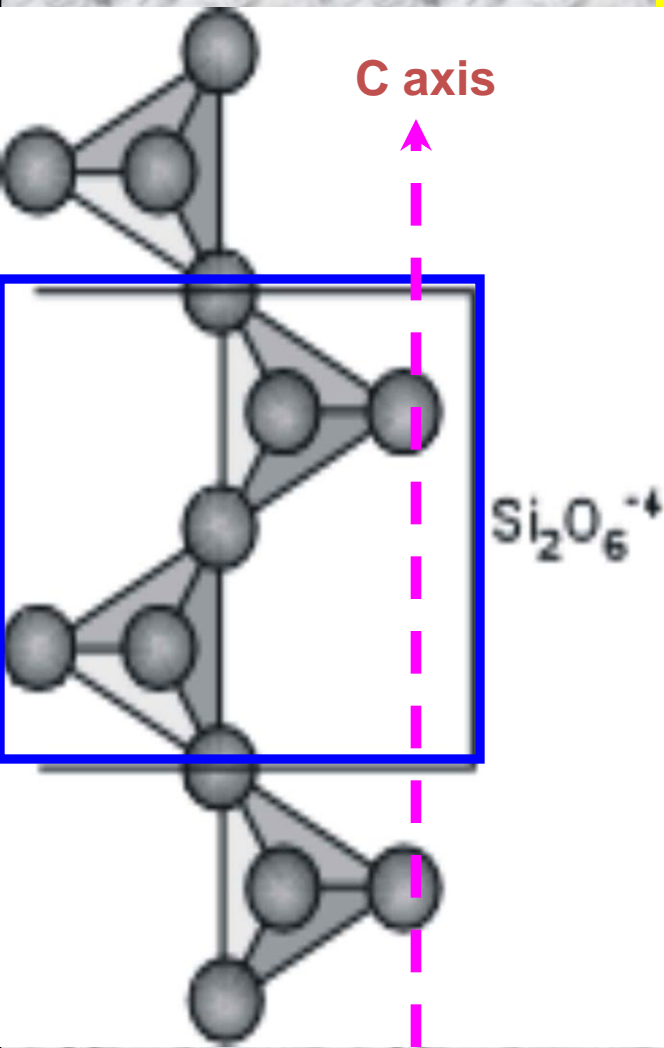


**INO(DOUBLE) SILICATE**  
(Amphibole)



**PHYLLO SILICATE** (Mica)

# SINGLE CHAIN SILICATES : THEIR PHYSICAL AND CHEMICAL PROPERTIES



The single chain silicates have a basic structural unit consisting of linked  $\text{SiO}_4$  tetrahedra that each share 2 of their oxygens in such a way as to build long chains of  $\text{SiO}_4$ . The basic structural group is thus  $\text{Si}_2\text{O}_6$  with an Si:O ratio of 1:3. The most important inosilicates are the pyroxenes. These have a general structural formula of:



where X =  $\text{Na}^+$ ,  $\text{Ca}^{+2}$ ,  $\text{Mn}^{+2}$ ,  $\text{Fe}^{+2}$ , or  $\text{Mg}^{+2}$  filling octahedral sites called M2

Y =  $\text{Mn}^{+2}$ ,  $\text{Fe}^{+2}$ ,  $\text{Mg}^{+2}$ ,  $\text{Al}^{+3}$ ,  $\text{Cr}^{+3}$ , or  $\text{Ti}^{+4}$  filling smaller octahedral sites called M1

