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Mineralogy is the science of minerals. All the material products of Nature can be assigned to three kingdoms Animal, Vegetable and Mineral. To the mineral kingdom belong those products which have not been endowed with life, and they include minerals and rocks belonging to our Earth.

A Mineral, is a naturally occurring homogeneous substance, inorganically formed, with distinctive physical properties, a definite chemical composition, and an ordered atomic structure.

From the definition it follows that a substance to be called a mineral must possess the following general characters:

i) The qualification ‘naturally occurring” is essential because it is possible to reproduce most ‘artificial’ or ‘synthetic’ minerals in the chemical laboratory.

Eg. Evaporating a solution of NaCl produces crystals indistinguishable from those of the mineral ‘halite’, but such laboratory produced crystals are not minerals.

ii) A mineral is a ‘**homogeneous substance**’ that is to say, it consists of a single (mostly solid) phase-one kind of material only, which cannot be separated into simpler compounds. Each part should have the same physical and chemical properties throughout.

iii) The restriction of minerals to “**inorganically formed**” substances eliminates those homogeneous substances produced by organic matter.

Eg. Coal, Oil, etc., may not be regarded as minerals in strict sense.

iv) The requirement of a “**definite chemical comp.**” implies that a mineral is a chemical compound and chemical compounds have a definite composition which is readily expressible by a formula. It is important to distinguish between a ‘definite’ and a ‘fixed’ chemical comp.

Many minerals vary in composition, (i.e. the composition is not fixed), but this variation is within definite limits.

v) An ‘**ordered atomic arrangement**’ is the criterion of the crystalline state another way of expressing is to say that minerals are crystalling substances. Under favourable conditions of formation the ordered atomic arrangement may be expressed in the external crystal form.

A mineral is a homogeneous compound of its constituent elements, and a rock is a heterogeneous aggregate of its constituent minerals.

Minerals are broadly classified into “**rock forming**” minerals and “**economic minerals**”. The former make up the bulk of a rock and are further classified into “**Primary**” and “**Secondary**” according to their mode of origin; and “**essential**” and "**accessory**" as per their relative abundance in a rock. Economic minerals are those which are of value to man.

An elementary course in mineralogy may be conveniently divided into 1. Crystallography; 2. Physical mineralogy; 3. Optical mineralogy; 4. Crystal structure and x-ray analysis; 5. Chemical mineralogy; 6. Descriptive mineralogy; 7. Gemology; 8. Determinative mineralogy.

PHYSICAL PROPERTIES OF MINERALS

Minerals possess certain physical properties by which they can be identified megascopically. Practically all properties of a mineral depend upon the nature of the constituent elements and their arrangement.

The physical properties of minerals will be dealt with under the following headings:-

1) Characters depending upon light : colour, luster, transparency, optical properties.
2) Characters depending upon senses: Taste, odour, feel.
3) Characters depending upon the state of aggregation, Form, Hardness, Cleavage, Fracture, Tenacity etc.
4) The specific Gravity of minerals.
5) Characters depending upon heat: Fusibility, Conductivity.
6) Characters depending upon Magnetism, electricity, and radioactivity.

Colour : Colour depends upon the absorption of some and the reflection of others of the coloured rays or vibrations (wave lengths) which compose ordinary white light. When a body reflects light to so small an extent as not to effect the eye, it appears black, but when it reflects all the vibrations of the different colours which compose white light, it appears white. Again, if it reflects the red vibrations of ordinary light and absorbs all the other vibrations. It appears red. (Colour being in effect white light minus the absorbed wave lengths). The causes of colour in minerals are varied and complex. The true colour of a pure mineral depends on the nature and arrangement of the constituent ions (chemical comp.). Thus minerals containing Al, Na, K, Ca, Mg, Ba, as their main ions are generally colourless or light – coloured whilst those with Fe, Cr, Mn, Co, Ni, Cu are coloured, often deeply. Sometimes it is unrelated to comp, but depends on crystal structure and bond type, as in the contrast between the polymorphs of carbon, diamond being colourless and transparent, graphite black and opaque. Sometimes it is due to impurities, eg. varieties of chalcedony. Minerals which have a constant and characteristic colour are termed "**idiochromatic**" those whose colour is variable are called "**allochromatic**".

Lons or groups of ions which produce characteristic colours are known as "**chromophores**". Thus the hydrated Cu^2ion is the chromophore in the green and blue secondary copper minerals.

Streak :- The streak of a mineral is the colour of its powder, and may be quite different from that of the mineral in mass. For instance, black hematite gives a red powder. Streak is observed by producing a small quantity of the powdered mineral by scratching with a knife of file or by rubbing the mineral on a piece of unglazed porcelain or roughened glass called a "**streak-plate**".

Most transparent and translucent minerals have a white streak; dark minerals with non-metallic luster have a streak usually lighter than the colour; minerals with a metallic luster have; streak often darker than the colour.

Play of Colours :- Some minerals, when turned about or looked at in different directions, display a changing series or prismatic colours, such as are seen in the rainbow or on looking through a glass prism. This is called a "play of colours". Diamond, precious opal, Labradorite.

Change of Colour :- is a some what similar phenomenon extending over broader surfaces, the succession of colours being produced as the mineral is turned. Ex. Certain varieties of feldspar (S. Norway). The change of colour is caused by the interference of light reflected from thin plates of other minerals enclosed in parallel planes within the feldspar.

"**Schiller**" :- A nearly metallic luster shown by certain surfaces of minerals such as hypersthenes or schiller-spar is due to a somewhat similar cause.

Opalescence is a somewhat pearly or milky appearance (reflection) shown by opal and Moonstone. Opalescence is usually observed to best advantage on specimens with rounded and polished surfaces.

Iridescence is a display of prismatic colours due to the interference of rays of light in minute fissures which wall in thin films of air or liquid. These fissures are often the result of incipient fracture (cleavage cracks). Eg. Limonite, quartz, mica, calcite.

Chatoyancy :- The changeable, wavy, silky sheen shown by some minerals with a fibrous structure is known as "chatoyancy". Eg. Satin-spar (Gypsum) Tiger's-eye. Minerals with this property, cut with a convex surface, called the "Cabochon" cut, are frequently use as gems.

Tarnish:- After certain minerals have been exposed to atmosphere, the colour or the exposed portions differs districtly from that of the freshly fractured surfaces. Eg. Bornite, Copper Erubescite.

Asterism :- Some minerals exhibit a concentration of light along lines radiating from a centre, a property called asterism in reference to its star-like appearance (in reflected light). This concentration results from twinning or from regularly oriented inclusions. Some sapphires and rubies have this property when viewed in reflected light, Some samples of phlogopite will produce the effect by transmitted light provided that the light comes from a point source.

Transparency or diaphaneity – This is stated in terms of the relative ability of minerals to allow light to pass through them.

A mineral is **transparent** when the outlines of objects seen through it appear sharp and distinct. Eg. Rockcrystal (Quartz) Sellenite, etc.

Minerals are said to be **sub-transparent** or **semi transparent** when objects seen through them appear indistinct.

Eg. Fluorite, Topaz etc.

A mineral which, though capable of transmitting light, cannot be seen through is "**translucent**". This condition is very common among minerals. When no light is transmitted the mineral is "opaque" but it must be noted that this refers only to the appearance as usually seen. A large number of apparently opaque minerals become translucent when cut into very thin sections.

Lustre :-lustre may be defined as the appearance of a surface in reflected light. Lustre is a function of the transparency, refractivity, and structure of a mineral.

The luster of minerals differs both in intensity and kind, depending upon the amount and type of reflection of light that take place at their surfaces.

Kinds :- There are several kinds of luster.

"Metallic", the ordinary luster of metals Eg. Ag, Cu, Au, Fe, etc., When feebly displayed this lustre is termed "submetallic" Eg. Chromite, cuprite. This lustre ordinarily shown by "Non-metallic" minerals fall under the following groups:-

"Vitreous", the lustre of broken glass. Eg. Quartz when less well developed, it is called "Subvitreous", Eg. Calcite.

"Resinous", the lustre of resin, Eg. Opal, amber sphalerite.

"Pearly" the lustre of a pearl, Eg. Talc, selenite.

"Silky", the lustre of silk. This is peculiar to minerals having fibrous structure. Eg. Asbestors. Satin Spar etc.

"Adamantine", the lustre of a diamond.

"Greasy" the lustre of an oiled surface, Eg. Nepheline "Earthy", the lustre of earth (not shiny) Eg. Chalk, kaoline.

Degree :- The lustre of minerals may be different degrees of intensity, according to the amount of light reflected from their surfaces.

Splendent (Brilliant):- When the surface of a mineral is sufficiently brilliant to reflect objects distinctly, as a mirror would do. Eg. Hematite, mica.

Shining :- When the surface is less brilliant and objects are reflected indistinctly. Eg. Celestite, calcite.

Glistening :- When the surface is still less brilliant and is incapable of giving any image. Eg. Talc.

Glimmering :- Denotes still more feeble lustre than Gilstening Eg. Flint.

Dull :- Minerals with no lustre (no light is reflected from the surface) Eg. Chalk.

Luminescence :- The production of visible light by any means whatsoever is called "luminescence" When produced by heat, it is "thermoluminescence". Luminescence is the emission of light resulting from all processes except incandescence. It is usually produced by irradiation, generally with ultraviolet light. "**Phosphorescence**" is the property possessed by some substances of emiting light after having been subjected to certain conditions as heating, rubbing, or exposure to electric radiation or to ultra-violet light. Pieces of quartz when rubbed together in a dark room emit a phosphorescent light.

(Phosphorescence is the continued emission of light after irradiation is terminated).

Fluorescence :- Some minerals emit light whilst exposed to certain electrical radiations. This phenomenon is best exhibited by “fluorspar” and for this reason is called **fluorescence**.

(Fluorescence is the emission of light at the same time as the irradiation).

The luminescence caused by scratching, rubbing or pounding is called “Triboluminescence”

Taste :-Minerals soluble in water generally possess a characteristic taste, which may be designated as follows :-

Saline – the taste of common salt.

Alkaline – that of potash and soda

Acid – the sour taste of H_2SO_4

Cooling – the taste of Nitre or Potassium chlorate

Astringent – that of green vitriol

Sweetish astringent – that of alum

Bitter – that of Epsom Salts

Pungent – A sharp and bitting taste – ammonium chloride

Metallic – decomposed pyrite

Odour :- Some minerals give off characteristic odours when breathed upon, rubbed, scratched, pounded or heated, which are designated as follows:-

Argillaceous – the clay-like odour obtained by breathing upon kaoline.

Horse – raddish – the odour of decaying horse-raddish given when selenium compounds are heated.

Sulphurous – the odour of burning sulphur given off by pyrites when struck, or by many sulphides when heated.

Foetid – the odour of rotten eggs, due to the liberation of hydrogen sulphide. Eg. Limestone.

All iaceous – the odour of Garlic, given when arsenic compounds are heated eg. Arsenopyrite.

Bituminous – The odour produced by minerals containing organic matter. Eg. Asphalt.

Feel : (Tough) :- the impression one receives by handling or touching a mineral is designated as its “feel” or “tough”. The following terms are in common use.

Cold – the feel of good conductor of heat, eg. cu, Ag) Greasy or soapy-the slippery feel of Talc

Harsh or Meager – Rough to the touch eg. chalk

Smooth – without projections or irregularities. eg. sepiolite.

Some porous minerals like chalk “adhere” readily to the tongue.

STATE OF AGGREGATION

Form :- Under favourable circumstances minerals assume the definite geometrical forms of “Crystals”, the recognition of which is a valuable aid in their identification. The following general descriptive terms are associated with the crystal characters of minerals:-

“Crystallized” – a term denoting that the mineral occurs as well developed Crystals.

“Crystalline” – a term denoting that no definite crystals are developed, but a confused aggregate of imperfectly formed crystal grains that have interfered with one another during their growth.

“Cryptocrystalline” – a general term to denote the possession of mere traces of crystalline strucuture.

“Amorphous” – is used to describe the complete absence of crystalline structure.

Minerals assume various indeterminable forms that are not necessarily dependent on crystal character. These forms are described by the following terms, which have their customary meanings:-

“Acicular” – fine needle – like crystals, natrolite.

“Amygdaloidal” – Almond shaped mineral masses occurring in small cavities in lavas. Zeolites, copper.

“Bladed” – A tabular or platy structure, the individuals resembling knife – blades eg. Kyanite.

“Botryoidal” – closely united spherical masses, resembling bunch of grapes. Eg. chalcedony, psilomelane.

“Capillary” – fine hair – like form eg. Millerite.

“Columnar” – resembling slender coloums, hornblende, gypsum.

“Concretionary” and “nodular” – spherical nodules eg. flint

“Concentric” – spherical layers about a common centre eg. agate.

“Dendritic” – Branching, fern-like, tree-like, forms eg. Manganite.

“Fibrous” – fine thread like strands

Eg. Asbestos, wavellite

“Foliated” – thin and separable leaves, Mica.

“Granular” – in grains, saccharcidal (lump of sugar)

“Lamellar” – Separable plates or layers, wollastonite

“Lenticular” – Pellets, (Lens shaped), concretionary

“Mammilary” – Large mutually interfering spheroidal masses, eg, Malachite.

"Oolitic" – small rounded particles, limestone.

"Pisolitic" – rounded particles, the size of peas, Bauxite.

"Radiating" or "divergent" – fibres arranged around a central point, stibnite.

"Reniform" – kidney shaped – Hematite.

"Reticulated" – cross – meshes like net; Silver, Rutile.

"Scaly" – Small plates, Tridymite.

"Stellate" – fibres radiating from a centre to produce star like forms; wavellite.

"Tabular" – broad flat surfaces, wollastonite, celestite.

"Wiry" or filiform" – thin wires often twisted like the strands of a rope; native silver.

Isomorphism :- This term was introduced in 1819 by Mitscherlich. Minerals with analogous chemical composition which crystallize with similar structures and hence have similar crystal forms are said to be isomorphous.

(Substances with analogous formulae and in which the relative sizes of cations and anions are similar often have closely related crystal structures-isomorphism).

