MINERALOGY

Study of minerals including their
*** formation,**
*** occurrence,**
*** properties,**
*** composition and**
*** classifications.**

Definition of a *Mineral*:

- **Naturally occurring,**
- **homogeneous solid,**
- **inorganically formed,**
- **with definite (but generally not fixed) chemical composition**

and

- **highly ordered atomic arrangement.**

Scope of Mineralogy:

To acquire the knowledge of importance of the minerals like

- ***rock forming minerals for geological study***
- ***Ore forming minerals for economic importance***

Rock forming minerals

****Silicates***

Common or essential	**Accessory**
Quartz	**Zircon**
Feldspar	**Titanite**
Nepheline	**Rutile**
Sodalite	**Garnet etc.**
Leucite	
Micas	
Pyroxenes	
Amphiboles	
Olivine	

****Others***

Calcite, Dolomite, Apatite, Bauxite etc

Ore forming minerals

Minerals	**Ore**	
Hematite	***Iron (Fe)***	
Magnetite	**-do-**	
Ilmenite	**-do-**	
Pyrite	**-do-**	
Chalcopyrite	***Copper (Cu)***	
Malachite	**-do-**	
Azurite	**-do-**	
Covellite	**-do-**	
Galena	***Lead (Pb)***	
Sphalerite	***Zinc (Zn)***	
Calcite, Dolomite	***Limestone***	
Magnesite	***Magnesite***	**etc.**

Branches of mineralogy

- **Descriptive Mineralogy**
  - **Physical properties**
  - **Chemical properties**
- **Optical Mineralogy**
  - **Optical properties**

PHYSICAL PROPERTIES OF MINERALS

I. Properties depending upon light

1. *Color*:

First and most easily observed properties.
Distinguishing criterion for many, but unreliable and changeable for some

- **depends upon the absorption of some and the reflection of others of the colored rays or vibrations which compose ordinary white light.**

♦ **Corundum (Al_2O_3)**

❖ **Ruby: Deep red**
absorbs all the other vibrations, except red

❖ **Sapphire: Dark blue**
absorbs all the other vibrations, except blue

The true color of a pure mineral depends on:

- **the nature and arrangement of the constituent ions. e.g.**

Al, Na, K, Ca, Mg, Ba -- generally colorless or light colored

Fe, Cr, Mn, Co, Ti, Ni, V, Cu -- generally colored.

Different types of <u>bonding of carbon</u> atoms are responsible for:

- ✓ **the colorless nature of diamond**
- ✓ **the black nature of graphite.**

<u>Valency</u> can effect the color:

- **Divalent iron Fe^{2+} is commonly green**
- **Trivalent Fe^{3+} is generally red, brown or yellow with both blue or deep green.**

Another coloring agent is the <u>mechanical admixture of impurities</u>,

- **which can give a variety of colors to colorless mineral e.g.**

- **due to the presence of finely dispersed chlorite, quartz may be green**

- **due to the presence of MnO_2 or carbon, calcite may black.**

2. ***<u>Streak</u>*:**

Color of a finely powdered mineral (= constant color)

- **done in streak plate (H7) - unglazed porcelain**

- **Hematite - cherry red,**
- **Magnetite - black,**
- **Quartz - colorless**

3. *Luster*:

Refers to the general appearance of a mineral surface in reflected light.

A) Metallic:- having the brilliant appearance of a metal.

- **Opaque, with black or very dark streak e.g.**
  - **galena,**
  - **pyrite,**
  - **gold etc.**

B) Non-metallic: - light colored and transmits light (through thin edges).

- **Colorless to very light color streak**

Type	Description	Mineral examples
Adamantine	brilliant like diamond	cerussite, anglesite
Vitreous	shiny like glass (broken)	quartz
Resinous	appearance of resin	sulphur, sphalerite
Pearly	milky reflectance like pearl	talc, brucite, gypsum
Greasy	oily appearance	halite (common salt)
Silky	fibrous appearance	asbestos, fibrous gypsum
Dull or earthy	no lustre	soil, clay

C. Sub-metallic:- intermediate between metallic and non-metallic e.g.

- **chromite, cuprite etc.**

4. ***Diaphaneity*:**

- **The amount of light, which is transmitted through a mineral, is a measure of its diaphaneity.**
- **This physical characteristic is described as**
  - **i) Transparent**
  - **ii) Translucent**
  - **iii) Opaque.**

5. ***Fluorescence*:**

(The emission of light as the result of any process other than incandescence (= burn by heat) is called "Luminescence")

- **Mineral that luminesces during exposure to**
  - **⇒u.v. light,**
  - **⇒x-rays,**
  - **⇒cathode rays**

  are called "Fluorescent".

The property is called "Fluorescence". e.g.

- **fluorite, calcite, willemite (Zn_2SiO_4) etc.**

6. ***Phosphorescence*:**

If the luminescence continues after ⇒the exciting rays are cut off, the mineral is said to be phosphorescent. e.g.

- **diamond, ruby etc.**

With the development of synthetic phosphorous, fluorescence has become a commonly observed phenomena in

- **fluorescent lamps,**
- **paints,**
- **cloth and**
- **tapes.**

II) Physical properties depending upon the state of aggregation:

1. Specific gravity (G):

The ratio between the wt. of a substance and the wt. of an equal volume of water at 4^0C.

Important for fine crystals or gemstones.

G of a crystalline substance depends on:

i) the kind of atoms of which it is composed

(ii) the manner in which the atoms are packed together.

Example for Ist condition: Orthorhombic crystals:

Mineral	Composition	At. Wt. of cation	Sp. Gr. (G)
Aragonite	$CaCO_3$	40.08	2.95
Strontianite	$SrCO_3$	87.62	3.76
Witherite	$BaCO_3$	137.34	4.29
Cerussite	$PbCO_3$	207.19	6.55

Example for IInd condition:

Mineral	Composition	Crystal System	(G)
Diamond	C	Isometric	3.52
Graphite	C	Hexagonal	2.23
Calcite	$CaCO_3$	Rhombohedral	2.71
Aragonite	$CaCO_3$	Orthorhombic	2.95

Average Sp. Gr.:

- **Determined merely by lifting the specimen**

➢ **Non-metallic minerals:**
2.65 to 2.75 (quartz - feldspar)

➢ **Metallic minerals:**
5.0 and above (graphite 2.23, silver 10.5)

Determination of Sp. Gr.