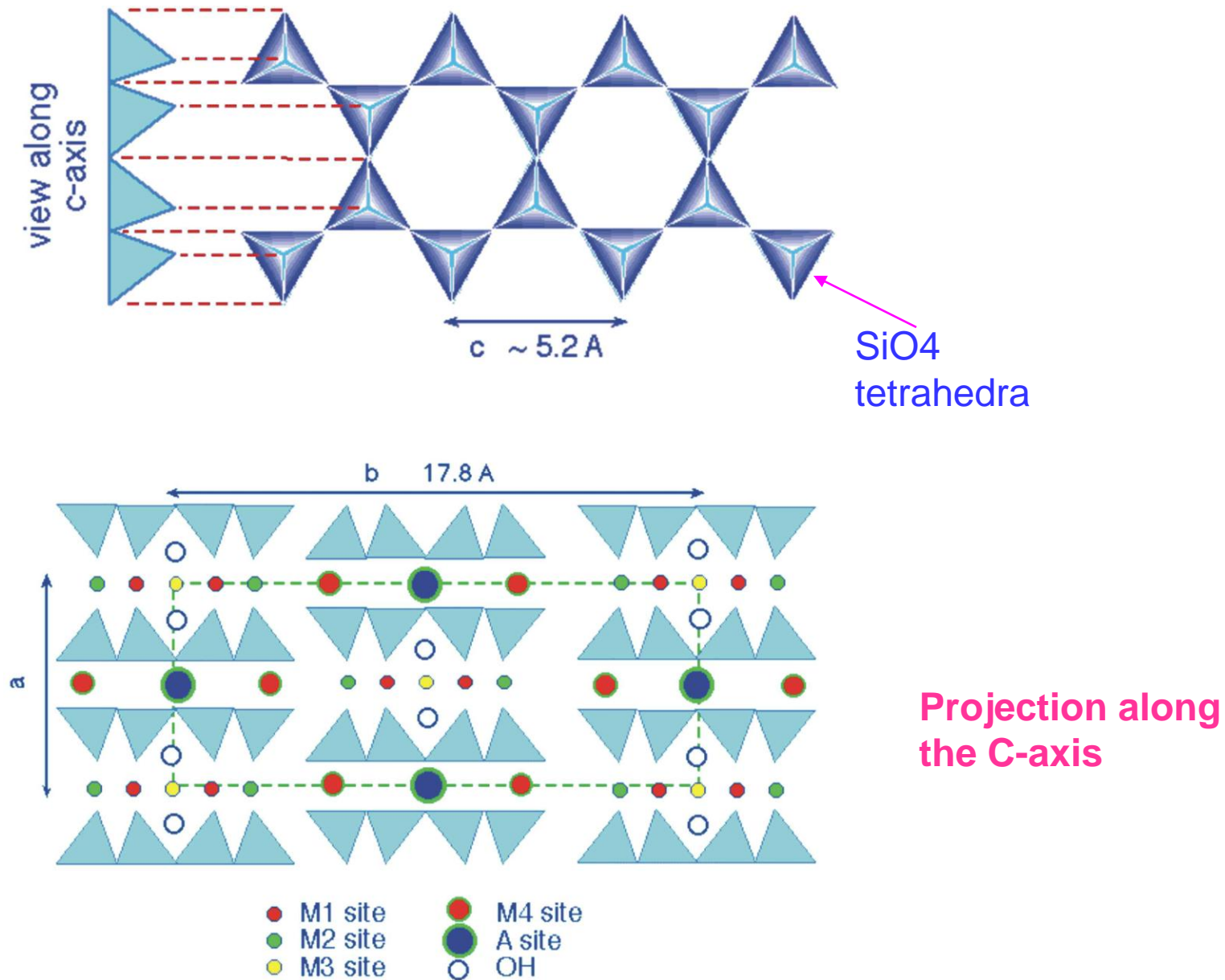
Z =  $\text{Si}^{+4}$  or  $\text{Al}^{+3}$  in tetrahedral coordination