Aragonite group (Orthorhombic)	**Calcite group (Trigonal)**
Ba CO3 (Witherite)	Ca Co_3 – Calcite
Pb CO3 (Cerussite)	Mn Co_3 – Rhodochrosite
Sr CO3 (Strontianite)	Fe Co_3 – Siderite
Ca CO3 (Aragonite)	Zn Co_3 – Smithsonite
	Mg Co_3 – Magnesite

The important factor in isomorphism is similarity in size relations of the different ions, rather than any chemical similarity.

The Garnet group & plagioclase feldspars are the good illustrations of isomorphous replacement.

Polymorphism :- An element or compound that can exit with more than one atomic arrangement is said to be polymorphous.

(Two minerals of markedly different physical properties may have identical chemical composition).

Each arrangement has different physical properties and a distinct crystal structure; that is, the atoms or ions are arranged differently in different polymorphs of the same substance. A polymorphic substance may be described as "dimorphic", "trimorphic" etc., according to the number of district crystalline forms. Polymorphism is an expression of the fact that crystal structure is not exclusively determined by chemical composition, and there is often more than one structure into which the same atoms or ions in the same proportions may be built up.

Eg.	Diamond –	cubic	Enantiotrophy
	Graphite –	hexagonal	quartz $\rightleftarrows$ Tridymite

Dimorphic : Calcite-Hexagonal

Aragonite-Orthorhombic
Pyrite-cubic
Marcasite-Orthorhombic

Trimorphic :

	Sp.Gr.
Rutule – Tetragonal	- 4.25
Anatase – Tetragonal	- 3.90
Brookite – Orthorhombic	- 4.15

Pseudomorphism : Pseudomorphism is the assumption by a mineral of a form other than that which really belongs to it.

A mineral can be replaced by another mineral without any change in the external form. There are two types, one in which no change of substance occurs, the other in which there is addition of some element and removal of others.

The first type is that observed when one polymorph changes to another without change in external form; this specific type of pseudomorphism is known as “Paramorphism” eg. calcite after aragonite.

Pseudomorphs may be formed in several ways :-

1. A pseudomorph by investment or “incrustation” is produced by the deposition of a coating of one mineral on the crystals of another.

Eg. Quartz on fluorspar; smithsonite on calcite.

2. A pseudomorph by “infiltration” is formed when the cavity previously occupied by a certain crystal is refilled by the deposition in it of different mineral matter by the infiltration of solution.

3. A pseudomorph by “replacement” arises by the slow and gradual substitution of particles of new and different material matter for the original particles which are successively removed by water or other solvents. This kind of pseudomorphism differs from the preceding in the circumstance that the new tenant enters before the old tenant has entirely evacuated its quarters.

4. A pseudomorph by “alteration” is due to gradual chemical change which crystals sometimes undergo their composition becoming so altered that they are no longer the same minerals, although they still retain the old forms.

Eg. Olivine to Serpentine

Gypsum after anhydrite; chlorite after garnet.

Etch Figures :- When crystals are subjected to the solvent action of certain liquids or gases, small geometrical depressions appear on their surface. The shape of these figures called ‘etch’ or “etching figures,” is intimately associated with the internal structure of the crystal. Eg. Calcite-dolomite-in determining symmetry with the help of etch figs.

Symmetry is higher

Hardness :

Hardness of a mineral is generally defined as its resistance to scratching and relative hardness has been employed as a diagnostic property. It was given qualitative precision by the Austrian Mineralogist “Mohs”, who in 1822 proposed the following scale of relative hardness.

1. Talc
2. Gypsum or Rock Salt
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase Felspar
7. Quartz
8. Topaz
9. Corundum
10. Diamond

Each of these minerals will scratch those minerals lower n the scale, and will be scratched by those higher in the scale. The intervals on this scale are about equal except for that between concurdum and diamond which is estimated to be 30 or more times as great.

Hardness varies very greatly in minerals. Hardness may be tested by rubbing the specimen over a tolerably fine-cut file and nothing and amount of powder and the degree of noise produced in the operation. The less the powder and the greater the noise, the harder is the mineral. A soft mineral yields much powder and little noise. The noise and the amount of powder are compared with those Produced by the minerals of the Mohs set used as standard examples for hardness tests.

The hardness test may also be made by endeavouring to scratch the specimens enumerated in the list with the mineral under examination. If, for example, the mineral scratches orthoclase but does not scratch quartz it has a hardness between 6 and 7.

Hardness may also be tested by means of a pen knife (upto 6½) or even the finger nail (upto 2½).

Finger nail-upto 2.5
Copper coin-upto 3
Knife blade-upto 5.5
Window glass – 5.5
Streak plate-6.5
Steel file 6 to 7

Hardness like other physical properties depends on the automic structure of the mineral. It increases with the density of packing in the structure, with the valency of the ions, and with the decrease in ionic size. The structural control results in hardness varying in different directions in the crystal. This difference is usually very small but in the mineral kyanite hardness varies between 7 and 5.

[Kyanite – Disthene (old name) i.e., strengths)

Tenacity : Under this heading is included the behavior of minerals when an attempt is made to break, cut, hammer, crush, bend, or tear them. The most important kinds of tenacity are the following :

a) Sectility :- A mineral is said to be sectile when it can be cut with a knife and the resulting slice breaks up under hammer eg. Graphite, gypsum, steatite.

b) Malleability :- A mineral is malleable if a slice cut from it flattens out under a hammer. (i.e. into thin sheets) eg. native gold, silver, copper.
c) Flexibility :- is the property of blending. Thin layers of the mineral can be bent without breaking, and they remain bent after the pressure has been removed eg. Talc, selenite.
d) Elasticity :- Thin layers of the mineral may be bent without breaking, but they resume their positions when the pressure is removed. Eg. mica.
e) Brittleness :- Easily broken or powdered and cannot be cut in to slices eg. Quartz, Pyrites apatite.
f) Ductile :- Can be easily drawn into wire. Eg. copper silver.

Cleavage :- The property of splitting along definite planes is called “cleavage” (This property is constant with regard to number of planes and direction in all specimens of any given mineral, although it may vary in regard to the quality. [The possible number of cleavages range from none to six].

A mineral can be cleaved either by striking it a properly directed blow with a hammer or by pressing upon it in a definite direction with the sharp edge of a knife blade. Cleavage takes place between those palnes in which atoms are most closely bonded. These planes are called “Cleavage planes” and are parallel to possible crystal faces and are so designated.

Eg. cubical cleavage-galena, halite.

Octahedral Cleavage – Fluorite, diamondetc.

Cleavage is closely related to crystalline form and the internal structure of the crystal. In each cleavable mineral, the directions of the cleavage-planes are parallel to a certain face or to certain faces of a form in which the mineral may crystallize. In the plane of cleavage the atoms of the mineral are more closely packed together or the mutual electrical charges are greater than in directions at right angles to the cleavage – plane. This plane, therefore, is a plane of least cohesion and hence splitting or cleavage easily occurs along it. Substances with no crystalline structure, that is, amorphous substances, show no cleavage.

Certain rocks, such as slate, which split readily into thin sheets are said to be cleaved, but this property of “slaty cleavage” is the result of recrystallization under pressure and has no connection with the cleavage which exists in minerals.

Minerals may show several cleavages but one is generally obtained with greater ease than the others. Cleavage is described by stating the crystallographic direction followed by the cleavage planes, and the degree of perfection shown by such planes. The quality of cleavage is described by terms such as “perfect” (eminent), “good”, ‘distinct’ “poor” “indistinct”, “difficult” etc., “Perfect” cleavage is present when a mineral breaks along the cleavage and is difficult to break except along the cleavage. (eg. calcite, muscovite). A mineral has “good” cleavage when breaks easily along the cleavage, but such minerals can also be broken transvers to it (eg. felspar).

Minerals with “distinct” cleavage break most readily along the cleavage but also fracture easily in other directions; consequently, individual cleavage surfaces are seldom large (eg. scapolite). In minerals with “indistinct” cleavage, fracturing takes place as readily as cleavage, and careful inspection is necessary to recognize the cleavage (eg. Beryl).

Cleavage is a reflection of internal structure and is indirectly related to chemical composition.

PARTING :- This is a separation somewhat similar to cleavage and is sometimes called “fales cleavage”. It differs from clevage, however, in that it does not occur in all specimens of a given mineral. The cause of this property is believed to be structural planes of weakness resulting from twinning, shearing developed after the formation of the mineral, or oriented inclusions. In some minerals parting is a sign of beginning alteration along certain planes; in twinned crystals it often takes place along composition planes. The secondary twin-planes and the gliding planes are called “partings”.

Eg. Corundum has basal, rhombohedral; and prismatic partings.

FRACTURE :

The fracture of a mineral refers to the character of the surface obtained when minerals are broken in directions other than those along which cleavage or parting may take place. Minerals with no cleavage yield fracture surfaces very easily. As amorphous substances are devoid of cleavage, they always show fracture surfaces when shattered by a blow.

The following types of fracture may be distinguished :

(i) Conchoidal : The mineral breaks with a curved (Concave or convex) and shell-like fracture.
Eg. Quartz, flint, natural glasses.

(ii) Uneven – The fracture—surface is rough by reason of minute elivations and depressions.
Eg. Rhodonite.

(iii) Even : The fracture surface is flattish or nearly flat, eg. chert, lithographic limestone.

(iv) Hackly—The surface is studded with sharp and jagged elevations. Eg. copper (cast iron when broken).

(v) Splintery : The mineral breaks into splinters or fibres, eg. Pectolite.

(vi) Earthy : The irregular fracture characteristic of earthy substances. Eg. Chalk, Kaoline.

SPECIFIC GRAVITY : (Sp. Gr.) :-

The specific gravity of a body is the ratio of the weight of the body to that of an equal volume of water. For accurate measurements the temperature and pressure must be controlled.

The Sp. Gr. Of minerals depends on the atomic weight of the constituent elements and the way their atoms are packed in the crystal-structure.

Eg. Mineral	Formula	At. Wt. of cation	Sp. Gr.
Celestine	Sr. SO4	Sr.-87.83	2.9

Barytes	Ba. SO4	Ba-137.35	4.5
Anglestle	Pb SO4	Pb 207.21	6.3
Packing: Eg.	Diamond	3.52	
	Graphite	2.3	

The Cardinal principle employed in most determinations of Sp.Gr. is that the loss in wt. of a body immersed in water is the wt. of a volume of water equal to that of the body. If Wa is the wt. of the body in air, Ww its wt, in water, then Wa,-Ww is the wt. of the water displaced by the body and the sp. gr. of this is Wa/Wa-Ww.

METHODS OF DETERMINING SP. GP :- The following are the chief methods of determining Sp. Grs. in mineralogy, the particular method chosen depending usually upon the size and character of the specimen under examination.

(i) With the ordinary chemical balance for fragments of a solid mineral about as big as walnut.
(ii) With Walker's steelyard, for large specimens.
(iii) With Jolly's Spring Balance, for small specimens.
(iv) By measuring displaced water, for the rapid determination of the approximate Sp. Gr. Of a number of specimens of a mineral.
(v) With the "pycnometer" or Sp. Gr. Bottle, for friable minerals, small fragments or liquids.
(vi) With heavy liquids, used mainly for the separation of mineral mixture into their pure components according to their sp. grs, but also for approximate determinations of Sp.gr. of mineral grains. For this latter determination, the diffusion column and Westphal Balance may be employed.

WALKER'S STEELYARD: - this instrument is useful for determining the Sp. Gr. of large specimens. The essential part of the apparatus is the long graduated beam which is pivated near one end counter balanced by a heavy wt. suspended to the short arm. The specimen is suspended and moved along the beam until it counter balance the constant wt., the level position of the beam being observed by a mark. The reading (a) is taken. The specimen is then immersed in water and moved along the beam until the constant wt. is again balanced and a second reading (b) is obtained. The reading (a) and (b) are inversely proportional to the wts. Of the body in air Hence.

$$Sp,Gr. = \frac{\frac{1}{a}}{\frac{1}{a} = \frac{1}{b}} = \frac{b}{b-a}$$

Whence the Sp. Gr. is given by dividing the second reading by the difference between the second and first readings.

Jolly's Spring Balance :- This instrument consists of a spring suspenced vertically against a graduated scale. To the lower end of the spring are attached two scale-pans, one below the other, the lower scale-pan being always immersed in water. The reading (a) of the bottom of the mineral is placed in the upper pan, and a second reading (b) taken. The specimen is then transferred to the lower pan, and a third reading (c) taken.

Then (b-a) is proportional to the wt. of the mineral in air, and (b-c) to the loss of wt. in water so that

$$Sp.gr. = \frac{b-a}{b-c}$$

The pycnometer or Sp. Gr. Flask :- The pycnometer is a small flask (bottle) fitted with a ground-glass stopper which has a vertical capillary opening.

The empty pycnometer, including the stopper, is first weighed (W1) ; the mineral sample is then placed in the flask and the combined wts. Determined (W2), water is added and the flask should be boiled to drive off any air. After cooling to room temp, the flask is filled so that the capillary tube; the combined wt. of the flask, sample, and water is determined (W3). The flask is then emptied and refilled with water, and the wt of the filled flask is determined (W4). Then the Sp. Gr. can be determined as follows :-

$$Sp.Gr. = \frac{(W2-W1)}{(W4+W2)-(W3-W1)} \; or \; \frac{(W2-W1)}{(W4-W1)-(W3-W2)}$$

Fusibility :- The ease with which a substance changes from the solid state to the liquid state, or melts is called its fusibility. Some minerals are decomposed by heat and do not fuse; other vaporize without fusion.

A scale of 6 minerals, of which the temp. of fusion was supposed to increase by somewhat equal steps, was suggested by Von kabell and modified by penfield.

1. Stibnite : Fuses easily in a luminous flame; also in a closed below red heat. Melting Pt. 525^{o}c.
2. Natrolite (Chalcopyrite): Fuses in a luminous flame; also in a closed tube below red heat. M. P. 965^{o}C.
3. Almandite (Garnet):– Fuses readily in the blow-pipe flames but will not fuse in a luminous flame but will not fuse in a luminous flames, M. P.1050^{0}C
4. Actinolite:- Edges are easily rounded in the blow pipe flame. M. P. 1200^{0}C.
5. Orthoclase :- Edges are fused with difficulty in the blow-pipe flame. 1300^{0}c
6. Bronzite (enstatite):- Only very thin edges can be rounded in the blow-pipe flame. M.P. 1400^{0}C
7. Quartz – infusible in the blow-pipe flame.