In order to determine sp. gr. accurately, the mineral

a) must be homogeneous and pure
b) must be compact with no cracks or cavities
c) must not less than one cubic cm.

$$\text{Sp. Gr.} = \frac{Wa}{Wa - Ww}$$

where Wa = wt. in air, Ww = wt. in water

Different methods of determination:

Method	For
i)Jolly Balance	very small specimens
ii)Pycnometer	friable minerals, small fragments or liquids
iii) Heavy liquid method or Sink and Float method	distinguish heavy and light minerals

Example: bromoform (G 2.89) and methylene iodide (3.33) miscible with acetone (0.79),
Take an example of quartz (2.65), tourmaline (3.20) and garnet (4.25)

- **In bromoform qz would float, others sink.**
- **Tourmaline floats in methylene iodide, garnet would sink.**

iv) Ordinary chemical balance	fragments of a solid mineral as big as walnut.
v)Walker's steelyard	large specimens (by measuring the displaced water).

III) Properties depending upon magnetism:

I. *Ferromagnetic*:

Materials that show strong magnetic attraction when subjected to a magnetic field. eg.

- **native iron,**
- **iron pyrites,**
- **pyrrhotite,**
- **lodestone**

II. *Paramagnetic*:

When ferromagnetic materials are heated above a specific temperature their strong magnetic properties will be replaced by a comparatively weak magnetism, which is a function of the strength of the applied magnetic field. Materials exhibiting such weak magnetism, as a result of a strong magnetic field, are known as paramagnetic. e.g.

- **Magnetite at 85^0C - paramagnetic.**

III. *Diamagnetic*:

Very weak magnetic response in a direction opposite that of any externally applied field. e.g.

- **native bismuth,**
- **zircon,**
- **calcite etc.**

IV) Physical properties depending upon cohesion and elasticity:

1. *Cleavage*:

Tendency of minerals to break parallel to atomic planes just as the faces of the external form of a crystal.

⇒Recognized in two ways:

- **On the basis of Nature and**
- **Structure of the crystals.**

On the basis of Nature:

- ◊ ***Perfect*** = **well developed**
- ◊ ***Good*** = **Less perfect**
- ◊ ***Fair/ Poor*** = **Not so distinct**

On the basis of structure:

- ◊ **1 set,**
- ◊ **2 set,**
- ◊ **3 sets etc. or**
  - **Cubic,**
  - **Octahedral,**
  - **Prismatic,**
  - **Basal etc.**

2. ***Parting***:

Break along planes of structural weakness caused by

⇒twinning,

⇒deformation etc.

(=false cleavage). e.g. parting present in

- **magnetite,**
- **pyroxenes,**
- **corundum etc.**

3. ***Fracture***:

The form or kind of surface obtained by breaking in a direction other than that of cleavage in crystallized minerals, and in any direction in massive minerals.

⇒Fracture is classified as:

a) Conchoidal:

- **a concentric,**
- **dish-shaped fracture**
- **similar to the broken surface of a glass. e.g. quartz.**

b) Fibrous or splintery:

- **like fibres, e.g. serpentine**

c) Hackly:

- **jagged fractures with sharp-edges, e.g. cast iron**

d) Even:

- **flat surface, e.g. chert**

e) Uneven or irregular:

- **with rough and irregular surface, e.g. cassiterite (Tinstone)**

4. *Hardness*:

The resistance that a smooth surface of a mineral offers to scratching is its hardness (H) = Scratchability.

- **Depends upon ionic bonding**
- **Increase in hardness with**
  - **⇒decreasing ionic size and**
  - **⇒increasing ionic charge.**

Australian Mineralogist F. Mohs in 1824 gave a Hardness scale:

Hardness scale	Mineral	Composition
1	Talc	$Mg_3Si_4O_{10}(OH)_2$
2	Gypsum	$CaSO_4.2H_2O$
3	Calcite	$CaCO_3$
4	Fluorite or Fluorspar	CaF_2
5	Apatite	$Ca_5(PO_4)_3$ (F,Cl,OH)
6	Orthoclase Feldspar	$KAl_3Si_3O_8$
7	Quartz	SiO_2
8	Topaz	$Al_2SiO_4(F,OH)_2$
9	Corundum	Al_2O_3
10	Diamond	C

Others:

- **Copper coin 3**

- **Finger Nail 2 to 3**
- **Pocket Knife 5 to 6**
- **Steel Knife 6.5**
- **Glass 5.5**

Determination of (H):

- **Tested by rubbing the specimen over a tolerably fine cut file noting**
  - **the amount of powder and**
  - **the degree of noise produced in the operation.**
- **less the powder and**
- **greater the noise,**
- **harder is the mineral.**

5. *Tenacity*:

The resistance that a mineral offers to

- **breaking,**
- **crushing,**
- **bending or**
- **tearing,**

in short its cohesiveness is known as tenacity.

a) Brittle:

- **breaks and powders easily, e.g. pyrite, apatite**

b) Malleable:

- **that can be hammered out into thin sheets**

c) Ductile:

- **that can be hammered out into thin wires**

e.g. Ag, Au, Cu etc.

d) Sectile:

- **can cut into thin layers with a knife, e.g. graphite, gypsum**

e) Elastic:

- **mica sheets**

f) Plastic:

- **Talc, chlorite etc.**

Crystal Habits and Aggregates

Crystallinity

- **Crystalline**
  - ◊ **Macro Crystalline**
  - ◊ **Micro Crystalline**
  - ◊ **Crypto Crystalline**
- **Amorphous (no Crystallinity)**

Habits

1. Minerals in isolated or distinct crystals may be described as:

Type	Nature	Mineral example
a) Acicular	needle like crystals	natrolite
b) Capillary and filiform	hair like or thread like	millerite
c) Bladed	like a knife blade	kyanite

2. For group of distinct crystals:

a) Dendritic	divergent branches, plant like	crystallized gold
b) Reticulated	net like	rutiles in some mica
c) Divergent or radiated	radiating crystal groups	stibnite
d) Drusy	a surface covered with a layer of small crystals	quartz

3. Parallel or radiating groups of individual crystals:

a) Columnar	column like	hornblende
b) Bladed	aggregate of many flattened blades	kyanite
c) Fibrous	fibres	asbestos
d) Stellated	star like	wavellite
e) Globular	small spherical or hemispherical groups	cassiterite
f) Botroidal	like 'bunch of grapes'	chalcedony
g) Reniform	kidney shaped	variety of hematite
h) Mammilary	same as botroidal but larger	malachite
i) Colloform	spherical forms	aragonite

4. A mineral aggregate composed of scales or lamellae:

a) Foliated	easily separable into plates or leaves	gypsum
b) Micaceous	splits into thin sheets	micas
c) Lamellar or tabular	flat, plate like	wollastonite
d) Plumose	feather like	stibnite

5. A mineral aggregate composed of grains = Granular

6. Miscellaneous terms :

a) Stalactite	**elongated cones, cylinders**	**limonite**
b) Concentric	**superimposed upon one another about a common center**	**talc**
c) Oolitic	**formed of small spheres**	**oolites**
d) Banded	**narrow bands of different color**	**chert**
e) Massive	**Compact material without any form**	**iron ores**
f) Amygdaloidal	**sub-globular**	**zeolites**
g) Concretion	**masses formed by deposition of material about a nucleus**	**flint in chalk**

Crystal structures of mineral

The orderly arrangement of atom in a crystal is known as the crystal structure.