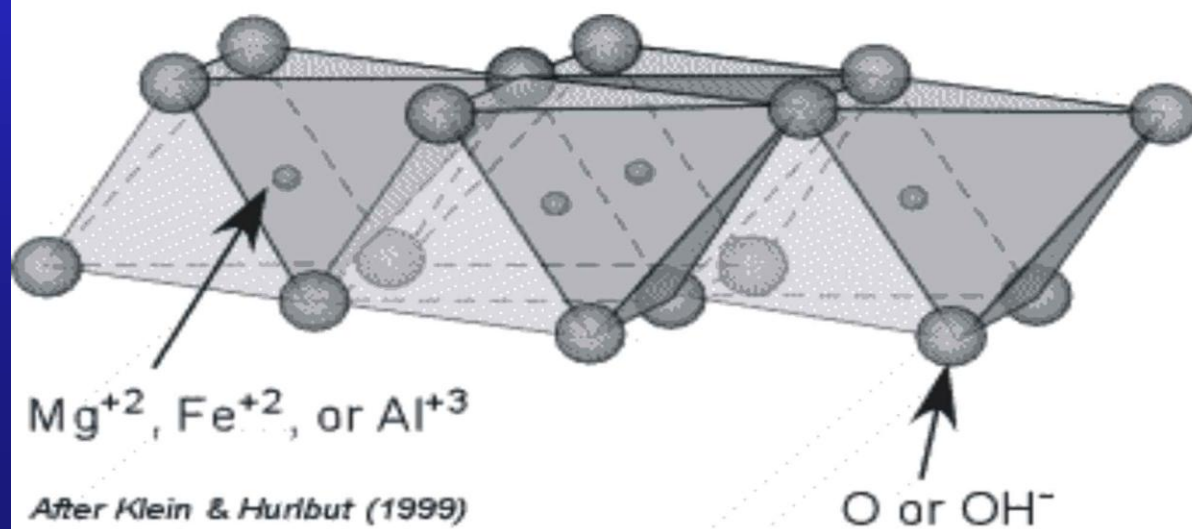
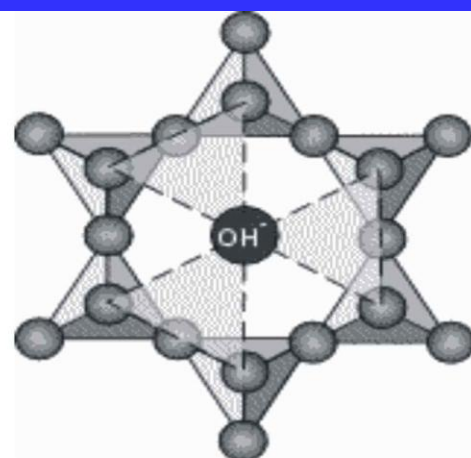
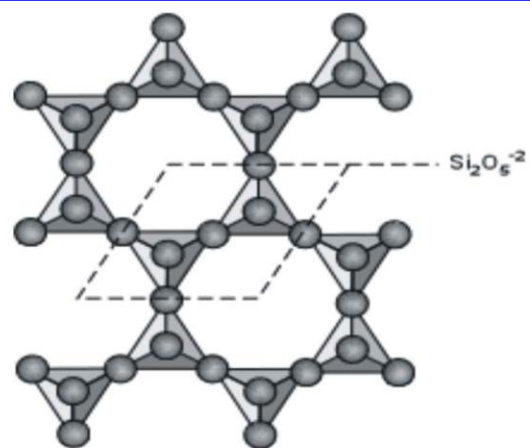
## REPEAT UNITS