Heat of Formation :- the heat liberation or absorbed when two elements or compounds to from a single substance is called the “Heat of Crystallization”

Heat of Inversion :- For many minerals there is a relatives small range of temp and pressure under which they may be considered stables. Changes in either factor may result in a change to other forms, accompanied by the liberation or absorption of heat. This heat is called the heat of inversion, its value is not known for many minerals.

Thermal conductivity:- thermal conductivity is the ability of a substance to transfer heat. The amount of heat in calories that passes through a substance 1.cm. square and 1. Cm. thick in one second is a measure of its thermal conductivity Experiments indicate that this property varies with the length of the crystallographic axes of minerals, being equal in all directions in isometric minerals, but having multiple values in crystals in the other systems.

Thermal Expansion :- Most minerals expand upon application of heat. The uniformity of this expansion varies for the same reason that thermal conductivity varies, as stated above. The value is commonly stated as the co-efficient of the amount of volume increase per unit volume when a rise in temp, from 0 to 1c occurs.

Specific heat :- The amount of heat, stated in calories, required to raise the temp; of 1 gram of mineral 1c is the specific heat of that material.

Magnetic properties:- only a few minerals are ferromagnetic ie., strongly attracted by a simple bar or horseshoe magnet. Of these the commonest are magnetite, pyrrhotite. Sometimes specimens of magnetite are themselves natural magnets and will attract iron fillings and when suspended will orient themselves with the long axis of the specimens are called "lodestone".

All minerals, however, are affected by a magnetic field. Minerals which are slightly repelled by a magnet are said to be "dia-magnetic". Those which are slightly attracted are said to be "paramagnetic". Ferromagnetic substance form a subgroup of paramagnetic substance.

i. Highly magnetic – magnetite, pyrrhotite.
ii. Moderately magnetic **:-** Siderite, iron-garnet, chromite, ilmenite, hematite, wolfram.
iii. Weakly magnetic **:-** Tourmaline, spinels, monazite.
iv. Non magnetic :- Quartz, calcite, feldspar, corundum, cassiterite.

When certain rocks crystallize the magnetic particles in them become oriented in the earth's magnetic field exiting at that time and place. The direction of this "fossil" magnetic field can be determined on samples of the rocks in the laboratory and this study is known as "palaeomagnetism".

Electrical Properties:- Minerals vary in their capacity for conducting electricity. With regard to electrical properties, minerals can be divided into two groups, the conductors and the non conductors. Electrical conductivity varies with crystallographic direction in anisotropic substances.

These electric properties are frequently classified as follows :

Frictional Electricity – The charges produced by friction. Eg. Polished gem stores, topaz, diamond.

Pyroelectricity - The charges acquired by some minerals as a result of temperature changes are termed pyroelectricity. Eg. Tourmaline, when heated becomes negatively charged at its sharp end and positively charged at the blunt end.

Piezoelectricity:- Electrical charges produced by pressure on a mineral are called piezo-electricity. Eg. Quartz.

Electrical conductivity and Thermoelectricity are the other two properties of minerals.

Radioactivity:-

Many minerals containing elements of high atomic weight are radioactive and emit emanation or radiations which affect a photographic plate. The chief radioactive elements are radium itself, uranium and thorium, but certain isotopes of potassium and rubidium are much greater important in geology.

Uranium and thorium atoms disintegrate spontaneously at a constant rate unaffected by the temperature, the pressure, or the nature of the compound in which they occur. Disintegration is accompanied by three types of radiation; alpha radiations, which consists of positively charged helium nuclei (alpha-particles); Beta radiation, which consist of negatively charged electrons and gamma radiation, which is a form of X-rays. Radio-activity can readily be detected by the radiation produced either by its effect on photographic film or by means of a Geiger counter or Scintillometer.

The ultimate product of the disintegration of Uranium and Thorium is lead, as indicated below:-

$U^{238} \rightarrow Pb^{206} + 8He^{4}$

$U^{235} \rightarrow Pb^{207} + 7He^{4}$

$Th^{232} \rightarrow Pb^{208} + 6He^{4}$

$K^{40} \rightarrow$ (Argon) A^{40}

$Rb^{87} \rightarrow Sr^{87}$

For each isotope the decay takes place at a determined and constant rate since it is a nuclear process, when the radioactive mineral is formed, the radiometric clock is started.

Modes of Minerals Formation

It is estimated that 95% of the earth's crust is composed of igneous rocks. The great majority of the minerals in the earth's crusted therefore will have been formed by crystallization from melts. Three-fourth of the igneous material, however, is blanketed by a thin covering of sediments and matasediments. The minerals in such rocks are more in evidence and thus become equally important. Modes of formation of ore minerals are also important because of the economic value.

One basic principle that holds for all modes of mineral formation is the fact that "At the time of its formation a mineral is in equilibrium with its environment".

CHIEF MODES :-

(i) From Fusion :- The greater part of the minerals that form the crust of the earth have been formed by solidification from fused rock material. That is, they are o were originally, constituents of igneous rocks.

(ii) From Solutions :- Many minerals have been formed by crystallization from a solution. This obviously of the group of saline minerals, and vein minerals.

(iii) From a Vapour :- Minerals may be formed by a direct crystallization from a gas. Such minerals are most commonly found to connection with volcanic fumeroles, and pneumatolysis.

It should be emphasized that the boundary lines between the three modes of formation are very indefinite.

Formation of Minerals from Fusion :- An igneous rock has its origin in a fused mass of rock constituents known as a magma. An igneous magma may be considered as a heavy complex solution in which the various elements present are more or less free to circulate and under the proper conditions to unite to form mineral molecules. The composition of the magma will determine in large part the character of the minerals that compose the resulting rock. The elements O, Si, Al, Fe, Mg, Ca, Na, & K occur in varying proportions in igneous magmas but the constituent minerals of igneous rocks are composed essentially of them. The conditions under which the various minerals are formed are complex. They crystallize out from the cooling magma in general in the order of their solubilities. Although this order is a fairly definite one, the variation of the chemical comp. of the magma will vary the order of their crystallization. The fluidity of the magma and the temp. at which various minerals will crystallize are influenced greatly by the common presence in a magma of small amounts of substance that are known as “Mineralizers”. These are usually water vapour, co2, Fluorine, boric acid, S, & Cl. To some extent, these enter into the composition of various rock-making mineral, but the role they play in the formation of igneous rocks is more a physical one.

Formation of Minerals from Solution :-

1. By the Evaporation of Saline Waters-Ocean waters and the waters of salt lakes contain various salts in solution; when such waters become concentrated through evaporation, certain minerals are deposited. The normal order of crystallization is : Carbonates of lime and magnesia, calcium sulphate, sodium chloride, magnesium chloride and sulphate, potassium chloride, etc. The factor of concentration, temp, and proportions of the character of the minerals formed, their relative amounts, the order of the deposition etc.
2. By Precipitation from Ground water- the underground water slowly circulates through the rocks by means of the openings. Through a large part of its circulation, the water must exist at a high temp. and Pr. And under these circumstance it becomes a strong solvent and active chemical agent. On its passage through the rocks, if will have dissolved their more soluble constituents and will carry considerable amounts of dissolved mineral material. Under the changing conditions the water will not be able to retain all its mineral constituents in solution, and various minerals, their points of saturation being reached, will begin to crystallize out and be deposited on the walls of the fissure. Such a filled fissure is known as “**Mineral vein**”.

Formation of Minerals from Vapours :-

The direct formation of minerals from vapours is confined to such volcanic regions where mineral gases are discharged from fumeroles. Such deposits are rare and usually of small extent. Minerals deposited in this way include S, Tellurium, Arsenic sulphides, Boric acid, various chlorides etc. Vapours play a much more important role in the formation of the so – called pneumatolytic minerals.

Important modes of mineral formation are :

1. Crystallization from a melt
2. Sublimation
3. Preparation from solutions
    - Hydro thermal
    - Evoporites
    - Underground water
4. Metamorphic processes
5. Metasomatic processes
6. Weathering processes

Occurrence and association of minerals

The mineralogy of the different associations is summarized in the following tabulation.

The Magmatic Environment :-

1. **Igneous Rocks :**
    a) Silicates : Quartz, felspars, felspathoids, olivine, enstatite – hypersthenes, augite, aegirine, horn – blende, biotite, muscovite, zircon, Sphene.
    b) Phosphates : apatite, monazite.
    c) Oxides : magnetite, ilmenite, chromite.
    d) Sulphides : Pyrite, Pyrrhotite.
    e) Elements : platinum group, diamond (in ultra basic rocks)
2. **Pegmatites**
    a) Silicates : Quartz, felspars, felspathoids, olivine, enstatite – hypersthenes, augite, aegirine, horn – blende, biotite, muscovite, phlogopite, tourmaline, spodumene, lepidolite, zircon, thorite, spessartine, beryl, topaz, seapolite.
    b) Phosphates : Apatite, monazite.
    c) Oxides : Magnetite, ilmenite, hematite, cassiterite, uraninite, columbite, corundum.
    d) Halides : fluorite, cryolite.
    e) Sulphides : Arsenopyrite, stibnite, bismuthinite, molybdenite.
    f) Elements : Antimony; bismuth.
3. **Hydrothermal Deposits :**
    a) Silicates : Quartz, feldspar, muscovite, chlorite, epidote, hornblende, tourmaline, zeolites, topaz, apophyllite, rhodonite, axinite.
    b) Sulphates : barite.
    c) Carbonates : Calcite, dolomite, magnesite, rhodochrosite.
    d) Oxides : Cassiterite, magnetite, hematite, ilmenite, rutile, anatase, brookite.
    e) Halides : fluorite.
    f) Sulphides : Chalcopyrite, bornite, chalcocite, sphalerite, galena, pyrite, marcasite, stibnite, cinnabar.

   g) Elements : gold, silver, arsenic, antimony, bismuth.

3. **A Secondary Alteration Products of Ore Minerals :**
   a) Silicates : Chrysocolla, hemimorphite.
   b) Sulphates, etc : Anglesite, walfenite.
   c) Phosphates, Vanadates : Carnotite, Vanadinite, Pyromorphite.
   d) Carbonates : Malachite, azurite, cerussite.
   e) Oxides : Cuprite, hematite, goethite.
   f) Elements : Silver, Copper

4. **Fumarolic and Hot Springs Deposits :**
   a) Silicates : Quartz, (Chalcedony), opal, zeolites.
   b) Sulphates : gypsum, alunite, etc.
   c) Oxides : Hematite, magnetite.
   d) Halides : Halite, etc.
   e) Sulphides – pyrite, cinnabar, stibnite,
   f) Elemenes : Sulphur

The Sedimentary Environment :

5. **Resistates :**
   a) Silicates : Quartz, feldspars, muscovite, biotite garnet, tourmaline, zircon, topaz, kyanite, andalusite.
   b) Phosphates : monazite.
   c) Oxides : magnetite, ilmenite, corundum, casstiterite, rutile, spinel, chromite.
   d) Elements : gold, platinum, diamond.

6. **Hydrolysates :**
   a) Silicates : Quartz (Chalcedony), opal, clay - minerals, glauconite.
   b) Oxides : bauxite.

7. **Oxidates :**
   a) Oxides : Limonite, hematite, pyrolusite, psilomelane.

8. **Reduzates :**
   a) Carbonates : Siderite
   b) Sulphides : pyrite, marcasite
   c) Elements : Sulphur

9. **Precipitates :**
   a) Phosphates : Apatite (Phosphorite)
   b) Carbonates : Calcite, aragonite, dolomite.

10. Evoporites :

- a) Sulphates : gypsum, anhydrite.
- b) Carbonates : Calcite, aragonite, dolomite, sodium carbonates.
- c) Borates : Borax.
- d) Nitrates : Soda-nitre.
- e) Halides : Halite, carnallite, etc.

The Metamorphic Environment :

11. Low Grade :

- a) Silicates : Quartz, albite, talc, serpentine, chlorite, tremolite-actinolite, epidote, muscovite, sphene, tourmaline, pyrophyllite, spessartine.
- b) Carbonates : Calcite, dolomite, magnesite, siderite.
- c) Oxides : Rutile, anatase, brookite, Magnetite, hematite, brucite.
- d) Sulphides : pyrite, pyrrhotite
- e) Elements : Graphite.

12. Medium Grade :

- a) Silicates : Quartz, plagioclase, microcline, orthoclase, kyanite, andalusite, staurolite, serpentine, garnet, hornblende, epidote, muscovite, biotite, tourmaline, scapolite, idocrase.
- b) Carbonates : calcite, dolomite.
- e) Oxides : Rutile, magnetite, hematite, ilmenite, corundum, spinel.
- d) Sulphides : Pyrite, pyrrhotite.
- e) Elements : Graphite.

13. High Grade :

- a) Silicates : Quartz, plagioclase, orthoclase, microcline, andalusite, sillimanite, forsterite, pyroxenes, cordierite, garnet, wollastonite, hornblende, tourmaline, sphene.
- b) Carbonates : Calcite.
- c) Oxides : Magnetite, hematite, ilmenite, corundum, spinel, rutile.
- d) Sulphides : Pyrite, pyrrhotite.
- e) Elements : Graphite.

Meteorites :

14. Iron Meteorites :

- a) Elements : Nickel-iron, graphite, diamond.
- b) Sulphides : Troilite, cohenite.

15. Stony Meteorites :

a) Silicates : Olivine, enstatite, hypersthenes, diopside, plagioclase.

b) Sulphides : Troilite

c) Elements : Nickle-iron, graphite.

Occurrence in Rocks : Although many minerals are found as rock constituents, those which can be termed common and characteristic rockmaking minerals are comparatively few in number. In addition to the more imp. and common rock-making minerals there is a group of minerals which are characteristically found as rock constituents but in a minor way. These minerals are known as “accessory rock-making minerals”. Igneous, Sedimentary & Metamorphic rocks.

The common contact **Metamorphic** minerals found in limestone are as follows : Graphite, spinel, corundum, tremolite, pyroxene & lime garnets.

The most common of the **Pneumatolytic contact** minerals are vesuvianite, scapolite, phlogopite, tourmaline, Topaz and fluorite.