Structure type:

Isomorphism:

Chemical compounds, which have
⇒an analogous composition and
⇒a closely related crystalline form, are called 'isomorphous' and the phenomena are called 'isomorphism'. e.g.

Barite group of sulphates -

- **$BaSO_4$ (barite),**
- **$CaSO_4$ (anhydrite),**
- **$SrSO_4$ (celestite),**
- **$PbSO_4$ (anglesite)**

Aragonite group of carbonates -

- **$CaCO_3$ (aragonite),**
- **$BaCO_3$ (witherite),**
- **$SrCO_3$ (strontianite),**
- **$PbCO_3$ (cerussite)**

Calcite group of carbonates -

- **$CaCO_3$ (calcite),**
- **$MgCO_3$ (magnesite),**
- **$FeCO_3$ (siderite),**
- **$MnCO_3$ (rhodochrosite),**
- **$ZnCO_3$ (smithsonite).**

Synonyms = Isostructural or isotypous

Polymorphism :

The ability of a specific chemical substance

- **to crystallize with more than one type of structure (such as a function of changes in**
  - **temperature,**
  - **pressure or**
  - **both)**

is known as 'polymorphism' (= many form).

Various structures of such a chemical element or

compound are known as 'polymorphic forms' or 'polymorphs'. e.g.

Comp.	Mineral	Crystal system	Hardness	Sp.Gr.
C	Diamond	Isometric	10	3.52
	Graphite	Hexagonal	1	2.23
FeS_2	Pyrite	Isometric	6	4.99
	Marcasite	Orthorhombic	6	4.85
$CaCO_3$	Calcite	Rhombohedral	3	2.71
	Aragonite	Orthorhombic	3.5	2.93
SiO_2	Low Quartz	Hexagonal	7	2.65
	High Quartz	-do-	7	2.53
	High tridymite	-do-	7	2.20
	High cristobalite	Isometric	6.5	2.20
	Coesite	Monoclinic	7.5	3.01
	Stishovite	Tetragonal	7	4.30

- **A chemical compound, which crystallizes in two forms genetically distinct, is said to be dimorphous. The phenomena are called 'Dimorphism'. e.g. C, FeS_2, $CaCO_3$**

- **A chemical compound which crystallizes in three forms genetically distinct is said to be 'Trimorphous'. e.g. TiO_2: rutile (tetragonal),**

Octahedrite (tetragonal), Brookite (orthorhombic)

Pseudomorphism:

If a crystal of a mineral is altered so that

- **the internal structure or**
- **chemical composition changed**
- **but the external form is preserved,**

it is called a pseudomorph (= false form). e.g.

- **Pyrite (FeS_2) may change to limonite $FeO.OH.nH_2O$,**

but it will preserve all the external features of the pyrite.

Such a crystal is described as a pseudomorph of limonite after pyrite.

Formed in several ways:

i) Substitution - removal or replacement of original materials e.g. qz after fluorite (CaF2)

ii) Encrustation - deposition of a coating of one mineral on the crystals of another e.g. qz on fluorspar

iii)Alteration - change. e.g. olivine into serpentine.

Solid Solution:

A solid that has

- **an homogeneous crystal structure**

⇒in which some equivalent sites are occupied by different ions. e.g.

- **olivine = forsterite (Mg_2SiO_4) + fayalite**

(Fe_2SiO_4).

Chemical properties of minerals:

Mineral as a chemical system:

Minerals as regards their chemical constitution, are either

- **the uncombined elements in a native state or**
- **definite compounds of these element**

formed in accordance with chemical laws.

Mineral= chemical compound =Elements =molecules, atoms

- **related to**
  - **at. wt.,**
  - **mol. wt.,**
  - **symbol,**
  - **formula,**
  - **metals,**
  - **non-metals,**
  - **elements,**
  - **chemical compound,**
  - **chemical reaction,**
  - **acids,**
  - **bases and**
  - **salts.**

Classification of Minerals:

- out of *3000* minerals, *200* are classified.

- Chemical composition has been the basis for the classification of minerals since the middle of the *19th* century.

- Classified nearly all dependent either
◊ upon their chemical components or
◊ the structure or
◊ forms of their crystals.

- American Mineralogist *J.D. Dana* have classified all the minerals into 8 chemical classes

- Modern Classification - 12 classes
(based on *C. Palache, H. Berman*, and *C. Frondel*)

1. Native elements - Au, Ag, Cu, S, graphite, diamond etc.

2. Sulphides - galena, sphalerite, pyrite etc.

3. Sulfo-salts - enargite etc.

4. Oxides - a) simple - (cuprite, corundum, rutile)
and
multiple - spinel etc.
b) hydroxides - bauxites

5. Halides - halite, fluorite etc.

6. Carbonates - calcite, dolomite etc.

7. Nitrates - Nitre (KNO_3)

8. Borates - Borax

9. Phosphates, Arsenates, and Vanadates - monazite, apatite, turquoise etc.

10. Sulphates and Chromates - barite, gypsum etc.

11.Tungstates and Molybdates - wolframite, scheelite, wulfenite

12. Silicates and Titanates (Titano-silicates):

a) Neso silicates - olivine, garnet, kyanite, sillimanite, andalusite, zircon, titanate (sphene)

b) Soro silicates - epidote

c) Cyclo silicates - cordierite

d) Ino silicates - Single Chain - pyroxenes
Double Chain - amphiboles

e) Phyllo silicates - talc, mica, chlorite, clay minerals

f) Tecto silicates - <u>quartz</u>, <u>feldspar</u>, <u>feldspathoid</u>, <u>scapolite</u>, <u>zeolite</u> etc.

<u>Others</u>:

- **Oxalates - salts of organic acids - whewwelite, oxammite**

- **Hydrocarbons - a) simple - chiefly members of the paraffin series**
  - **scheererite,**
  - **paraffin,**
  - **ozocerite etc.**

b) Oxygenated - amber, copalite

c) Complex native - petroleum, ashphalt, coal etc.