2- Pyroxene, 3-, 5-, 7- Pyroxenoid

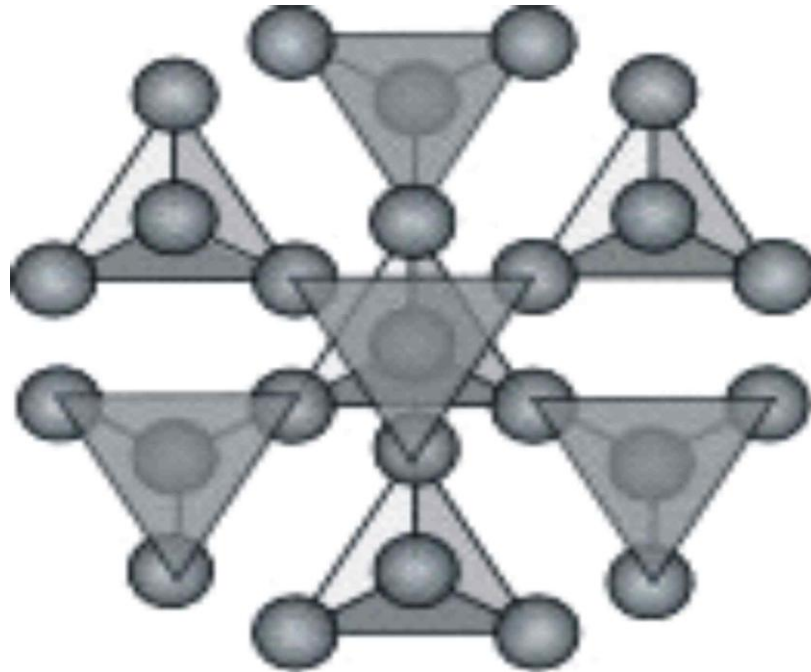
Rhodonite ( $\text{MnSiO}_3$ ), Wollastonite ( $\text{CaSiO}_3$ )

## Structure of AMPHIBOLE









All the corners of a  $\text{SiO}_4$  tetrahedron are linked with the corners of the neighboring tetrahedron resulting in a  $\text{Si} : \text{O} = 1:2$

## Solid solutions

- Practically all naturally occurring minerals containing Fe-Mg-Mn-Ca or Na-K etc are solid solutions
- Quartz ( $\text{SiO}_2$ ) is not a solid solution
- Olivine contains two (there are more) members  
Forsterite  $\text{Mg}_2\text{SiO}_4$   
Fayalite  $\text{Fe}_2\text{SiO}_4$   
Natural olivine is a solid solution of FO-Fa

## **Ionic Substitution**

**Substitution is possible if difference in radii is  $< 15\%$**

**Substitution is possible between ions of same charge, or else through coupled substitution maintaining charge balance**

**If two ions compete for the same site, the one with higher ionic potential is preferred**

**Substitution can be limited if there is a large difference in electronegativity or difference in bonding character between two ions of same charge and similar size.**

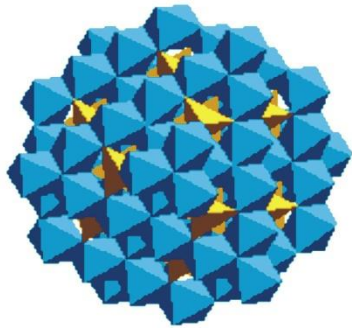
**Ionic Substitution leads to formation of solid solution**

## Some interesting details about Olivine

- **Nesosilicate: Isolated  $\text{SiO}_4$  Tetrahedra**
- **Most common mineral in the Earth's mantle**
- **$(\text{Mg,Fe})_2\text{SiO}_4$**
- **Mg, Fe form  $\text{MO}_6$  Octahedra that link Tetrahedra**
- **Olivine is Orthorhombic near surface conditions called Alpha olivine**
- **At higher P-T, Alpha olivine changes to Beta olivine which contains sites that contain (OH)**
- **At still higher P-T, changes to gamma olivine which is isometric and can contain OH**
- **At still higher P-T changes to perovskite structure**

# High Pressure Polymorph of Olivine

## RINGWOODITE

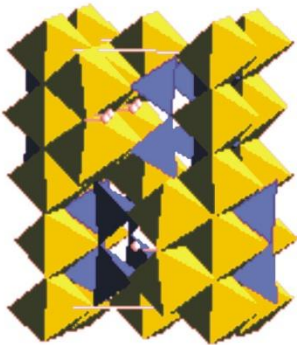


$(\text{Fe,Mg})_2\text{SiO}_4$  in the spinel (Cubic) structure is known as **ringwoodite** ( $\gamma$ ). Here, Si atoms occupy the tetrahedral sites (yellow) and Fe and Mg atoms occupy the *edge-sharing* octahedral sites (blue).