The very common vein minerals are : Pyrite, chalcopyrite, galena, sphalerite, chalcocite, marcasite, arsenopyrite, stibnite, etc.

THE GENESIS OF MINERALS

A mineral is the final product of a complex of natural processes, and its characteristics, its geological environment, and its associated minerals are all clues that when properly evaluated elucidate the conditions under which it formed and its subsequent history.

Chemical composition of the Earth’s crust :

The mineralogy of the earth’s crust is ultimately controlled by the abundance and distribution of the chemical elements.

It is found by analysis that only & elements O, Si, Al, Fe, Ca, Na, K, Mg -- are present in amounts greater than 1% and these eight make up nearly 99% of the eart’s crust. Of the major elements, Oxygenis absolutely predominant, making up about half the crust by wt. The crust as a whole is essentially a packing of oxygen anions, bonded by silicon and the ions of the common metals., O, Si, & Al, collectively make up 90% of the atoms in the earth’s crust. It is obvious then that the dominant minerals must be quartz and silicates and aluminosilicates of iron, Mg, Ca, Na and K.

The major Chemical elements in the earth’s crust :

	Wt. percent	Atom Percent	Volume Percent
O	46.40	62.19	94.04
Si	28.15	21.49	0.88
A1	8.23	6.54	0.48
Fe	5.63	2.16	0.49
Mg	2.33	2.05	0.33
Ca	4.15	2.22	1.18
Na	2.36	2.20	1.11

K	2.09	1.15	1.49

Geochemical classification of the Elements :

An element is often very specific in regard to the type of minerals it forms. Some elements such as gold and the platinum metals, nearly always occur in the native state. Others, such as copper, Zn and Pb, are found mainly as sulfides. Many elements, for example, the alkali and alkaline earth metals, generally occur as oxygen compounds, especially silicates or aluminosilicates, and are never found native or as sulphides. The inert gases, as the name implies, form no minerals at all. A useful geochemical and mineralogical classification of the eliments is into four groups : **Lithophile,** those occurring mainly in oxygen compounds ; **chalcophile,** those occurring mainly as sulphides; **Siderophile,** those occurring mainly as native elements, and **atomphile,** gaseous elements not readily forming compounds and therefore present mainly in the atmosphere. Some elements may appear in more than one group, since the type of compounds an element forms is dependent not only on the nature of the elements but also on the temperature, the pressure, and the other elements present when it formed. For instance, most of the iron in the crust is present as oxides or silicates, but under conditions of low oxygen and high sulphur, iron sulphides are formed, and under highly reducing conditions when little sulphur is present native iron may be produced. Such variations are indicated in the following table by enclosing the element in parentheses under the group of secondary affinity.

Table :

Geochemical classification of the Elements :-

Lithophile	**Chalcophile**	**Siderophile**	**Atmophile**
Li, Na, K, Rb, Cs,	Cu Ag, Zn, Cd, Hg	Pt, Ir, Os,	Inert
Be, Mg, Ca, Sr, Ba,	In, Ti, Pb, As, Sb,	Ru, Rh, Pd,	gases,
B, Al, Sc, Y,	Bi, S, Se, Te, Ni,	Au, (Fe)	N, (o)
Rare Earths	Co, (Fe), Mo, Re		
C, Si, Ti, Zr, Hf,	(Mn), (Ga) (Ge)		
Th; P, V, Nb, Ta, O	(Sn)		
Cr, W, U, H, F, Cl,			
Br, I, Fe, Mn, Ga, Ge,			
Sn, (Mo), (Cu), (Zn),			
(Pb), (Ti), (As), (Sb),			
(Bi), (S), (Se), (Te),			
(Ni), (Co)			

The geochemical character of an element is government largely by the electronic configuration of its atoms, which, in turn, controls, the type of compounds the elements forms. Hence geochemical character is closely related to position in the periodic table. Lithophile elements are those which ionize readily or form stable oxyanious (such as Co_3^{-2}, So_4^{-2} ,Po_4^{-3}), and in their compounds bonding is largely ionic in character; chalcophile elements ionize less readily, and thus tend to form covalent compounds with sulphur (and selenium and tellurium, when present) the siderophile elements are those for which metallic bonding is the normal condition and which do not readily form compounds with oxygen or sulpher. A knowledge of the geochemical character of an elements enables us to predict the type of minerals it is likely to form and the associations in which it is likely to occur.

Mineralogical Composition of the Earth's Crust :-

The number of minerals an element forms and the geological environment in which the minerals occur are largely controlled by the abundance of the element and its geochemical character. On first consideration it seems remarkable that the earth's crust, which is made up of more than 80 elements (excluding the short lived radio active ones)., contains only about 2,000 different compounds (i.e. Minerals) and most of these are quite rare. The total number of inorganic compounds is of course, far greater, but most of them are not found as minerals, less only very stable compounds can occur as minerals, less stable compounds either do not form in nature or soon decompose. Another limitation on the number of minerals is the geochemical association of certain elements. Thus there are no rubidium minerals, even though rubidium is a relative abundant element; geological processes fail for separate rubidium from the far more abundant potassium, and all the rubidium in the earth's crust is dispersed in potassium minerals. Similarly the 15 rare earth elements form very few minerals, indeed altogether they form fewer than does antimony, an element much lower in abundance than most of them. This is due largely to the very similar ionic radii of the rare earths and their uniformly lithophile character consequently their crystal chemistry is essentially that of a single element.

Thus the mineralogy of the crust is much simpler than we might expect from its elemental composition. The limitation in mineralogy variation are still more marked when we turn from the earth's crust as a whole to specific geological environments. In general, three major types of environment may be recognized; magmatic, sedimentary and metamorphic. Each of these can be divided into subsidiary environments, according to the variety of physical and chemical conditions. The mineralogy of each will depend upon the temperatures and pressures of crystallization and the variation in chemical composition of the materials. Thus all sedimentary environments are characterized by a moderate range of temperatures (generally between $0^{o}C$ and $30^{o}C$) and essentially constant (atomospheric) pressure, but the source materials may be igneous rocks, metamorphic rocks, pre-existing sedimentary rocks. Ore-bearing veins, or, in fact, any mineral of the crust. Magmatic environments are characterized by high to moderate temperatures, and a wide variation of pressure, but in general a much more limited variation in chemical composition. Metamorphic environments cover a wide range of temp. and pressure, and the materials may be pre-existing rocks of any kind. It is thus convenient to consider the origin and associations of minerals within the framework of these three major groupings.

Mineral Formation and The Phase Rule :

In discussing mineral formation we find that three factors control the minerals in a specific environment : the bulk composition, and the temperature and pressure at which crystallization takes place. This qualitative statement has a quantitative expression in a basic law of physical chemistry, known as the "Phase Rule", which states that : "In any system at equilibrium the number of phases (P) plus the number of degrees of freedom (F) is equal to the number of Components (C) plus two or $P+F=C+2$".

Component -- The composition of a material system (i.e. a limited amount of material, whether solid, liquid, or gas, or all three together) can be stated in terms of its components. The **components** of a system are the smallest number of independent chemical entities (elements or compounds) by which any composition in the system may be expressed.

Eg. Olivine-Components are $Mg_2 Si^o_2$ and $Fe_2 Si^o_4$.

This is now as a two component, or binary system. Dipending on the number of components, we speak of systems being unary, binary, ternary, quaternary, etc.

Phase : A phase is any portion of a system that is physically homogeneous within itself and is mechanically separable from the other portions. Any pure mineral is a single phase, any rock is a system in which the phases are the individual minerals. In any system the number of phases is related to the number of components by the "Phase Rule".

Degrees of Freedom (also known as Variance) :

This is the number of variables which must be fixed in order to define the condition of the system. The degrees of freedom in geological systems are bulk composition, temp and Pr.

Equilibrium : Equilibrium exists in any system when the phases exist together in a stable relationship indefinitely if the external conditions are maintained unchanged.

The formula $P+F=C+2$, may be written in the form of $P=C+2–F$

This emphasizes that the number of phases (i.e. minerals) increases with the number of components, in other words, the greater the chemical complexity of a rock the larger the number of minerals that may be found in it. In any system the maximum number of phases will occur when $F=0$, when $P=C+2$. In any geological environment the condition of absolutely fixed and const. temp. and Pr. is extremely improbable. Because these two degrees of freedom normally vary considerably, as during the crystallization of a magma or the metamorphism of a rock, we are usually dealing with bivarient systems, in which $F=2$. Substituting $F=2$ into the phase rule we obtain $P=C+2–2$ or $P=C$; This expression is known as the "mineralogical phase rule", and it can be stated thus : "In a system of n components at arbitrary pressure and temperature the maximum number of mutually stable minerals does not exceed n".

We may now consider a few examples :

The System with n=1 :- Any individual elementis a one-component system. Sulphur, for example, can exist in two distinct solid phases, orthorhombic and monoclinic each of these is stable over a particular range of temp. and pressure. At any fixed pressure the two phases can exist together in equilibrium only at a fixed temp.(at atm. Pr. this temp. is 95^{o}c). Any compound which does not decompose on melting can be considered a one component system. Thus Sio^2 is a one-component system for which a number of phases (i.e. polymorphs) are known. Each of these polymorphs is the stable form over a considerable range of temps. and prs. However, two polymorphs can coexist in equilibrium only under fixed conditions of temp. & pr., trydimite and quartz, for example, are in equilibrium at 1 atm. Pr. and 867°c. Hence we normally find only one form of SiO_2 in a particular rock.

The system with n=2 : The mineralogical phase rule predicts that in such a system the maximum number of minerals will be two. This is illustrated by this system Na Al SiO_4 – SiO_2, in which the following minerals are possible (omitting the high temp. polymorphs of SiO2) : nepheline, quartz albite (Na Al Si_2 O_8 = Na Al SiO_4+2 SiO_2), and Jadeite (Na Al Si_2O_6 = Na Al SiO_4 + SiO_2). In igneous rocks we find the associations.

Nepheline+albite

Albite+quartz

In metamorphic rocks we find the associations.

Albite+quartz Generally speaking, in any rock

Jadeite+quartz which has reached equilibrium

Jadeite+elbite we find only 2 of the 4 possible minerals in this system.

The system with n=3 : Such a system is MgO Al_2O_3 -SiO_2, in which some ultrabasic rocks and metamorphosed shales fall. There are no less than 14 minerals in this system. But in any rock we do not find associations of more than 3 of them together. Typical associations are … (Mg_2SiO_4) + Spinel (Mg Al_2O_4) + enstatite ($MgSiO_3$) in peridotites, or

Corundum (Al_2O_3) + spinel + cordierite ($Mg_2Al_4Si_3O_{18}$) in metromorphosed shales.

The mineralogical phase rule is thus a very significant principle in mineral formation, and it expresses the limited mineralogy of most common rocks. Considering an igneous rock, for example, which can be expressed in terms of the components O, Si, Al, Fe, Mg, Ca, Na & K (i.e. an eight component system). We might expect a maximum of 8 minerals. The actual number of minerals is usually less, because some of these components are not completely independent, being capable of replacing each other, atom for atom, in minerals-for instance, Ca and Na in plagioclase, Fe and Mg in the ferromagnesian minerals.

SILICATE STRUCTURES

The silicates include a large number of minerals. Many of these are quite rare, but others make up a large part of the earth's crust. The crust has been estimated to be about 95% silicate minerals, of which some 60% is feldspar and 12% quartz. The predominance of silicates and aluminosilicates reflects the abundance of O, Si and Al, which are the commonest elements in the crust (O = 47%, Si = 28%, Al = 8%).

Prior to the elucidation of the crystal structure of the silicates their comp. was generally interpreted in terms of hypothetical silicic acids, all of which were derived from a theoretical orthosilicic acid H_4 SiO. Some of the hypothetical silicic acids are:

Orthosilicic acid : H_4Sio_4

Metasilicic acid : $H_2SiO_3 = (H_4SiO_4 - H_2O)$

Orthodisilicic acid : $H_6Si_2O_7$ = ($2H_4$ SiO_4-H_2O)

Metadisilicic acid : $H_2Si_2O_5$ = ($2H_4$ SiO_4-$3H_2O$)

Trisilicic acid : H_4 Si_3O_8 = ($3H_4SiO_4$-$4H_4O$)

In this way ratios of Silicon to Oxygen could be derived to fit any composition. The silicic acid theory had some success in the interpretation of the simpler compounds, such as orthosilicates, and metasilicates, but led to manifest absurdities when applied to more complex minerals. Thus the isomorphous compounds albite, and anorthite were placed in different groups. The silicic acid classification of the silicate minerals has now been superseded by one based on the crystal structures of these compounds.

The fundamental unit in the building of silicate minerals is the Sio_4 –tetrahedron in which the silicon atom (or cation) is situated at the centre of a tetrahedron whose corners are occupied by four oxygen atoms. The average distance between the centres of two adjacent oxygens is 2.7 A^o i.e. almost twice the radius of the oxygen. Classification of the silicates is based on the different ways in which the Sio_4 –tetrahedra occur, eitherseparately or linked together. They are as follow:

1. Independent Tetrahedral groups; Orthosilicates, Nesosilicates -- SiO_4:

(Island)

In this class the silicon-oxygen tetrahedra are present as separate entities. The resultant composition is Sio_4. Adjacent tetrahedra are united through cations which surround the oxygens. These cations are never part of the basic tetrahedron. The Si : O ratio normally is 1:4. When less than this, it indicates that some oxygen atoms not present in the tetrahedra are present elsewhere in the structure. An example of a mineral built up in this way is forsterite (Olivine), Mg_2 SiO_4.

Considering valencies of the SiO_4 –tetrahedron, we see that silicon has four positive, and each oxygen two negative valencies, i.e. there are 8 negative valencies in all; the group as a whole therefore had 4 negative valencies in excess. In the forsterite structure, cations (Mg) lie between the tetrahedral groups and contribute the necessary positive charges to make the structure electrically neutral. There are, in effect, 2 Mg ions to every SiO_4 –group, as in the formula Mg_2 SiO_4. The name “nesosilicate” is derived from the Greek for ‘island’ since the SiO_4 groups remain separate units in the structure.