Formation of minerals in different endogenous and exogenous process:

Formation of minerals:

- complex - more than one process may enter

- among the agencies

⇒water plays a dominant role. It may be

- **water vapor,**
- **meteoric (rain) water,**
- **connate water (= entrapped in sediments at the time of their deposits)**
- **magmatic water(underground magmatic source),**
- **metamorphic water (water present at metamorphism), or**
- **ocean, lake or river water.**

- other agencies -

⇒temperature,

⇒pressure magmas,

⇒gases,

⇒vapors,

⇒solids in solution,

⇒atmosphere,

⇒organisms and

⇒country rocks.

Processes:

A) Endogenous:

Taking place or originating within the earth crust, such as

1. the solidification of magmas (Igneous process)

2. the operations of metamorphism (metamorphogenetic process)

1. Igneous process: Temperature ranges from 500^0 - 1500^0C

Process	Mineral formed
a) Magmatic concentrations	diamond, magnetite, Pt, Cr, Ni, Al
b) Sublimation	NaCl, oxides of Fe and Cu
c) Contact metasomatism	Fe, Cu, Zn, Pb, W, Au, Ag, Mn, garnet, graphite

(Metasomatism is the

- **replacement of one rock by another rock of different**
  - **mineralogical and**
  - **chemical composition.**
- **The minerals, which compose the rock,**
  - **are dissolved and**
  - **new mineral formations are deposited in their place.)**

d) Hydro-thermal processes	
i) Cavity fillings	**magnetite, pyrite, hematite, Au, qz**
ii) Replacement	**clay minerals, dolomites**

2. Metamorphogenetic process:

Metamorphic process, Temperature about 400^0C

Process	Cause	Mineral deposits
a) Metamorphosed deposits	**formed out of earlier deposits, result of regional metamorphism**	**asbestos, talc, graphite, Fe, Mn**
b) Metamorphic deposits	**formed ores from rocks, not from earlier deposits**	**garnet, corundum, bauxites**

***Exogenous*:**

Due to surface processes e.g.

- **deposition in a salt lake or**
- **sorting by river actions etc.**

Process	Mineral deposits
a) Weathering residual deposits	Fe ore, bauxite, kyanite, Ni
b) Detrital, alluvial or placer deposits	magnetite, diamond, rutiles, Au, Pt
c) Chemical - organic deposits*	limestone, sulphur

***(Bacterial processes, evaporation process, oxidation and supergene enrichment process)**

DESCRIPTIVE MINERALOGY

SULPHIDES: **Galena, Sphalerite, Pyrite etc.**

***PYRITE*: (= iron pyrites) FeS_2 (46.6% Fe, 53.4% S)**

***Color*: - pale brass yellow**

***Streak*: - greenish or brownish black**

***Luster*: - metallic**

***Transparency*: - opaque**

***Hardness*: - 6 - 6.5 (usually hard for sulphides)**

***Tenacity*: - brittle**

***Cleavage*: - absent**

***Fracture*: - conchoidal**

***Sp. Gr.*: - 5.02 (high)**

***Crystal system*: - cubic (faces usually striated)**

***Habit*: - crystalline**

Chemical Properties:-

- **frequently carries minute quantities of Au and Cu as microscopic impurities**
- **When heated in closed tube, gives sublimate of S, leaving a magnetic residue**
- **Soluble in nitric acid, insoluble in HCl**

***Diagnostic properties*: - *distinguished from gold by its brittleness and hardness (H 2.5-3)**
***cubic crystals**
***striations on faces**

***Occurrence*: - formed at both high and low temperature, but largest at high temp**
- occurs as a magmatic segregation, as an accessory minerals in igneous rocks
-in contact metamorphic deposits and in hydrothermal veins
-common mineral in sedimentary rocks
-associated with many minerals, but most frequently with
***chalcopyrite,**
***sphalerite and**
***galena**

***Uses*: - for Fe ore in those countries where oxide ores of Fe are not available**
- chief source of S for
***H_2SO_4 and**
***ferrous sulphates (copperas)**

(copperas - used in dyeing, inks, preservatives of woods and disinfectants)

-may be cut as gemstone = Marcasite (polymorph of pyrite)

Pyrite = fire (in Greek)
brilliant sparks emitted when struck by steel.

***OXIDES*:**

a) Simple and multiple:
i) Simple oxide - cuprite, corundum, rutile.

***RUTILE*: TiO_2 (Ti - 60%, O - 40%)**

- **red, reddish brown to black**
- **H 6 - 6.5**
- **uniaxially positive**
- **tetragonal**
- **vertically striated prism faces**
- **after fusion with Na_2CO_3, it can be dissolved in H_2SO4**
- **pleochroic**
- **high relief**
- **high order interference colour**

***Occurrence* - *in granite**granite pegmatites**gneisses**mica schists**metamorphic limestone and dolomite**

***Association* - with magnetite, zircon and monazite**

***Uses* - *as coating of welding rods**Ti derived is used in alloys**for electrodes in arc lights**

ii) Multiple Oxide :

<u>*SPINEL*</u>: $Mg\ Al_2O_4$ (MgO - 28.2%, Al_2O_3 - 71.8%)
- red, blue, white etc.
- Isometric, octahedral crystals
- Fe^{2+}, Zn and less commonly Mn^{2+} substitute for Mg in all proportions. Fe^{3+} and Cr may substitute in part for Al
-red clear variety = *Ruby spinel*

***Occurrence* - in a common high temperature mineral occurring in**
- **contact metamorphosed limestone and**
- **metamorphic argillaceous rocks poor in SiO_2**

- accessory minerals of dark igneous rocks
- as rolled pebbles in stream sands

***Association* - in contact metamorphic rocks with**
- ❖ **phlogopite**
- ❖ **pyrrhotite**
- ❖ **chondrodite and**
- ❖ **graphite**

***Uses* - *colored and transparent as gems**
***commonly inexpensive**
***known wt. 80 carats**

***CARBONATES*: Calcite, Dolomite etc.**

***CALCITE*: $CaCO_3$ (CaO - 56%, CO_2 - 44%)**

- **white to colorless**
- **may be different colors - impure brown to black**
- **Transparent and colorless = Iceland spar - used for Nicol Prism**
- **H - 3**
- **G - 2.71**
- **vitreous to earthy**
- **hexagonal**
- **habit - prismatic, rhombohedral scalenohedral**
- **twinning common**
- **uniaxially negative**
- **Mn2++, Fe2+ and Mg may substitute for Ca and a complete solid solution series extends to rhodochrosite (MnCO3) above 550^0C.**

Diagnostic properties:

- **fragments effervesce readily in cold dilute HCl - distinguished from dolomite**
- **lower sp. gr. than aragonite.**

***Occurrence*:**

- **as a rock forming mineral**
  - ❖ **limestone,**
  - ❖ **marbles,**
  - ❖ **chalk**
- **as cave deposits - stalactite, stalagmites**

- **as primary mineral in some igneous rock**
  - ❖ **carbonatites and**
  - ❖ **nepheline syenite**

***Uses*:**

- **most important for manufacture of cements and limes for mortars**

Limestone ($CaCO_3$) _ 900^0C _ CaO (quicklime) + CO_2;

quicklime + sand = common mortar.