SPINEL ( $\text{AB}_2\text{O}_4$ )



## WADSLEYITE

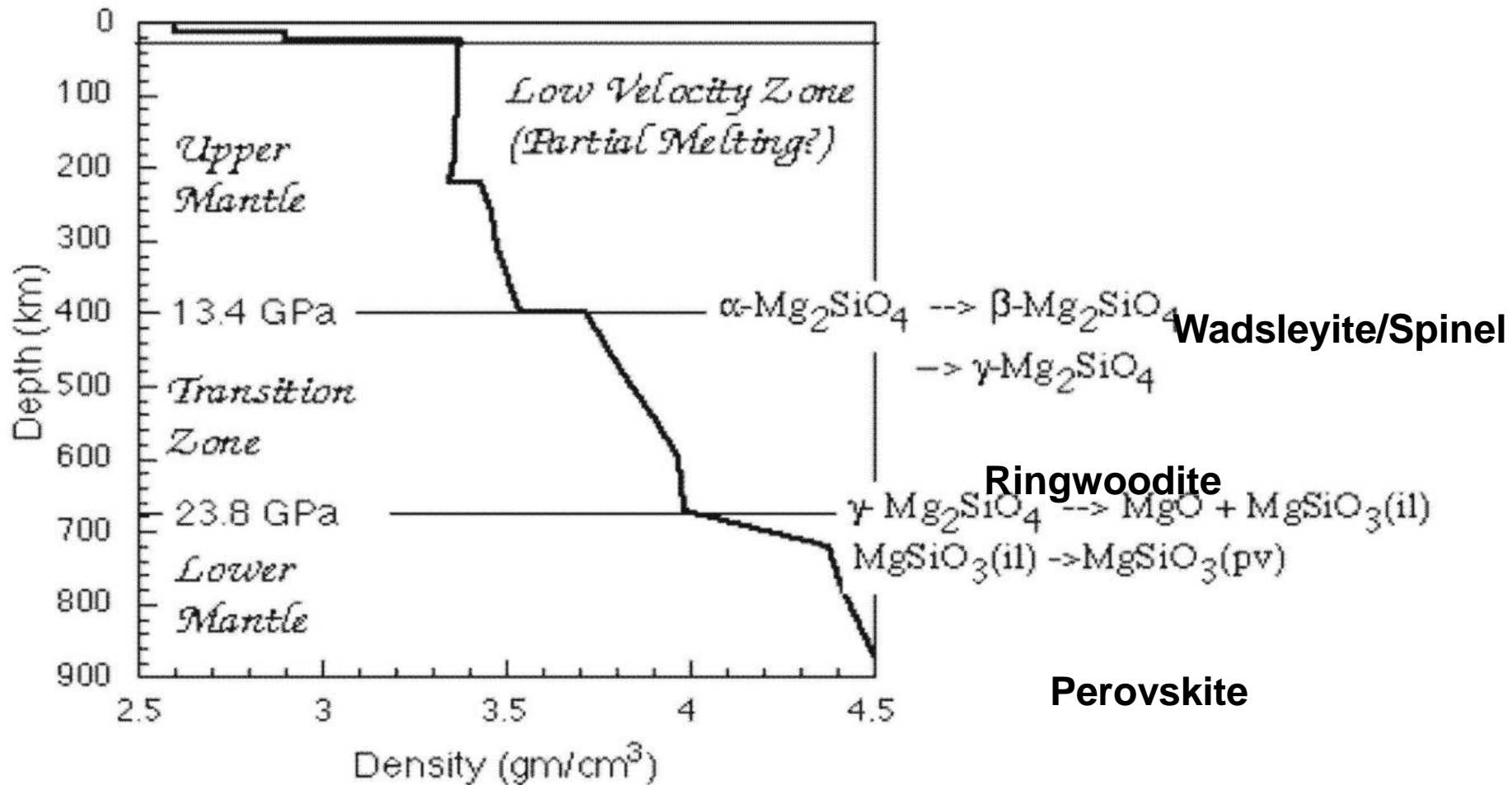


OH in the  
structure

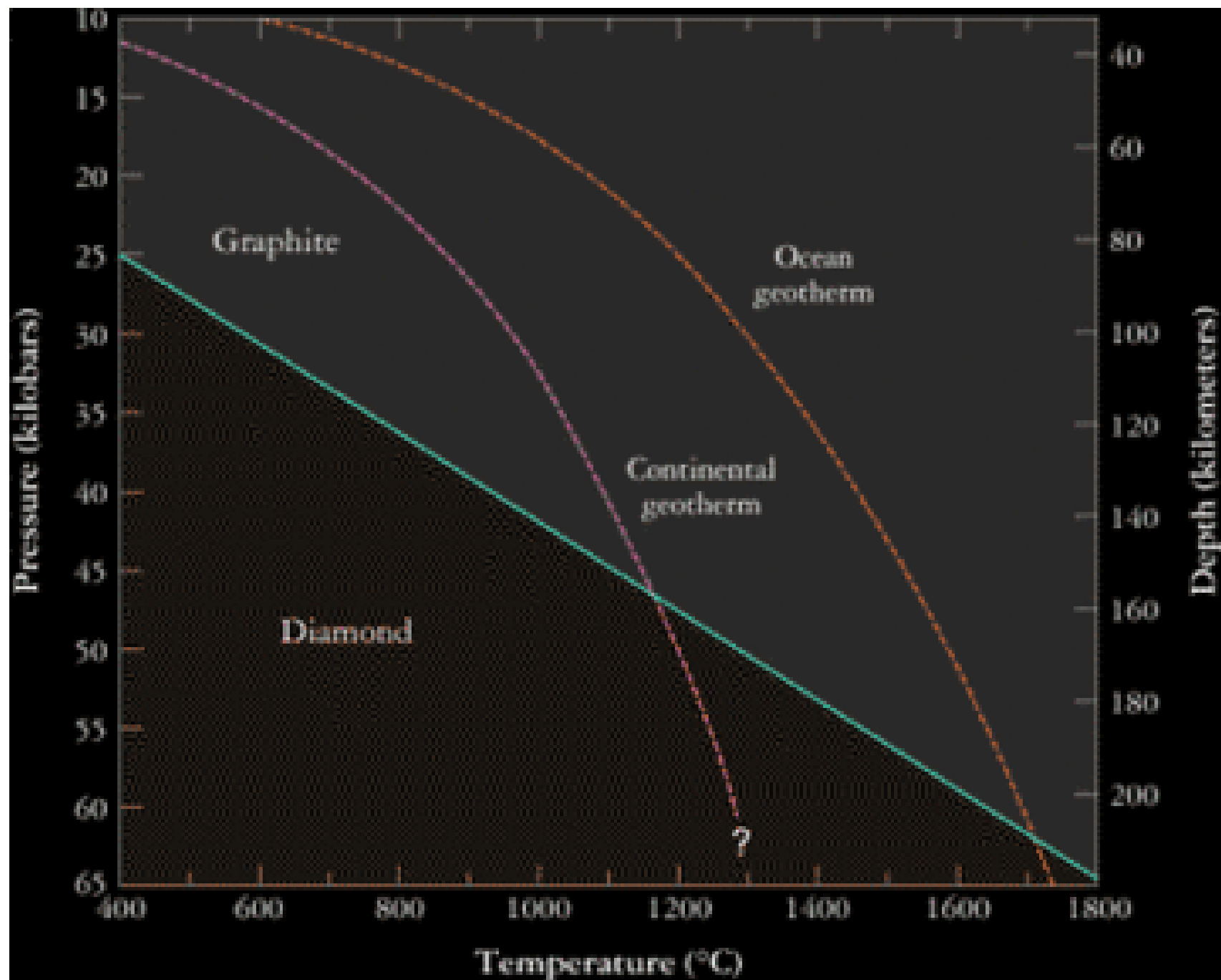
Intermediate between the olivine and spinel (ringwoodite) structure is a phase known as **wadsleyite** ( $\beta$  ( $\text{Mg,Fe})_2\text{SiO}_4$ ). The wadsleyite (or beta-spinel) structure is currently of great interest because it is being invoked as a reservoir of water (as chemically bound OH) in the Earth's mantle.