2. Double Tetrahedra, pyrosilicates, Sorosilicates, Si_2 O_7:

(Group)

Two silicon-oxygen tetrahedra are linked by the sharing of one oxygen inert between them; the resulting composition is Si_2 O_7. These in turn are linked through other cations to form the expanded network. The charge on any Si_2 O_7 –group is –6 (=2 x 4 – 7 x 2), so that three divalent ions are needed to balance it. Eg. Melilite (in Slags) Ca_2 $MgSi_2O_7$, Hemimorphite, $Zn_4Si_2O_7(OH)_2H_2O$.

The name “Sorosilicate” is derived from Greek for “group”.

3. Ring structures, Metasilicates, Cyclosilicates, Sin O_{an}

(ring)

In this type two of the oxygens of each tetrahedron are shared with neighbouring tetrahedra, and the angular positions of the tetrahedra are such that closed units of a ring-like structure result. Theoretically, an indefinite number of closed rings are possible. Rings of 3, 4 & 6 tetrahedra are known. All known minerals in this class have either trigonal or hexagonal symmetry.

A ring of 3 tetrahedra has the comp. Si_6O_9 and

A ring of 6 trtrahedra has the comp. Si_6O_{18}.

both formulae being multiples of Si_3O_8

Eg. Benitoite – Ba Ti Si_3 O_9 – 3 member ring Tourmaline-

Axinite- $(Ca, Mn, Fe)_3$ Al_2 (BO_3) Si_4 O_{12} OH – 4 member ring. Beryl – $Be_3Al_2Si_6O_{18}$ – 6 member ring.

In Beryl the Si_6O_{18} – rings are stacked one above another in columns, which are linked laterally by the Be-ions (in 4 coordination) and the Al-ions (in 6 coordination).

4. Chain Structures, Metasilicates Inosilicates.

(Fibre)

Single – (Si_2O_6) SiO_3

double Si_4O_{11}

Tetrahedra are joined together to produce of indefinite extent. There are two principal modifications of this structure yielding somewhat different composition: (a) **Single Chain**- In which Si : O is 1 : 3, (joined to 2 oxygen atoms – open characterized by poroxenes; and

(b) **Double chain** : In which alternate tetrahedra in two parallel single chains are cross linked and Si : O ratio is 4:11, (alternately 2 & 3 oxygen atoms characterized by amphiboles.

These chains are indefinite in extent, are elongated usually in the C direction of the crystal, and are bonded to each other by the metallic elements.

Examples :

Single Chain : Eg. pyroxenes – The chains consist of a large number of linked Sio_4 –groups, each sharing two oxygens, and have the composition n (Si_2O_6). The apexes of the tetrahedra forming a chain all point in the same direction (eg. Diopside) Ca Mg (Si_2O_6); here the excess negative charge on the Si_2O_6 –chain is balanced by the valencies of the Ca and Mg cations. The chains run parallel to the C-axis of the mineral and are bonded together by the calcium and Magnesium ions which lie between them. Each Mg is coordinated by 6, and each Ca by 8 oxygens.

Double chain : When two single chains are placed side by side, with the apexes of Tetrahedra all pointing one way, and are linked by sharing oxygen atoms at regular intervals, a ‘double chain’ results; Si_4 O_{11}; Eg. **Amphibole – Tremolite** – Ca_2 Mg_5 $(Si_4 O_{11})_2$ $(OH)_2$. All the amphiboles contain hydroxyl (OH), as an essential constituent, to the extent of about one (OH) – radical to eleven oxygens.

In both pyroxenes and amphiboles extensive substitution of cations by others of similar size and charge takes place, giving rise to a great variety of compositions which can, however, be accounted for on the basis of the atomic structure.

5. Sheet Structures, Disilicates, Phyllosilicates, Si_4O_{11}:

(phylon-leaf)

Three oxygens of each tetrahedron are shared with adjacent tetrahedra to form extended flat sheets. This is the double chain inosilicate structure extended indefinitely in two directions instead of only one. This linkage gives an Si : O ratio is 2 : 5 (or 4 : 10) and is the fundamental unit in all mica and clay structures. The sheets from a hexagonal plenar network responsible for the principal characteristics of minerals of this type their pronounced pseudohexagonal habit and perfect basal cleavage parallel to the plane of the sheet.

Eg. pyropyllite – $Al_2\ Si_4\ O_{10}\ (OH)_2$

6. Three – dimensional networks, Silica Type

Frame- work Structures, Tectosilicates, SiO2

(Frame work)

Every SiO_4 Tetrahedron shares all its corners with other tetrahedra (every oxygen ion is shared between two tetrahedr), giving a three- dimensional network in which the Si:O ratio is 1 : 2. The various forms of Silica have this arrangement. In SiO_2 the positive and negative charges balance. In silicates of this type the silicon is partly replaced by Al, and the comp is (Si, Al) O_2. The Substitution of Al^3 for Si^4 requires additional positive ions in order to restore electrical naturality Eg. Nepheline Na (Al SiO_4). Felspars & zeolites are examples of this division.

Structural Classification of the Silicates :

Classification	Structural Arrangement	Si:O	Shared Corners	Repeat Unit	Example
Nesosilicate	Independent Tetrahedra	1:4	O	$SiO\ \frac{4}{4}$	Forsterite
Sorosilicats	Two tetrahedra sharing one oxygen	2:7 (1:3$\frac{1}{2}$)	1	$Si_2O\frac{6}{7}$	Hemimorphite
Cyclosilicates	Closed rings of tetrahedra each sharing two oxygens	1:3	2	$SiO\frac{2}{3}$ Si_6O_{18}	Beryl
Inosilitates	Continuous single chains of tetrahedra each sharing two oxygens	1:3	2	$SiO\frac{2}{3}$ (Si_2O_6)	Enstatite (Pyroxene)
	Continuous double chains of tetrahedra sharing alternately 2&3 Oxygens	1:2$\frac{3}{4}$ 4:11	2$\frac{1}{2}$	$Si_4O\frac{6}{11}$	Amphibole
Phyllosilicates	Continuous sheets of tetrahedra each sharing 3 oxygens	1:2$\frac{1}{2}$ 2:5	3	$Si_2O\frac{2}{5}$ (Si_4O_{10})	Mica

Tektosilicates	Continuous framework of tetrahedra each sharing all 4 oxygens	1:2	4	SiO_2	Quartz

Corresponding to different linkages of the tetrahedra are different compositions, habits, and physical properties in the various types of silicates. The bondage within Si-O framework is much stronger than the bonding between metal cations and the framework. Cleavage planes are parallel to Si-O chains.

Eg.	Sheet structure –	Platy form – micas	
	Chain structure	Prismatic or	Pyroxenes &
		Fibrous	Amphiboles
	3-D – network	equidimensional Crystals	

Nesosilicates : Olivine, Garnet, Sphene Topaz

Aluminium silicates, staurolite (Andalusite etc.)

Sorosilicates : Epidote, Idocrase

Cyclosilicates : Tourmaline, cordierite, Axinite, Beryl.

Inosilicates : Pyroxenes, Amphiboles.

Phyllosilicates : Mica, Hydrous Magnesium silicates

(Talc, Serphentine, etc.)

Hydrous Aluminium silicates (clay)

Tectosilicates : Felspar, Felspathoid, Quartz, Zeolite.

DESCRIPTION OF MINERALS

Minerals may be classified in several ways, nearly all dependent either upon their chemical components or the structure or forms of their crystals.

FORMS OF SILICA

The forms of silica, including hydrated forms, can be grouped as below.

Crystalline: Quartz, Tridymite, cristobalite cryptocrystalline: chalcedony, Jasper, Flint, etc. cryptocrystalline hydrous : Opal, chalcedony (some), sinter, Diatomite etc;

Quartz

Comp: SiO_2; cryst. Syst. – Hexagonal-Trigonal;

Form-crystals usually hexagonal prisms, massive, granular

Colour-colourless, when pure; Lusst-vitreous;

Fract-conchoidal; cleavage-none; H-7; Sp.gr-2.65

Opt. properties:- colourless; no cleavage, relief low

Brief-weak; pol. Colours-First order grey or yellow.

Transverse sections-isotropic; elongation is positive.

Varieties:- Rock crystal-purest and most transparent;

Amethyst-purple or violet coloured transparent; Rose quartz-pale pink or rose coloured; smoky quartz-smoky-yellow or smoky-brown; Morion-black; Milky quartz-milk white; cat's eye-minutely fibrous structure, exhibit play of colours;

Occurrence:- Quartz occurs as an original constituent of the more acid igneous rocks, sandstones, quartzites, many metamorphic rocks; veins and geodes.

Uses:- Building trade, sands are employed in moulding, glass making etc, Abrasive material; in the manufacture of pottery; to control the frequency of radio circuits (piezoelectricity)

Tridymite:-

Comp: SiO_2

Cryst. Syst.: Orthorhombic inverting; to thexagonal; com Form; Minute, six-sided plates. Colour: colourless to white Sp. Gr. 2.28 – 2.33. R.I – 1.47.

Occurrence: Tridymite is the stable form of silica at temps. between 870^o and 1470 ^{o} C at atmospheric pressure; it occurs in acid volcanic rocks.

Cristobalite:-

Comp: SiO_2: cryst. syst: cubic: R1= 1.48 Occurrence: occurs as minute cubes or octahedral in certain laves.

Cryptocrystalline Silica : Chalcedonic

Silica : Chelcedonic Silica :

Comp : A mixture of crystalline silica and hydrated silica,

i.e. of quartz (SiO_2) and opal (SiO_2. nH_2O)

Com. Form : cryptocrystalline structure and fibrous

Colour : varied; white, grey, etc; Lustre: Rather waxy.

Opt. prop:- Colourless: fibrous kinds show black crossed nicols, fibres showing negative elongation.

Varieties : 1) Chalcedony includes a number of subvarieties based mainly on colour; the chief are : Carnelian-reddish; Sard-brownish.

Blood stone bright green (plasma) with red, Agate- a variegated chalcedony, composed of different coloured bonds.

Moss Agate or Mocha stone – a chalcedony containing small dendrites

Onyx and sardonyx – flat – bandes varieties of chalcedony.

2) Flint : is compact cryptocrystalline silica of a black colour, or shades of grey and occurs in bands.

Hornstone and chert are grey to black opaque forms of Cryptocrystalline silica, resembling flint.

3) Jasper : Is an impure opaque form of cryptocrystalline silica, usually of red, brown, and yellow colours, rarely green. It is opaque. Egyptian or Ribbon Jasper-merely clay or shale.

HYDROUS SILICA, OPAL

Opal :

Comp : Hydrous silica $Si\,O_2\ n\ H_2O$

Form : Compact, reniform, colour white, grey, yellow;

Lustre : Subvitreous; Fract; conchoidal; H: 5. 5-6.5; Sp. Gr. 2.2.

Opt. Prop : Isotropic; Colourless; Low R. 1.

Varieties : Precious opal-gem variety; hydrophane;

Hyalite; Wood Opal; Siliceous Sinter; Float sone;

Diatomaceous Earth; etc.

Occurrence : Opal itself is most likely a dried-up gel and owes its distinctive properties to its structure.

THE FELDSPAR FAMILY

The Feldspars are the most important group of the rock-forming minerals. They are dominant components of most igneous rocks, and they are employed in the classification of such rocks. They are aluminous silicates of potassium, Sodium, Calcium or barium, and may be considered as isomorphous compounds of the following substances.

Orthoclass (Or) Potassium Aluminium Silicate ($KAl\,Si_3O_8$)

Albite (Ab) – Sodium Aluminium silicate Na ($Al\,Si_3\,O_8$)

Anorthite (An) – Calcium Aluninium silicate Ca ($Al_2Si_2O_8$)

Celsian (Ce) – Barium Aluminium silicate Ba ($Al_2Si_2O_8$)

Replacement of part of the silicon by aluminium occurs in all the feldspars, and the alkali metal ions are held in spaces in the frameworks. Isomorphous substitution of one kind of alkali metal for another gives rise to the varieties of feldspar. Thus, when Na replaces some of the K in orthoclase, the variety "Soda-orthoclase" is formed; replacement of some K by Ba gives "hyalophane", intermediate between orthoclase and celsian. The "Plagioclase series consists of solid solutions of albite and anorthite in all proportions.

POTASH-FELDSPARS	**BARIUM-FELDSPARS**
Orthoclase	Hyalophane-Celsian
Microcline	

Soda orthoclase

Soda Microcline or Anorthoclase

Albite-Oligoclase-Andesine-Labradorite-Bytwenite- Anorthite

Soda Feldspar Lime-Feldspar

THE PLAGIOCLASE FELDSPARS

General Characters : Colour : Whitish, grayish; H:6; Sp. Gr: 2.5 to 3; cryst; orthoclase, hyalophame, celsian and Soda orthoclase crystallize in Monoclinic system; Microcline, soda microcline and plagioclase in Triclinic. Cleavage : Two principal cleavages, Monoclinic Parallel to basal pinacoid and clinopinacoid, Triclinic-parallel to basal pinacoid and side pinacold; twinning simple in orthoclase, repeated in plagioclase; occurrence; Igneous rocks.

Celsian : $BaAl_2Si_2O_8$

Cryst syst : Monoclinic; Form : Crystals, massive;

Col : Colourless; H: 6-6-5; sp. Gr : 3.37;

Occ : Celsian is not a common feldspar; it occurs in dolomitic limestone.

Hyalophane : Silicate of Al, Ba and K

Intermediate between $KAlSi_3O_8$ and $BaAl_2Si_2O_8$

with K in excess of Ba.

Hyalophane is a rare mineral.

Orthoclase : $KAlSi_3O_8$

Cryst, syst : Monoclinic; form: crystals, also massive, Twinning : common on three laws 1) Carlsbad law (010), 2) Baveno law (021), 3) Manebach law (001) cleavage : perfect; colour : white, red, greenish grey; lustre : vitrecus to pearly; Fract : conchoidal to uneven; H:6; Sp gr : 2.57. Opt. Pro : R.1, lower than balsam; birefringence : low; polarization colours : first order greys; twinning : carlsbad common.

Varieties:- Adularia, Moonstone, Sanidine, Sunstone.

Occurrence – More acid igneous rocks, pegmatites, metamorphic rocks, sandstones.