75% $CaCO_3$ = cement grade limestone

- **in building industry**
  - **as dimension stones**
    - **for construction as well as**
      - **decoration stones**

PHOSPHATES:

***APATITE*:**

Fluor - apatite - $Ca_5F(PO_4)_3$
Chlor - apatite - $Ca_5Cl(PO_4)_3$
Hydroxyl - apatite - $Ca_5(PO_4)_3(OH)$

F, Cl and OH can substitute each other.

- **usually some shade of**
  - **green or**
  - **brown**
  - **also blue**
  - **violet and**
  - **colorless**
- **streak - white**
- **Transparent to translucent**
- **Luster - vitreous to sub-resinous**
- **cleavage - very poor, parallel to basal plane**
- **Fracture - conchoidal to even**
- **Tenacity - brittle**
- **H - 5 -scratch by knife**
- **Crystal system - hexagonal**
- **Habit - crystalline**
- **G - 3.15 - 3.20**
- ***Optical props*: uniaxially negative, high relief**

Diagnostic props :-

- **crystals**
- **colors and**
- **hardness**
- **Soluble in acids and gives the phosphate test with ammonium molybdates**

***Occurrence*:**

- **as accessory mineral**
  - **in all rocks**
  - **in pegmatites,**
  - **in crystalline limestone**

- **found in titaniferous magnetite bodies**
- **phosphate materials of bones and teeth are members of the apatite group**

***Uses*: * important - as fertilizers**
*** minor - for production of phosphorous chemicals**
*** transparent - as gems**

***Varieties of Phosphates* - two major varieties:**

a) Apatite - with definite composition

b) Rock phosphates (no definite composition) e.g.
- **phosphorite,**
- **phosphatic limestone,**
- **guano,**
- **bone beds etc.**

Phosphorite = Collophone - from accumulation of organic remains
Steffelite - showing original structure of the parent rock
Coprolite - phosphate found in sedimentary rocks
Asparagus - translucent greenish yellow crystallized variety
Osteolite - massive impure altered phosphate

SILICATES

◊ **most important minerals**

◊ 25% of the known minerals with a few minor exceptions all the igneous rock forming minerals are silicates and

◊ they constitute well over 90% of the earth's crust

***Classification*:**

According to *Dana* :

I) Anhydrous silicates

1. Dislicates, Polysilicates - feldspars
2. Metasilicates - Amphiboles, pyroxenes
3. Orthosilicates - Nephelite, garnet
4. Subsilicates - tourmaline, andalusite, kyanite

II) Hydrous - Micas, talc, serpentine, kaolinite etc.

(Quartz in oxides)

Modern classification:

1. NESOSILICATES:

- **Olivine**
- **Garnet**
- **Kyanite**
- **Andalusite**
- **Sillimanite and**
- **Zircon**

OLIVINE:

Forsterite - Mg_2SiO_4 and
Fayalite - Fe_2SiO_4

- **olive green colour**
- **vitreous**
- **conchoidal**
- **H - 6.5 to 7**
- **G - 3.27 to 4.37**
- **orthorhombic**
- **Forsterite : biaxially +ve,**
- **Fayalite : bi -ve**

Diagnostic properties:

- **glassy luster**
- **fracture**
- **colour**
- **slowly soluble in HCl**

***Occurrence*:**

- **in dark colored igneous rocks like**
  - **gabbro**
  - **peridotite and**
  - **basalt**
- **Dunite = made up of almost wholly olivine**

***Association*: with**

- **pyroxene**
- **plagioclase**
- **magnetite**
- **corundum, chromite and serpentine**

***Alteration*:**

◊ very readily altered to serpentine

***Uses*:**

◊ clear green variety = peridote - as gems

◊ mined as refractory sand for the casting industries

Chrysolite is synonym for olivine.

GARNET GROUP:

Structural formula: $A_3B_2(SiO_4)_3$**, where**

A = Ca^{2+}**,** Mg^{2+}**,** Fe^{2+}**,** Mn^{2+}

B = Al^{3+}**,** Fe^{3+}**,** Cr^{3+}

Pyralspite

- **Pyrope -** $Mg_3Al_2(SiO_4)_3$
- **Almandine -** $Fe_3Al_2(SiO_4)_3$
- **Sperrastine -** $Mn_3Al_2(SiO_4)_3$

Ugrandite

- **Uvarovite -** $Ca_3Cr_2(SiO_4)_3$
- **Grossular -** $Ca_3Al_2(SiO_4)_3$
- **Andradite -** $Ca_3Fe_2(SiO_4)_3$

- **most commonly red, also brown, yellow, white, green, black**
- **streak - white**
- **transparent to translucent**
- ***Luster* - vitreous to resinous**
- ***Cleavage* - absent**

- ***Fracture*** **- conchoidal to uneven**
- ***H*** **- 6.5 to 7.5**
- ***G*** **- 3.5 to 4.3**
- **Isometric**
- ***Optical properties*** **- RI very high, isotropic**

Diagnostic properties:

- **colour**
- **isometric crystals**
- **hardness**

Occurrence**:**

- **common mineral in metamorphic rocks such as**
  - **gneisses**
  - **schists - mica schists , hornblende schists**

Association**: with**

- **olivine**
- **serpentine associated with chromite**

Alteration**: alters to**

- **talc**
- **serpentine**
- **chlorite**

Uses**: - as gems**

- **green andradite**

❖ **deep red almandine**

- for abrasive purposes = sand paper

Name: Latin - granatus = like a grain

Al_2SiO_5 Group (Aluminium silicates)

Al_2SiO_5 - (Al_2O_3 - 63.2%, SiO_2 - 36.8%)

❖ **Andalusite**
❖ **Sillimanite**
❖ **Kyanite**

Props.	Andalusite	Sillimanite	Kyanite
Colour:	Flesh red, reddish brown, olive green	brown, pale green, white	usually blue, middle blue - margins colorless
Luster:	vitreous	vitreous	vitreous to pearly
H:	7.5	6 to 7	5 parallel to length of crystals 7 perpendicular to crystals
G:	3.16 to 3.20	3.23	3.55 to 3.66
XL sys.:	Orthorhombic	orthorhombic	triclinic
Cleavage	poor	1 set perfect	1 set perfect
fracture:	uneven	uneven	Hackly
Opt. Props.	pleochroic, biaxially negative	bi +ve	weakly pleochroic, bi –ve
Variety:	Chiastolite	x	X
Diag.	H, nearly square	cleavage	bladed crystals, good cleavage, blue

props.:	**prism**		**colour, different (double) hardness**
Occu:	**metamorphosed rocks of clayey composition**	**high temperature metamorphosed argillaceous rocks**	**high pressure, moderate temperature metamorphic rocks as kyanite-gneiss, schist.**
Assoc:	**with cordierite, kyanite, sillimanite**	**with corundum**	**with garnet, staurolite, and corundum**
Uses:	**for use in manufacture of spark plugs and transparent as gems**	**for high grade porcelain**	**as in andalusite**