# Phase Transitions in the Earth's Mantle

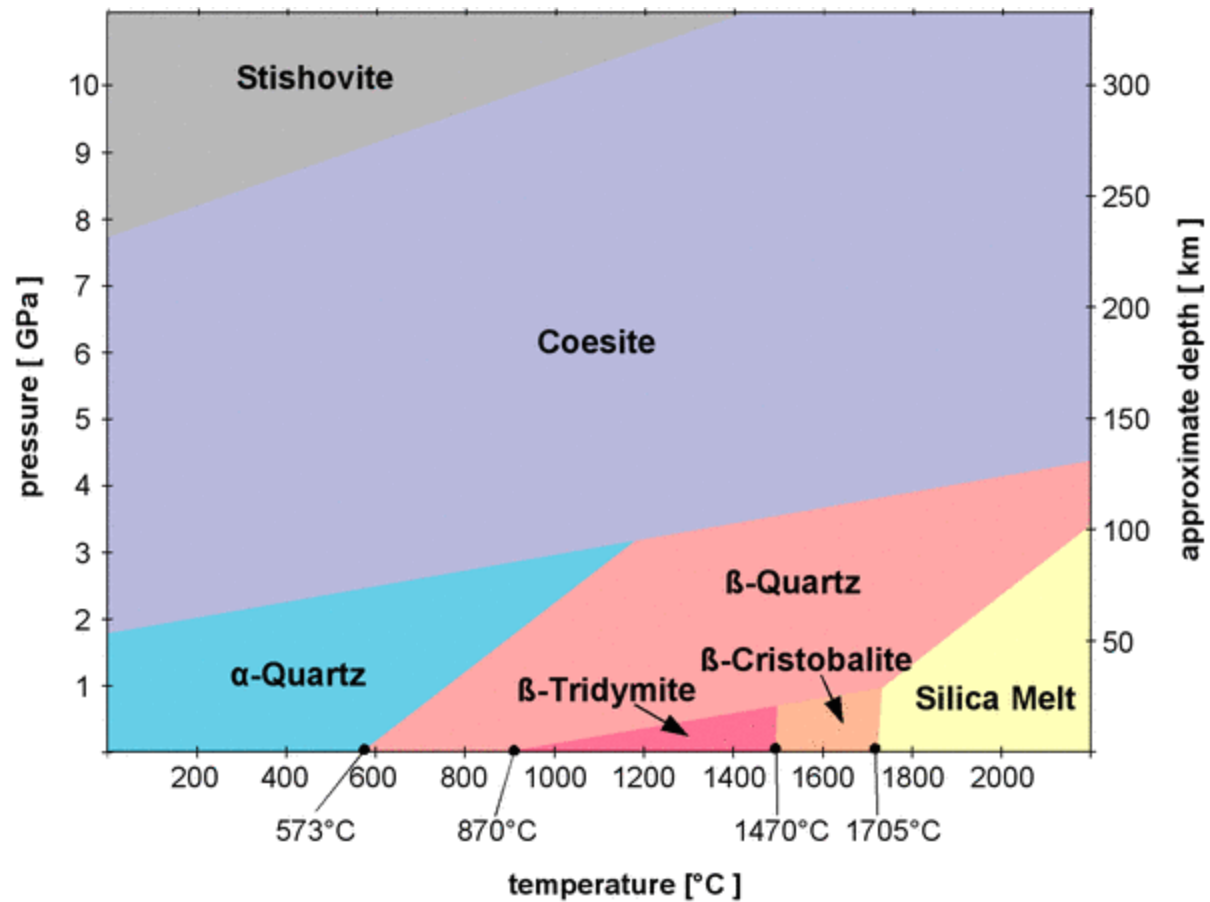


**Alpha to Beta at 410 Km, Beta to Gamma at 520 Km,  
Gamma to Perovskite at 660 Km**





## Polymorphism



# Structure of Minerals



Diamond



Graphite

## Polymorphs of Carbon