Uses : The alkali-feldspars are used in the manufacture of porcelain and pottery for the production of glazes on earthenware, sanitary ware and enameled brick, in the manufacture of opalescent glass, abrasive etc.

Microcline:- $K\ Al\ Si_3\ O_8$

Cryst. syst : Triclinic; form: Crystals massive;

Twinning : Simple and repeated –albite law; peric line law;

Cleavage: perfect; colour; grayish white; pinkish; bright green as in Amazonstone; Lustre : vitreous; H.6 – 6.5; sp. Gr: 2.56.

Opt. prop: Between crossed nicols shows the characteristic “cross-hatched” appearance due to repeated wedge shaped twinning on the albite and periclinic laws; optically negative.

Occurrence: In Acid igneous rocks; sandstones etc.

Soda – Orthociase : Soda – orthoclase is a link between orthoclase and albite, consisting of orthoclase in which part of k is substituted by Na, its comp. expressed as (K, Na) $AlSi_3O_8$; it is like orthoclase in general properties.

Anorthoclase or **Soda-Microcline**:- comp: (Na, K) $AlSi_3O_8$

Cryst syst: triclinic; form crystals; granular.

Perthite: perthite consists of laminar intergrowths of albite or oligoclase in orthoclase, Perthite intergrowths most likely result from the un-mixing at lower temps. of potash feldspars with a small proportion of soda-feldspars which together formed homogeneous crystals at higher temps.

Plagioclase Feldsapars

The plagioclases or soda-lime feldspars, form a solid-solution series between albite; Na $Al_2Si_3O_8$ and anorthite, $CaAl_2Si_2O_8$. The limits of the various members of the plagioclase series may be defined as below:

Albite, Ab_{100} An_0 to Ab_{90} An_{10} i.e. with less than 10% An.

Oligoclase, Ab_{90} An_{10} to Ab_{70} An_{30} i.e. with 10-30% An.

Andesine, Ab_{70} An_{30} to Ab_{50} An_{50} i.e. with 30-50% An.

Labradiorite, Ab_{50} An_{50} to Ab_{30} An_{70} i.e. with 50-70% An.

Bytownite, Ab_{30} An_{70} to Ab_{10} An_{90} i.e. with 70-90% An.

Anorthite, Ab_{10} Ang_{90} to Ab An_{100} i.e. with more than 90% An.

The plagioclase show a continuous gradation in their physical properties-sp. gr; crystal form; R.1; etc; from albite to anorthite.

Sp.gr. Albite 2.605, Anorthite-2.765

Cryst. Syst : Triclinic, cleavage: Two sets perfect; Twinning: simple as in orthoclase, repeated on Albite and pericline laws; The R.1, increases from albite to anorthite.

The optical orientation of the plagioclase changes with the composition. The optic sign of the plagioclase also depends on their composition.

Distinction Between Quartz and Feldspar :

	Quartz	**Feldspar**
From :	Pyramidal or Prismatic crystals	Tabular crystals
Lustre :	Vitreous	Pearly on cleavage planes
Cleavage :	None	perfect, two sets
Striations :	When present	Only in plagioclase

perpendicular to the length of the crystal	but along the length

Feldspathoid Family

In the Feldspathoid Family is grouped a number of minerals which in certain respects show similarities with the feldspars, especially in their types of chemical comp. The members of the Feldspathoid Family are :

Leucite – K (Al Si_2 O_8)

Nepheline – K ($AlSiO_4$) natural, Artificial Na ($AlSiO_4$)

Cancrinite – 4 (Na Al Si O_4) Ca Co_3 H_2 O

Sodalite – 3 (Na Al SiO_4) Nacl

Hauyne – 3 (Na Al SiO_4) Ca SO_4

Nosean – 3 (Na Al Si O_4) Na_2 SO_4

Lazurite – 3 (Na Al Si O_4) Na_2 S

It will be noticed that leucite differs in composition from orthoclase K Al Si_3 O_8 in having a lower ratio of silica to alumina.

Leucite : K Al Si_2 O_6

Cryst. syst: cubic; from : Crystals; cleavage : imperfect:

Colour; white or ashy grey; streak: colourless;

Lustre : Vitreous; Fract : conchoidal; H.5.5-6; Sp.gr. 2.5;

Opt. prop : rounded crystals: R.1.-low; very low poralization colours;

Occurrence : Volcanic rocks, rocks rich in potash.

Uses : For the production of potash-fertilizer and of Aluminium-Italy.

Nepheline : (Nephelite, Eleolite) :-

Comp : Artificial nepheline is Sodium aluminium silicate, in natural nepheline potassium is always present.

Cryst. syst : Hexagonal, Form : Crystals, massive,

Cleavage : Distinct prismatic; imperfect basal;

Colour : colourless, white, yellowish, etc; Lust : vitreous;

Fract : Subconchoidal; H:5.5-6; Sp.gr. 2.5 – 2.6

Opt. prop : Biref : weak;

Occurrence : volcanic rocks; rocks low in silica and rich in soda; also plutonic igneous rocks.

Cancrinite : Cryst. syst. Hexaonal; form ; massive ; cleavage : perfect; colour : commonly yellow : H 5-6; Sp.gr 2.4 – 2.5.

Sodalite : 3 (Na Al Si O_4) Na Cl

Cryst. Syst : Cubic; Form : massive, dodecahedral crystals; cleavage : distinct; colour : Grey, bluish;

Streak : colourless; lust : vitreous; fract : conchoidal; H.5 -6; Sp.gr. 2.2.

Opt. prop : colourless; R.1. –low; Isotropic.

Occurrence : occurs in soda –rich igneous rocks low in silica.

Hauyne : cryst. syst : cubic; form : crystals; cleavage : dodecahedral fairly good; colour : Bright blue or greenish blue; Streak : colourless; H.5. 5-6. Sp.gr : 2.4-2.5

Opt. Prop : R. 1 low characterized by an abundance of mnute dark inclusions, often arranged in a black border.

Nosean : Like hauyne, cubic, grayish, etc.

Occurrence : Volcanic igneous rocks, low in silica and rick alkalies.

Lazurite, Lapis Lazuli : Cryst : cubic, form : crystals massive and compact; cleav : Imperfect; colour : Berlin blue or azure blue; Lust : vitreous; fract; uneven; H:5.5; Sp.gr. 2.38-2.45. Occurrence : In crystalline limestones of contact metamorphic origin.

Uses : ornamental purposes, blue paints, etc.

Distinction between feldspars and feldspathoid :

	Feldspars	**Feldspathoids**
Cryst syst	Monoclinic & Triclinic	Cubic & Hexagonal
Form	Tabular crystals	Massive
Lustre	Vitreous to pearly	Vitreous to greasy
Colour	Buff	Brown; green, blue
Cleavage	Perfect-2 sets	imperfect

PYROXENE FAMILY

Inosilicates – Si_2O_6 chain structure. In chemical composition the pyroxenes are silicates of iron, magnesium and calcium, sometimes with aluminium; some varieties contain sodium or lithium. Thus, several of the pyroxenes have a silicate comp. of R_2 (Si_2O_6), where R is Mg, Fe, or Ca, or more rarely Mn or Zn; in the other pyroxenes there is a substitution of A1 for part of the silicon, giving a formula of the type R [Si $Al]_2O_6$ where R is Ca, Mg Fe^2, Al or Fe^3. The alkali pyroxenes have a comp. represented by R^1 R^3 [Si_2 O_6] where R^1 is Na or Li and R^3 Fe or Al.

The pyroxenes crystallize in the orthorhombic, Monoclinic and triclinic crystal systems; most of the pyroxenes are characterized by a good prismatic cleavage. The orthorhombic and monoclinic members have closely similar atomic structures.

I. Orthorhombic Pyroxenes :
   Enstatite Mg Si O_3 (Mg_2 Si_2 O_6)
   Hypersthene (Mg Fe^2) SiO_3

II. Monoclinic Pyroxenes

a) Diopside-Hedenbergite series
   Diopside $CaMgSi_2O_6$
   Hedenbergite- Ca Fe^2 Si_2 O_6
b) Pigeonite (Ca, Mg) (Mg, Fe) Si_2O_6
c) Augite series (Aluminous)
   Augite $(Ca, Mg, Fe, Al)_2$ $(AlSi)_2O_6$
d) Alkali Pyroxene Series
   Acmite, Aegirite Na Fe^3 Si_2O_6
   Aegirite-Augite,
   Jadeite, Na Al Si_2 O_6
   Spodumene, Li Al Si_2 O_6

III. Triclinic Pyroxenes.

Rhodonite, $Mn_2Si_2O_6$ (Mn_2SiO_3)

Enstatite :- Mg SiO_3, with upto 15% iron silicate $FeSiO_3$, giving general comp. (Mg, Fe) SiO_3 cryst.

Syst :- Orthorhombic; Form: prismatic crystals, massive; cleav: well developed: two sets; colour: grey, green, brown, yellow, etc; Lust: vitreous, pearly: H: 5.5; sp.gr. :- 3.1-3.3.

Opt. prop:- colourless to pale-greenish; Two sets of cleavage.

Brief: low, Extinction-parallel, biaxial, optically positive variety:- Bronzite-iron bearing variety of enstatite.

Occurrence:- Intermediate and basic igneous rocks, peridotites, Serpentines.

Hypersthene:- (Mg,Fe) SiO_3, with more than 15% $FeSiO_3$ cryst syst: orthorhombic; form; crystals rare, prismatic, foliaceous or massive; cleav: prismatic, good, three sets; Col: Brownish-green, grayish black; Lust: Sub-metallic; Schillerization is very characteristic of hypersthenes. Fract. Uneven, H: 5-6, Sp.Gr: 3.4-3.5.

Opt prop :- Often well-marked pleochroism, polarization-First Order colours; biaxial; optically negative.

Occurrence : Basic igneous rocks, Charnockites, schists, Contact-metamorphosed argillaceous rocks.

Diopside :- CaMg (Si_2O_6)

Cryst. syst; Monoclinic; Form: prismatic crystals, granular: Cleav: good, col: white, green, colourless.

Lust: Vitreous; H: 5-6, Sp. Gr: 3.2-3.38.

Opt. prop:- colourless, Cleav-Two sets, R1-high; polarization colours of second and Third Orders; biaxial, optically positive.

Occurrence : Various igneous rocks, metamorphosed rocks.

Hedenbergite:- Ca Fe (Si_2O_6)

Cryst. syst: monoclinic, Form: crystals, masses,

Col: Black. H: 6 Sp.Gr: 3.7

Pigeonite :- It is intermediate in comp. between diopside hedenbergite and Clinoenstatite and rare in nature.

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

Cryst.syst: Monoclinic Form: Crystals, Twinning: Often twinned on the orthopinacoid; Cleav: Good, prismatic two sets; Col: Black, greenishblack, Lust: Vitreous; H: 5-6, Sp.Gr: 3.2-3.5.

Opt. prop:- Colourless to yellowish-brown; Feebly pleochroic: R.1 much higher; polarization colours are bright of second and Third Orders; biaxial, optically positive.

Variety: Diallage is a variety of diopside or augite.

Occurrence: Many volcanic rocks, plutonic rocks of basic composition, ultrabasic rocks such as pyroxenites and peridotites.

Acmite, Aegirine, Aegirite:-

Comp:- NaFe (Si_2O_6) usually with small amounts of Ca, Mg, and Al.

Cryst. syst :- Monoclinic; Form: prismatic crystals;

Cleav :- distinct-prismatic; Col: brown, green;

Lust :- Vitreous; H:6-6.5; Sp.Gr: 3.5-3.55.

Opt. prop :- Brief-strong: Acmite is markedly pleochroic.

Occurrence: soda-rich igneous rocks-

Aegirine-augite, Aegirite-Augite :- A series transitional between augite and aegirine, with intermediate characters.

Jadeite :- Na Al (Si_2O_6)

Cryst. syst: Monoclinic; Form; Massive, cleav: prismatic; two sets; Col: shades of green; Lust: subvitreous: H: 6.5-7, Sp.Gr: 3.3-3.35.

Use: As an ornamental stone.

Rhodonite:- Manganese spar :- $MnSiO_3$

Cryst.syste: Triclinic: Form: Crystals, massive; Cleav: perfect; Col: Flesh-red; Lust: vitreous, Fract, Uneven; H: 5.5-6.5; Sp.Gr. 3.4-3.6.

Occurrence : As a veinstone in lead and silver veins.

Uses: Ornamental work; for imparting violet colour to glass.

PYROXENOID FAMILY

Wollastonite, Tabular Spar :- Ca SiO3

Chain-structure with chains elongated along the b-axis and different in detail from the pyroxene-chains cryst syst: Commoner-Triclinic, rarer-monoclinic; Form: Tabular crystals; Cleav: perfect; Col: white-grey; Lust Vitreous, H: 4.5-5; Sp.Gr: 2.8-2.9.

Opt. prop :- Colourless, R1-moderately high; polarization colours of First and Low second Order; Optically negative

Occurrence: As a product of contact-metamorphism of impure limestones.

Pectolite :- Ca_2 Na H $SiO_3)_3$

Cryst : Monoclinic; Form: Masses, Col: white or greysh;

Lust : Silky, dull; H:5, Sp.Gr: 2.7-2.9.

Amphibole Family

Si_4O_{11} double chain type of structure.

In chemical composition they are analogous with the pyroxenes and are silicates of Mg, Fe, Ca sometimes Na, with or without Al. Their comp. is variable but can be represented by a formula of the type $X_{7\text{-}8}$ $(Si_4\ O_{11})_2$. (OH) $_2$, where x includes mainly Ca, Na, Mg, Fe, Al and Fe^3 with traces of other elements (eg Mn). Some part of the Si may be replaced by Al. Hydroxyl (OH) is always present, to the extent of about one (OH)-group to every eleven oxygens.

The amphiboles crystallize in the orthorhombic, monoclinic and triclinic crystal systems; there is a good cleavage.