***ZIRCON*:**

$ZrSiO_4$ (ZrO_2 - 67.2%, SiO_2 - 32.8%)

- **commonly some shade of brown**
- **also colorless, grey, green, red**
- **colorless streak**
- **usually translucent**
- **adamantine luster**
- **1 set cleavage**
- ***H* - 7.5**
- ***G* - 4.7**
- **XL sys - tetragonal**
- **conchoidal fracture**
- **uniaxially +ve**

Diag. props.:

- **colour**
- **luster**
- **xl**
- **H and G**

***Occurrence*:**

- **common and widely distributed accessory mineral in all types of igneous rocks as**
  - **granite**
  - **nepheline-syenite etc.**

***Uses*: - as gems**

- source of zirconium oxide.

2. SORO SILICATES:

- **clinozoisite**
- **epidote**
- **allanite etc.**

***EPIDOTE* :**

$Ca_2(Al,Fe)Al_2O(SiO_4)(SiO_7)(OH)$

- **shades of green (blackish-green, dark oil-green)**
- **vitreous luster**
- **transparent to opaque**
- ***cleavage* perfect parallel to the basal plane**
- ***H* - 6 to 7**
- ***G* - 3.25 to 3.45**
- **uneven fracture**

- **monoclinic crystal**
- **high refractive index**
- **bi -ve**

***Diag. props.*: - peculiar green colour**
- perfect cleavage

***Occurrence*:**

- **formed under conditions of regional metamorphism of the epidote-amphibolite facies**
- **commonly in metamorphic rocks**
  - **from impure calcareous rocks or**
  - **from igneous rocks rich in lime feldspar**
- **common in metamorphosed limestone with**
  - **calcium-rich garnets**
  - **diopside**
  - **vesuvianite and**
  - **calcite**
- **epidosite = metamorphic rock formed almost entirely of granular epidote**

***Uses*: - sometimes cut as a gem**
***Similar species* - Pistacite, Arendalite, Withamite.**

3. CYCLO SILICATES

***CORDIERITE*: $(Mg,Fe)_2 Al_4 Si_5 O_{18} \cdot nH_2O$**

- **Various shades of blue to bluish Grey colour**
- **vitreous luster**
- **transparent to translucent**
- **poor cleavage**
- **sub-conchoidal fracture**
- ***H* 7 to 7.5**
- ***G* 2.6 to 2.66**
- **orthorhombic crystal**
- **usually Bi -ve but sometime Bi+ve**

***Diagnostic Properties*:-**

- **fusible on thin edge - distinguish from qz**
- **Distinguished from corundum by lower hardness.**
- **Pleochroism is characteristic, if observed.**

***Occurrence*:**

-common constituent of contact and regionally metamorphosed argillaceous rocks

-in cordierite gneisses of high-grade metamorphic rocks

-in cordierite-hornfels of contact metamorphic origin

-also occurs as a magmatic mineral in norites due to contamination of gabbro magma by argillaceous sediments.

***Uses*: -**

transparent of good colour as gems = iolite or dichroite

Name after the French Geologist *P.L.A. Cordier*

3.

4. <u>INO SILICATES:</u> (Inos = fibre)

a) Single chain - *Pyroxene* Group:

General Formula: XYZ_2O_6

where, $X = Na^{+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, Mg^{2+}$, and Li^{+}

$Y = Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+}, Cr^{3+}$ and Ti^{4+}

$Z = Si^{4+}, Al^{3+}$

i) Orthopyroxenes (Orthorhombic)

Enstatite - $MgSiO_3$ (or $Mg_2Si_2O_6$)

Hypersthene - $(Mg,Fe)SiO_3$

ii) Clinopyroxenes (Monoclinic)

Diopside - $CaMgSi_2O_6$

Augite - $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$

Pigeonite - $Ca_{0.25}(Mg, Fe)_{1.75}Si_2O_6$

iii) Alkaline pyroxenes (Monoclinic)

Aegirine or Acmite - $NaFe^{3+}Si_2O_6$

Jadeite - $NaAlSi_2O_6$

Spodumene - $LiAlSi_2O_6$

iv) Pyroxenoid group (Triclinic)

Wollastonite - $CaSiO_3$

Rhodonite - $MnSiO_3$

Pectolite - $Ca_2NaH(SiO_3)_3$

b) Double chain - *Amphibole* Group

General Formula - $W_{0-1}\ X_2Y_5Z_8O_{22}(OH,F)_2$

where, W= Na,K
X= Ca^{2+}, Na^{+}, Mn^{2+}, Fe^{2+}, Mg^{2+} and Li^{+}
Y= Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+} and Ti^{4+}
Z= Si^{4+} and Al^{3+}

i) Anthophyllite $(Mg, Fe)_7\ Si_8O_{22}(OH)_2$ - orthorhombic

ii) Cummingtonite series (Monoclinic)

cummingtonite - $Fe_2Mg_5Si_8O_{22}\ (OH)_2$
grunerite - $Fe_7Si_8O_{22}(OH)_2$

iii) Tremolite series (Monoclinic)

Tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$
Actinolite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
(varieties - asbestos)

iv) Hornblende -(Monoclinic)

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

v) Sodium Amphibole Group (Monoclinic)

Glaucophane $Na_2Mg_3Al_2Si_8O22(OH)_2$
Riebeckite $Na_2Fe^{2+}Fe^{3+}Si_8O_{22}(OH)_2$
Arfvedsonite $Na_3Mg_4AlSi_8O_{22}(OH)_2$

vi) Cossyrite (Triclinic) Al-silicate of Na, Fe and Ti

Distinguish between amphibole and pyroxenes

Amphibole	*Pyroxene*
1. Cleavage 2 sets at 124^0 and 56^0	2 sets cleavage at 87^0 and 93^0
2. Commonly bladed	Hardly bladed
3. commonly pleochroic	commonly non-pleochroic
4. common crystals terminated by 3 faces	common crystals terminated by 2 faces
5. extinction angle about 16^0	extinction angle about 48^0

5. PHYLLO SILICATES:

TALC:

$MgSi_4O_{10}(OH)_2$

(MgO - 31.7%, SiO_2 - 63.5%, H_2O - 4.8%)

- **Apple green, Grey, white, or silver-white colour**
- **pearly to greasy luster**
- **translucent**
- **perfect basal cleavage**
- **sectile tenacity**
- ***H*-1**
- ***G* - 2.7 to 2.8**
- **monoclinic crystal**

***Diag. props.*: - softness**

- **greasy feel, soapy feel**
- **sectile**

***Occurrence*:**

- **it is a secondary mineral formed by the alteration of Mg-silicates e.g.**
  - ❖ **olivine**
  - ❖ **pyroxenes and**
  - ❖ **amphiboles**

- **occurs in low-grade metamorphic rocks -**
  - ❖ **soapstone**

***Uses*:**

- ➢ **in paint**
- ➢ **ceramics**
- ➢ **rubber**
- ➢ **insecticides**
- ➢ **roofing**
- ➢ **paper industries**

- **most familiar in talcum powder**
- **also used as an ornamental material for carving small objects**

***MICAS*: Mica Group**

Muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$

Biotite - $K(Mg,Fe)_3\ (AlSi_3O_{10})(OH)_2$

Phlogopite - $KMg_3(AlSi_3O_{10})(OH)_2$

Lepidolite - $K(Li,Al)_{2\text{-}3}(AlSi_3O_{10})(OH)_2$

Margarite - $CaAl_2(Al_2Si_2O_{10})(OH)_2$

Distinguish between muscovite and biotite:

Muscovite	***Biotite***
1. Colorless	**Usually dark green, brown to black**
2. Transparent in thin sheets	**thin sheets usually have a smoky colour (differing from muscovite)**
3. vitreous to silky or pearly luster	**splendent or shiny**
4. 1 set perfect cleavage (basal)	**1 set basal cleavage**
5. *H* - 2 to 2.5	**H- 2.5 to 3**
6. *G* - 2.76 to 2.88	**G - 2.8 to 3.2**
7. Monoclinic	**Monoclinic**
8. non-pleochroic	**strongly pleochroic**
9. parallel extinction	**parallel extinction**
10. Bi –ve	**Bi -ve**
11. *Diag. props*: colour, cleavage	**colour, cleavage**
12. *Occur*: in granites, granite-pegmatites; in metamorphic rocks as mica-schists	**in granites, granite-pegmatites as well as in gabbros, peridotites: in regional and contact metamorphic rocks**
13. *uses*: as insulating material in electrical apparatus	**Same as of Muscovite**

CHLORITE:

$(Mg,Fe)_3\ (Si, Al)_4O_{10}\ (OH)_2\ .\ (Mg,Fe)_3\ (OH)_6$

- **Green of various shades in colour**
- **vitreous to pearly luster**
- **transparent to translucent**
- ***H* - 2 to 2.5**
- ***G* - 2.6 to 3.3**
- **monoclinic crystal**
- **1 set perfect basal cleavage**

Diag. props.:

- **green colour**
- **micaceous habit and**
- **cleavage**

***Occurrence*:**

- **common in metamorphic rocks**
- **diagnostic mineral of the green-schist facies**
- **also common constituent of igneous rocks where it has formed as an**
  - **alteration of Mg-Fe silicates such as**
    - **pyroxenes**
    - **amphibole**
    - **biotite and**
    - **garnet**

- **green colour of many igneous rocks is due to this mineral**

CLAY MINERALS:

***KAOLINITE*:**

$Al_2Si_2O_5(OH)_4$

(Al_2O_3 - 39.5%, SiO_2 - 46.5%, H_2O - 14.0%)

- **White colour, often variously colored by impurities**
- **usually earthy luster, crystal plates pearly**
- **1 set perfect basal cleavage**
- ***H* - 2**
- ***G* - 2.6**

Diag. props.:

- **recognized usually by its claylike character**

***Occurrence*:**

- **chief mineral of kaolin or clay**

- **It is secondary mineral formed by:**
  - **⇒weathering or**
  - **⇒hydrothermal alteration of Al-silicates**
    - **❖ particularly feldspar**

***Uses*:**

- **most important of the industrial substances**
- **in ceramic industries**

Species: Dickite, nacrite, montmorillonite etc.

6. TECTO SILICATES:

A) SiO_2 Group:

i) Quartz

ii) Tridymite SiO_2

iii) Cristobalite

iv) Opal - $SiO_2 . nH_2O$

B)Feldspar Group:

i) K - feldspar

a) Microcline

b) Orthoclase $KAlSi_3O_8$

c) Sanidine

ii) Plagioclase Feldspars:

a) Albite $NaAlSi_3O_8$

b) Oligoclase

c) Andesine

d) Labradorite

e) Bytownite

f) Anorthite $CaAl_2Si_2O_8$

iii) Danburite $CaB_2Si_2O_6$

C) Feldspathoid Group:

i) Leucite $KAlSi_2O_6$

ii) Nepheline $(Na,K)\ AlSiO_4$

iii) Sodalite $Na_8(AlSiO_4)_6Cl_2$

iv) Lazurite $(Na, Ca)_8\ (AlSiO_4)_6\ (SO_4, S, Cl)_2$

v) Petalite $LiAlSi_4O_{10}$

D) Scapolite series:

i) Marialite $Na_4(AlSi_3O_8)_3$ (Cl_2,CO_3,SO_4)

ii) Meionite $Ca_4(Al_2Si_2O_8)_3$ $(Cl_2CO_3SO_4)$

iii) Analcime $NaAlSi_2O_6.H_2O$

E) Zeolite Group:

i) Natrolite $Na_2Al_2Si_3O_{10}.2H_2O$

ii) Chabazite $CaAlSi_4O_{12}.6H_2O$

iii) Heulandite $CaAl_2Si_7O_{18}.7H_2O$

iv) Stilbite $CaAl_2Si_7O_{18}.7H_2O$

(A) *QUARTZ*:

SiO_2 (Si - 46.7%, O - 53.3%)

- **Usually colorless or white but frequently colored by impurities**
- **streak absent**
- **vitreous luster, sometimes greasy and splendent**
- **transparent to translucent**
- ***cleavage* absent**
- **conchoidal fracture**
- ***H* - 7**
- ***G* - 2.65**
- **hexagonal crystal**

Diagnostic properties:

- **luster**
- **fracture**
- **crystal form**
- **absence of cleavage**

- **presence of striations perpendicular to 'c' axis**
- **distinguished from calcite by its high hardness**

***Occurrence*:**

- **common and abundant mineral occurring in a great variety of geological environments**
- **major constituent of granite pegmatites**
- **on the breakdown of qz-bearing rocks - accumulate as sand**
- **quartzite, metamorphic rock, composed mainly of quartz**