The elementary distinctions between the pyroxenes and amphiboles are given below:-

Amphiboles	**Pyroxenes**
Bladed forms common	Bladed forms uncommon
Prism angle 12_3	Prism angle 87°
Commonly Pleochroic	Commonly non-pleochroic
Common crystals terminated by 3 faces	Common crystals terminated by 2 faces
Twins with no re-entrant angle	Twins with no re-entrant angle
Orthopinacoid not present	Orthopinacoid present
Transverse sections,	Transverse sections
6-sided	8-sided
Extinction angle about 16°	Extinction angle about 48°
(on clinopinacoid)	

The amphiboles may be divided as follows:

I. Orthorhombic amphiboles

Anthophyllite $(Mg, Fe^2)_7\ Si_8O_{22}\ (OH)_2$

II. Monoclinic Amphiboles

a) Cummingtonite-Grunertie series

Cummingtonite $(Mg, Fe)_7 Si_8O_{22} (OH)_2$
Grunerite $(Fe, Mg)_7 Si_8O_{22} (OH)_2$

b) Tremolite-Actinolite series
Tremolite $Ca_2 Mg_5 Si_8O_{22} (OH)_2$
Actinolite – $Ca_2 Mg,Fe)_5 Si_8O_{22} (OH)_2$

c) Hornblende series
Hornblende – $[Ca, Na Mg, Fe, Al]_{7\text{-}8} [Al, Si]_8 O_{22} [OH]_2$

d) Alkali amphibole series
Glaucophane, $Na_2 [Mg, Fe]_3 [Al, Fe^3]_2 Si_8O_{22} [OH]_2$
Riebeckite, $Na_2 Fe_3 Fe_2 Si_8 O_{22} [OH]_2$
Arfvedsonite

III. Triclinic Amphibole

Cossyrite-aluminium silicate of Na, Fe, and Ti

Anthophyllite:- $[Mg,Fe]_7 Si_8O_{22} [OH]_2$ with some substitution of Si by Al.

Cryst. syst : Orthorhombic; cleav : perfect; form : aggregates of prismatic needles; col: shades of brown; lust : vitreous; H: 5.5-6; sp.gr. 3-3.2.

Opt, prop :- Perfect prismatic cleavage; colourless, yellowish; Pleochroic; Optically negative for most examples; straight extinction.

Occurrence : metamorphic rocks

Cummingtonite – Grunerite : $(Mg, Fe)_7 Si_8O_{22} [OH]_2$ the relative proportions of Mg and Fe varying cryst syst monoclinic; forms: Fibrous: cleav: perfect; Col: Greyish, brown; H : 5-6 sp. gr. 3-2.3.5. Opt. prop: Pleochroic; brief : strong; commingtonite is optically positive, grunerite negative; lamellar twinning commonly seen. Occurrence : metamorphic rocks.

Tremolite – Actinolite : $Ca_2Mg_5 Si_8O_{22} [OH]_2$ Tremolite; $Ca_{2(}Mg, Fe)_5 Si_8O_{22} (OH)_2$ Actionolite.

Cryst : Monoclinic; Form : Crystals, columnar:
Cleav : Perfect; col : Tremolite-white, actinolite-green,
Lust : Vitreous; H: 4-6; sp.gr. 2.9-3.2.

Opt. prop : Tremolite is colourless, Actionolite yellowishgreen; pleochroic; Brief : fairly strong polarization colours of second order: biaxial, optically negative.

Varieties : Asbestos, Nephrite, Uralite

Occurrence : In metamorphic rocks; tremolite in impure crystalline limestones and in calc- silicate-hornfelses. Actinolite in schists and greenstones.

Asbestos :- Mineralogically, asbestos includes the fibrous forms of amphibole, mainly actinolite. Under the term commercial asbestos are included the following fibrous minerals.

Chrysotile – fibrous serpentine

Actinolite – asbestos proper

Amosite – fibrous anthophyllite

Crocidolite – fibrous sode-amphibole.

The better grades, those with long fibres, are woven into fire-proof fabrics and are also used for brakelinings; shorter fibres are utilized in the manufacture of asbestos sheets, boards, roofing tiles, insulating cements etc.

Hornblende : (Ca, Mg, Fe, Na, Al)$_{7-8}$ Al, Si)$_8$ O$_{22}$ (OH)$_2$ in which Al replaces some part of the Si.

Cryst : Monoclinic; form : Crystals; Twinning; simple;

Cleav : Perfect; Col : black; lust : Vitreous; Fract : uneven; H : 5-6; Sp.gr. 3-3.47.

Opt. Prop : Two sets of cleavage; colour : shades of yellow, green or brown; markedly pleochoroic; R.1. fairly high.

Brief : fairly strong second order colours, optically negative.

Occurrence : Acid and Intermediate igneous Rocks, metamorphic rocks.

Glaucophane : $Na_2 (Mg,Fe)_3 (Al,Fe)_2 Si_8O_{22} (OH)_2$

Cryst. syst : Monoclinic; form ; Prismatic crystals, fibrous, massive : cleav : perfect; col : Blue, lust : Vitreous; H : 6-6.5; Sp.gr. 3-3.1.

Opt. prop:- Strongly pleochroic, optically negative

Occur : Metamorphic rocks.

Riebeckite :- $Na_2Fe_3Fe_2Si_8O_{22} (OH)_2$

Cryst : Monoclinic; Form : Prismatic crystals; cleav : perfect; col : Blue or nearly black; lust : vitreous; H : 4; sp.gr, 3;43.

Opt. prop : Strongly pleochroic; R.1. high; Brief: Low; varieties : crocidolite, cat's eye or tiger's Eye, crosstie, etc.

Occurrence : Acid igneous rocks.

Cossyrite, Aenigmatite : It is a silicate of iron, titanium and sodium with aluminium also, it occurs as black, triclinic crystals.

MICA FAMILY (Phyllosilicates)

Micas are distinguished by a perfect basal cleavage, which causes them split up into thin elastic plates, and by their splendent pearly, somewhat metallic lustre. They all crystallize in the monoclinic system, but the forms approximate to those of the hexagonal system. They possess Si_4O_{10} – sheet structure and perfect cleavage takes place parallel to the Si_4O_{10} – sheets.

In comp. the micas are silicates of Al and K, together with Mg & Fe, some varieties contain Na, Li or Ti, Hydroxyl is always present, and is commonly replaced in part by fluorine.

When a blunt steel punch is placed on a cleaved palte of mica and lightly struck, a small six-rayed star, the "percussion-figure" is produced.

The sp.gr. of micas ranges from 2,7 to 3.1 and the average Hardness is 2.5.

The mica differ from the chlorites and other micaceous minerals in 1) their content 2) the elasticity of their cleavage-flakes and 3) certain optical properties.

The members are :

Muscovite – potassium mica, white mica

Paragonite – Sodium mica

Lepidolite – Lithium potassium mica

Biotite – Iron magnesium mica, black mica

Phlogopite – Magnesium mica

Zinnwaldite, Glauconite.

Moscovite and phologopite are of considerable industrial importance, especially in the electrical industry.

Muscovite : Potash mica, Muscovy glass :- Com. $KA1_2$ $(Al\ Si_3)O_{10}$ $(OH,F)_2$. Al is substituted for Sl Cryst : Monoclinic, pseudo-hexagonal crystals, large plates massive or in disseminated scales; cleav: perfect, when heldup to a bright light the laminae may exhibit "asterism" col: white, green, yellow brown, black, lust: pearly; H : 2-2.5; sp.gr. 2.76-3.

Opt prop :- Colourless, Brief : strong: polarization colours being of high orders, optically negative.

Varieties : Sericite, Damourtie, Gilbertite

Occurrence : Acid igneous rocks-granite and pegmatite.

Metamorphic rocks-gneisses; and schists : detrital Sedimentary rocks-sandstones, clays etc.

Uses :- to cover lanthorns, for lamp chimneys, in electrical industry for insulating; in electrical apparatus. Ground-up mica for roofing material, in the manufacture of lubricants, wall-finishes, rubber types; powered mica is used to give the "forst" effect on Christmas, cards etc.

Paragonite :- $NaAl_2$ $(AlSi_3)O_{10}$ $(OH)_2$ A yellowish or greenish mica resembling muscovite.

Lepidolite :-$K\ (Li, Al)_3\ (Si, Al)_4\ O_{10}\ (OH,F)_2$

Cryst: Monoclinic; from : like Muscovite, masses; cleav : perfect, col : rose red, lilac; lust : pearly : H : 2.5-4, Sp.gr. 2.8-2.9.

Occurrence in pegmatites.

Biotite :- $K\ (Mg, Fe)_3$, $(Al, Si_3)\ O_{10}\ (OH, F)_2$ iron replaces Mg to a variable extent.

Cryst : Monoclinic, pseudo Hexagonal; Form : prismatic crystals; cleav : perfect, col. Black or dark green, lust : splendent;

H.2 5-3, sp.gr. 2.7-3.1

Opt. prop:- perfect cleavage; coloured; strongly pleachroic Rl. High; often alters into chlorite.

Occurrence : occurs as an original constituent of igneous rocks of all kinds; volcanic rocks; abundantly as amineral of metamorphic origin in gneisses and schists, hornfelses.

Phlogopite :- K Mg_3 $(AlSi_3)O_{10}$ $(OH,F)_2$

Cryst : Monoclinic, Form: Crystals, prismatic;

Cleav : perfect; Ccl: white, colourless, brown etc.

Lust : pearly, H.2.5-3, sp.gr. 2.78-2.85 – Opt: props: perfect cleavage; pleochroic.

Occurrence: Dolomites, crystalline limestones, in igneous rocks rich in magnesia.

Glauconite :- K $(Fe,Al)_2$ $(Si\ Al)_4$ O_{10} $(OH)_2$ Similar structure that of mica. Form : amorphous, olive col : Brittle mica – margatite.

CHLORITE FAMILY

Under the general name of “Chlorite” are included many ellied minerals which are related in comp. to the micas, but which contain no alakalies. They have the Si_4 O_{10} sheet structure, and in general may be considered as hydrous silicates of Al, Fe and Mg. Varieties depend on the proportions of Fe and Mg.

The chlorites are monoclinic and some are Pseudohexagonal. They are green in colour. The chlorites have a perfect basal cleavage. Hardness averaging about 2. Varieties are ; Clirochlore, monoclinic tabular crystal distinctly biaxial and optically positive. Penninite, pseudohexagonal but rarely monoclinic, gives uniaxial interference fig. Ripidolite, occurs tabular, radiating and granular forms.

Chlorite :- $(Mg, Fe)_5$ Al $(AlSi_3)O_{10}$ (OH)

Cryst : Monoclinic, at times pseuco-hexagonal,

Forms : perfect, Col : green of various shades;

Lust : Rather pearly: H 5-2.5; sp.gr. 2.65-2.94.

Opt. prop: Cleavage usually seen; lamellar twinning frequent : R.1. moderate.

Occurrence: Igneous rocks and Metamorphic rocks.

OLIVINE FAMILY

(Nesosilcates)

The Olivine family consists of an isomorphous series of nesosilicates with the general formula R_2 (SiO_4), in which R=Mg or Fe. The magnesim end-member is “Forsterite”, Mg_2SiO_4, : Intermediate between these two is Olivine, $(Mg,Fe)_2$ SiO_4.

Olivine, Peridot, Chrysolite :- $(Mg,Fe)_2$ SiO_4, with Mg in excess of Fe in most varieties. Cryst: Orthorhombic; Form : Crystals, massive; col: Shades of green, white or yellow to forsterite, brown or black in Fayalite; streak : Colourless; Lust : Vitreous;

Fract : Conchoidal: H : 6-7; Sp.gr: Forsterite – 3.2; Fayalite – 4.3; Olivine intermediate. Opt. prop :- elongated sections, traversed by cracks along which the mineral is usually altered into greenish serpentine-the alteration being marked by a network of iron-oxide; cleavage is not usually sean; R.1-high; Biref. –Strong; Polarization colours being bright colours of second order; biaxial, Optically positive in varieties with less than about 11% FeO, optically negative in those with more than 11% FeO.

Varieties : Forsterite-Mg_2SiO_4 –whitish-in crystalline limestones; Fayalite-$Fe_2 SiO_4$ –brown to black; Peridot is a gem variety of olivine.

Occurrence : Igneous rocks-Peridotites, dunite, gabbros, basalts and dolerites.

GARNET FAMILY

In composition the garnets are essentially silicates of various divalent and trivalent metals, their general formula being $R_3 R_2 (SiO_4)_3$. Where R_3 is Ca, Mg, Fe or Mn, R_2 is Fe, Al, Cr or Ti. The atomic structure of gernet has separate SiO_4 groups which are bonded together by the metal ions which lie between them.

The following are the principal members of this family :

Grossular : $Ca_3 Al_2 (SiO_4)_3$

Pyrope : $Mg_3 Al_2 (SiO_4)_3$

Almandine : $Fe_3 Al_2 (SiO_4)_3$

Spessartite : $Mn_3 Al_2 (SiO_4)_3$

Andradite : $Ca_3 Fe_2 (SiO_4)_3$

Uvarovite : $Ca_3 Cr_2 (SiO_4)_3$

The garnets crystallize in the “Cubic” system; Garnet occurs in thin sections are rounded crystals, traversed by branching cracks, and having no cleavage. Colour is a slight tinge of Pink. The R.1 is very high, isotropic. Hardness, ranges from 6.5 to 7.5; sp.gr. 3.5-4.3; garnets are common minerals in metamorphic rocks. The uses of garnets are two, as an abrasive and as a gemstone.

Grossular, Grossularite : $Ca_3 Al_2 (SiO_4)_3$

Form : Dodecahedron, Col : Pale olive-green; Lust vitreous; Sp. Gr : 3.5

Variety : Cinnamon-Stone

Occur : Metamorphosed impure limestones

Pyrope, Precious garnet :- $Mg_3 Al_2 (SiO_4)_3$

Form : Usually fragments; Col: Deep Crimson;

Lust : Vitreous; Fract : conchoidal; H:7.5; Sp.gr: 3.7.

Occur: Ultrabasic igneous rocks

Almandine, Almandite : $Fe_3 Al_2 (SiO_4)_3$

Form : Combination of crystals; Col : Deep red; Lust :

Vitreous : Fract : subconchoidal or uneven; H : 6.5-7.5; Sp.gr : 3.9-4.2.

Occur : frequent mineral in metamorphic rocks.

Spessartite, Spessartine : $Mn_3\ Al_2\ (SiO_4)_3$

Form : Dodecahedron : Col : Deep hyacinth or brownish-red;

Lust : Vitreous : Fract : Imperfectly conchoidal, H : 7.75; Sp.gr : 4.15-4.27.