***Uses*:** **- widely used as gemstones as**

- ❖ **amethyst**
- ❖ **rose quartz**
- ❖ **smoky quartz**
- ❖ **agate and**
- ❖ **onyx**

- **as sand, qz is used in mortar, in concrete**

- **in the manufacture of glass and silica brick**

- **in powdered form, it is used in**
  - ➢ **porcelain**
  - ➢ **paints**
  - ➢ **sandpaper**
  - ➢ **soaps**

- **in the form of quartzite and sandstone it is used as a building stone and for paving purposes**

- **made into lenses and prisms for optical instruments,**
  - ➢ **because of its transparency in both the**
    - **infrared and**
    - **ultra violet portions of the spectrum**

- **qz-wedges, cut from transparent crystal are used as an accessory to the polarizing microscope**

- **cut into small oriented plates and used as radio oscillators to permit both**
  - ➢ **transmission and**
  - ➢ **reception on a fixed frequency**

- **The tiny qz plate used in digital qz watches serves the same function as qz oscillators used to control radio frequencies.**

***Varieties*:**

a) Coarsely crystalline varieties:

i) Rock crystal
ii) Amethyst
iii) Rose qz
iv) smoky qz
v) Citrine and
vi) milky qz

b) Micro-crystalline (Crypto-crystalline) varieties:

I) Fibrous varieties:

i) Chalcedony (brown to grey)
ii) Carnelian (red chalcedony)
iii) Chrysoprase (apple green chalcedony)
iv) Agate (alternating different layers of chalcedony)
v) Onyx - layered chalcedony
vi) Sardonyx - onyx with white or black layers
vii) Bloodstone - green chalcedony with small red spots (tint) of jasper

II) Granular :

i) Flint - dark colour
ii) Chert - light colored
iii) Jasper - red coloured
iv) Prase - dull green colored

(B) *FELDSPAR* GROUP:

(Most important group of rock forming mineral)

i) K - feldspar
- Orthoclase,
- microcline,
- sanidine,
- anorthoclase (K,Na) $AlSi_3O_8$,

(Orthoclase to albite = Alkali feldspar)

ii) Plagioclase series

iii) Danburite

iv) Rare feldspars:

i) Celsian - $BaAl_2Si_2O_8$,

ii) Hyalophane - $(K, Ba)(Al, Si)_2 Si_2O_8$

General Characters:

- **Whitish, greyish or pale shades of red, green, yellow**
- **colorless to white streak**
- **generally vitreous**
- **transparent to translucent**
- **all shows good cleavages in two directions at an angle of 90^0 with each other**
- **H - about 6 (Orthoclase - 6)**
- **G - 2.55 to 2.76**
- **orthoclase, hyalophane, celsian - *monoclinic***
- **microcline, plagioclase, anorthoclase - *triclinic***
- **Twinning general in orthoclase and repeated in plagioclase**
- **Alkali feldspars alter commonly into sericitic mica and kaolin**
- **Plagioclase feldspars alter commonly into saussurite (mixture of albite, epidote etc.)**

Laminar intergrowths of Albite or Oligoclase in K-feldspar = *perthite*

Perthite visible to the naked eye = *macroperthite*

Perthite visible only by x-rays or electron microscope = *crypto perthite*

K-feldspar on plagioclase = *anti perthite*

Perthitic intergrowth is the result from the unmixing at lower temperatures of
⇒K-feldspars with a small proportion of Na-feldspar
⇒which together formed homogeneous crystals at higher temperatures
⇒Such intergrowths are the result of *'ex-solution*.'

(*Ex-solution*: the process whereby
◊ an initially homogeneous solid solution
◊ separates into two or more distinct crystalline minerals
◊ without the addition or removal of material to or from the system
◊ i.e. no change in the bulk composition. - occurs in cooling)

***Occurrence*:**
- **in igneous rocks**
  - **alkali feldspars in acidic igneous rocks**
  - **plagioclase in basic igneous rocks**

***Uses*: - chiefly in the manufacture of porcelain**

- when heated to high temperature feldspars fuses and acts as an cement to bind the material together

- **fused feldspar also furnishes the major part of the glaze on porcelain ware**
- **transparent varieties are used as gems**

(C)*FELDSPATHOID* GROUP:

- **Leucite**
- **Nepheline**
- **Sodalite**

-

- **Primary constituents of igneous rocks (except lazurite = lapis lazuli)**

- **Primary qz and feldspathoid never occurs together in the same rock**

- **If free silica present - forms feldspar**

***(D) SCAPOLITE* SERIES:**

- **Marialite**
- **Meionite**
- **Analcime (Metamorphic minerals)**

- **colorless, white or pale shades of blue, green and red**
- **colorless streak**
- **vitreous to pearly or rather resinous luster**
- **transparent to nearly opaque**
- **cleavage 2 sets**
- **sub conchoidal fracture**
- ***H* - 5 to 6**
- ***G* - 2.27 to 2.75**

- **tetragonal crystal, but Analcime is *Isometric***

***Occurrence*:**

- **scapolite occurs in crystalline schists, gneisses, amphibolites and granulite facies rocks**
- **in many cases derived from alteration of plagioclase feldspar**
- **also characteristic in crystalline limestone as a contact metamorphic mineral**
- ***associated* with**
  - ❖ **diopside**
  - ❖ **amphibole**
  - ❖ **garnet**
  - ❖ **apatite**
  - ❖ **titanite and**
  - ❖ **zircon**
- **Analcime - primary mineral occurs in some igneous rocks**
- **original constituent of analcime basalts**
- **association - with prehnite, calcite and zeolites**

***Uses*: colorless varieties are used as gems.**

***(E) ZEOLITE* GROUP:**

Group of hydrous silicates

***H* - 3.5 to 5.5,; *G* - 2.0 to 2.4**

***Occurrence*:**

- **found in cavities and veins in basic igneous rocks**
- **formed as alterations of volcanic tuff and volcanic glass**
- **occurrence of zeolites in various rock types is used to define the low-grade regional metamorphic zone known as the *'Zeolite facies'***

***Uses*: -construction materials**

***species*:**

Natrolite

- similar species - scolecite-$CaAl_2Si_3O_{10}.3H_2O$

Stilbite

- similar species –

Phillipsite - $KCa(Al_3Si_5O_{16}).H_2O$

Harmotone - $Ba(Al_2Si_6O_{26}).6H_2O$

Gmelinite - $(Na_2,Ca)(Al_2Si_4O_{12}).6H_2O$

Laumontite - $Ca(Al_2Si_4O_{12}).4H_2O$

Thomsonite - $NaCO_2(Al_5Si_5O_{20}).6H_2O$