Occur :- Acid igneous rocks.

Andradite : $Ca_3\ Fe_2\ (SiO_4)_3$

Form : Dodecahedron; Col ; Dark brown, green; Lust : Vitreous; H : over 7; sp.gr. 3.75-3.78.

Varieties : Colophonite, pyreneite, Melanite, Topazolite, Demantoid.

Occur : Igneous and metamorphic rocks.

Uvarovite :- $Ca_3\ Cr_2\ (SiO_4)_3$

Form : Dodecahedron; Col : emerald-green; Lust : Vitreous; H : 7.5; Sp.gr. 3.42.

Occur : In Serpentines rich in chromite.

EPIDOTE FAMILY

(Sorosilicates)

In chemical composition the group of minerals comprising the Epidote Family are complex silicates with the general 1 formula $R\frac{2}{2}\ R\frac{3}{3}\ O(SiO_4)\ (Si_2O_7)\ OH$. Where R_2 = Ca, Fe, R_3 = Al, Fe, Mn, Ce etc; The epidotes are all similar in their atomic structure, a mixed type containing both (SiO_4) and (Si_2O_7) groups.

They may be classified by their crystems into:

Orthorhombic Epidote :

Zoisite, $Ca_2\ Al_3\ (SiO_4)_5\ (OH)$

Monoclinic Epidote :

Clinozoisite $Ca_2\ Al_3\ (SiO_4)_3\ OH$

Epidote $Ca_2\ (Al, Fe)_3\ (SiO_4)_3\ (OH)$

Piedmontite, Ca_2 (Al,Fe'Min)3(SIO_4)3(OH)

Allanite, Orthite, (Ca,Fe,Ce)3(SiO_4)3(OH)

Zoisite :-Ca_2,Al_3(SIO_4)3(OH); replacement of Al by Fe provides a transition to epidote.

Form: crystals, massive; cleav : perfect; Col: white, grey, greenish;

Lust: Vitreous ; H : 6-6 5 ; 3 2-3,37.

Opt Prop:- colourless, pleochroic in pinks; R1-high Ab-normal polarization colours; optically positive ;

Variety : Thulite-rose pink

Occur :- Metamorphic rocks those formed from igneous rocks; as a constituent of saussurite, a mixture of episodes, albite, etc

Clinozoisite :-

Form :- crystals; Col: grey H : 6-7; Sp.gr :3.2-3.4.

Opt.Prop :- R.I-high; brief-low; optically positive.

Occur :- As secondary mineral in igneous rocks, metamorphic rocks

Episote :- pistacite :- Ca_2 (Al,Fe)3(SiO_4)(OH)

Form ; Crystals, masses ; cleav : perfect; Col : shades of green ;

Lust : vitreous; Fract : uneven ; H.6-7; Sp.gr: 3.25-3.5.

OPT. Prop :- Pleochroic; R.I- high,Brief :Strong; Polarization colour being bright second and third order ; optically negative.

Varieties : Pistacite, Arendalite, Withamite.

Occur : metamorphic rocks; (epidosite)

Piedmontite :- A manganiferous epidote, of a dark reddish colour; strongly pleochroic; Brief : Strong; optically positive; occurs as a constituent of certain metamorphic rocks.

Allanite . Orthite :- A cerium- bearing epidote, brown to black in colour; occurring in tabular crystals; strongly pleochroic; R.I-high; polarization colour of high order ; occur as an accessory mineral in igneous rock.

ZEOLITE FAMILY

In composition the zeolites are hydrated silicates of Ca and Al, sometimes with Na and K, and in many ways are analogous in comp. to the feldspar. They result in general from the alteration of the feldspar and aluminous minerals of igneous rocks and with the possible exception of analcite, occur only as secondary minerals, filling cavities joint-spaces, cracks and fissures, in such rocks as basalt.etc; their formation represent the final stages in the cooling-down of igneous magmas, and they are therefore linked up in origin with may ore-deposites

When heated before the blowpipe, the zeolites boil up, their name is derived from the Greek “Zein” to boil, and “lithos”, stone. Their Hardness varies from 3.5 to 5.5. Sp.gr ; 2 to 2.4.

The “fibrous Zeolites” have framework structures of linked SiO_4 -tetrahedra, which are arranged in groups of linked SiO_4-tetrahedra, which are arranged in group of 5; as will be seen from the formulae below, there is a group of $Si_5 O_{10}$ or 5(SiO_2)- types in easch case with Al replacing part of the Si.

In “Other zeolites “ different frameworks occur, but all conform to the comp. N (SiO_2).

Some of the Zeolite s are :

Cubic Zeolites : Analcite, $Na(AlSi_2)O_6.H_2O$

Fibrous Zeolites : Natrolite, $Na_2 (Al_2Si_3O_{10})2H_2O$

Scolecite, Ca $(Al_2Si_3O_{10})3\ H_2O$

Mesolite, intermediate between natrolite, and scolecite.

Thomsonite, $NaCa_2(Al_5Si_5O2_0)6H_2O$

Other Zeolites : Heulandite, $Ca2\ (Al_4Si_{14})O_{36}.12H_2O$.

Phillipsite, $(K,Na,Ca)\ (Al_2Si_4)O_{12}41/2H_2O$.

Harmotome, $(K,Ba)\ (Al_2Si_4)O_{14}5H_2O$

Stilbite, $(Na_2, Ca)(Al_2Bi_7O_{18})$

Chabazite, $(Ca,Na)\ (Al_2Si_4O_{12})6H_2O$

Laumonite. $(Ca)\ (AL_2SI_4O_{12})$

Minerals sometimes classed with zeolites :

Apophyllite, $K,Fca_4Si_8O_{20}8H_2O$

Pectolite, $K,FCa_4Si_8O_{20}8H_2O$

Prehnite, $Co_2Al(AlSi_3O_{10})(QH)_2$.

Analcite : Analcime :

Cryst : Cubic; Form : Crystals, Massive; Cleav : cubic;

Col : Milk-white; Lust : Vitreous; Fract : subcon-choidal : H : 5-5.5; 2.25

Opt. pro :- Colourless; R-I-much low : Isotropic.

Natrolote :-

Cryst : Orthorombic; Form : crystals, massive, fibrous; cleav;perfect; col; white lust; H ; 5-5,5; Sp. gr;2.2 2.25

Scoleccite :-

Cryst : Monoclinic; form : crystals, fibrous, massive; cleav; good; Col : white; silky ; H: 5-5.5; Sp.gr 2.2-2.4.

Mesolite :-

Crsyst : Monoclinic; Form: crystals, massive; Col: white; Lust: Vitreous; H: 5;Sp.gr:2-2.4

Thomsonite :-

Cryst : Orthorhombic; Form : crystalline; masses: cleav: Perfect; Col: snow – white; lust: vitreous to pearly; Fract: subconchoidal; H;5-5 5;Sp.gr;2.3-2.4,

Heulandite :-

Cryst: Monoclinic; Form: crystalline; masses; cleav; perfect; Col: white; Lust: Vitreous; Fract: subconchoidal; H : 3.5-4:Sp.gr:2.2

Phillipsite :-

Cryst: Monoclinica; Form: crystals, radiating aggregates; Col: white; Lust: Vitreous; Fract: uneven; H: 4-4.5; Sp.gr:2.2

Harmotome, Cross-stone :-

Cryst; Monoclinica; Form: penetration twins; Col: white; Lust: Vitreous; Fract; uneven; H: 4-4.5; Sp.gr: 2.3-2.5.

Stilbite :-

Cryst: Monoclinic; Form: crystals, sheaf-like aggregates, divergent and radiating; cleav: perfect; Col: white;Lust:vitreous H : 3.5-4; Sp.gr:2 1-2.2

Occ :- Trpically zeolitic; especially common filling the stream cavities of lavas.

Cnabazite :-

Cryst ; Hexagonal-Trigonal; Form. Crystals; Col: white; Lust: Vitreous. H: 3.5-5-4; Sp.gr 2.1

Laumonite :-

Cryst; Monoclinic: Form: Crystals; fibrous; Col: white: lust: vitreous; H: 3.5-4; Sp.gr: 2.2-2.3

ALUMINIUM SILICATE FAMILY

There are three aluminium silicates of the composition A2SiO5 Viz: Andalusite, Orthombic

Sillimanite, Orthorhombic

Kyanite, triclinic.

The crystal structure of all three minerals are closely related and contain independent SiO4-tetrahedra and chains of Al-O groups.

The aluminium silicates occur in metamorphic rocks mostly of argillaceous, occurs composition. The andalusite is formed under fairly high temps. And low stress, sothat it is typical of normal thermal aureoles around intrusive igneous rocks and of rocks produced by regional metamorphism under similar conditions. Sillimanite is produced at a higher temp and is stable under a certain amount of stress, so that it is found in rocks of the innermost zone of thermal metamorphism or in regional metamorphic rocks of highest grade. Kyanite is the form stable under stress, so that it characterizes regionally metamorphic rocks of intermediate grade and is absent from normal contact aureoles.

Andalusite is distinguished from sillimanite in thin section by its negative elongation; kynatie shows oblique extinction in certain sections in the prismatic zone.

The naturally occurring aluminium silicates are industrially important in the manufacture of refractory materials as the porcelain of sparking plugs,etc.

In addition to the aluminium silicates already mentioned there is also compound of rare occurrence in nature known as “**mullite**”. $Al_2Si_2O_{13}$.

Andalusite :- Al_2SiO_2

Cryst : Orthormbic; Form: crystals, massive; cleav: poor; Col: pearl-grey; Lust: Vitreous; Fract: uneven; H: 7.5; Sp.gr: 3.1-3.3.

Opt.Prop:- R I-moderately high; Brief-weak; negative elongation; biaxial: optically negative; a basal section yielding an acute bisectrix figure.

Varieties: chiastolite or macle; viridine or manganan dalusite.

Occurrence: metamorphosed rocks of clayey composition; as an accessory mineral in certain granites.

Sillimanite: (fibrolite) :-Al_2SiO_5.

Cryst: Orthorhmbic; Form:crystsls, wisp-like aggregates; cleav : perfect; col:shades of brown; Lust: Vitreous; Fract: uneven; H :6-7:Sp.gr.3.23.

Opt.prop:-R.I-high; brief-stronger; second order polarization colours; positive elongation; biaxial optically positive.

Occu:- in the inner zone of hornfelses resulting from the contact-metamorphism of argillaceous rocks, and in high-grade regionally metamorphosed rocks.

Kyanite, cynatie, disthene :-Al2SiO5

Cryst: Triclinic;Form: long, thin, blade-likr crystals cleav; parallel to pinacoids; Col: light blue; H : varies on different faces 4-7; S.gr:3.6-3.7

Opt.prop :- good cleavage cracks; R.I-high, brief-low; first to low second order polarization colours; oblique extinction; biaxial optically negative.

Occur :- characteristric of argillaceous rocks metamorphosed under high stress and moderate temp.

HYDROUS MAGNESIUM SILICATES

This division include talc, serpentine and meers chaum. (The chemically more complex magnesium silicate 'Vermiculite' is also placed in this group).

Talc-$Mg_3(Si_4O_{10})(OH)_2$

Serpentine-$Mg_6 (Si_2O_{10})(OH)_8$

Meerschaum-$Mg_4 (Si_6O_{15})(OH)_2 6H_2O$

Vermiculite-$MG_3 (Si_4O_{10})(OH)_2 nH_2O$

Talc –

Cryst: monoclinic; form: tabular, massive; cleav: perfect; col: white, apple-green; Lust: pearly; feel: greasy; H :Sp.gr: 2.7-2.8.

Opt.prop :- Colourless; R,I-higher; brief-strong; optically negative;

Varieties :- Steatite, soapstone;potstone; Rensselaerite; French chalk; indurated Talc.

Occurrence :- as a secondary mineral resulting from the hydration of Mg-bearing rocks; crystalline-schists;

Uses : as a filter for paints, paper, rubber, etc; and in plasters, lubricants in leather-making for crayons, toilet powder, etc.

Serpentine :-

Cryst; Monoclinic; Form : Massive, gradular or fibrous; cleav : one distinct parting; col : shades of green to black, red, yellow or brown; Lust : subresinous; Feel : sometimes slightly soapy; Fract ; conchoidal; H: 3-4; Sp.gr : 2.5-2.6.

Opt.prop :-Colour greenish yellow; R.I-low; brief-weak; Fibrous-optically positive; lamellar-optically negative. Varieties : precious or Noble serpentine, Antigorite, chrysolite, picrolite, Bastite, Schiller-spar, ophicalcite.

Occur :- Resilt from alteration, either by metamorphism or by end-stage action.

Uses : as a building stone, ornamental work, interior decoration,

Meerschaum, Sepiolite :

Form : Amorphous masses ; col : White; Lust : Dull; H ; 2-2.5; Sp.gr :2

Occur : alluvial deposites deriver from serpentine masses.

Uses : for making pipes.

Vermiculite :-

Cryst : Monoclinic, pseudomorphous after biotite or phogopite: cleav: present; H : 1.5: Sp.gr: 2.4;

Uses : building industry, insulation materials.

Hydrous Aluminium Silicates, Clay Minerals

Clays results from alteration or weathering of rocks chiefly of igneous origin. Clavs have the properties of becoming plastic when wet, of then being easily moulded, and of becoming hard and rock-like when heated to a suitable temp.

The clay minerals occur as very minute flaky crystals which have the Si4O14-sheet structure.

Some of them are :

Kaolinite, Nacrite, Dickite, $Al_4Si_4O_{10}$ $(OH)_8$

Halloysite, $Al_4Si_4O_{10}(OH)_8(8H_2O)$

Montmorillonite, $Al_4Si_8O_{20}(OH)_4$ nH_2O with MgAl. Beidellite, similar to Montmorillonite, but with AlSi.

illite, Ky Al_4 $(Si_8\text{-}yAly)O_{20}$ $(OH)_4$ (y=1-1.5).

Pyrophylite, $Al_2Si_4O_{10}$ $(OH)_2$

Allophane, amorphous silica-alumina gel.

Individual species of clay-minerals cannot be distinguished from one another expect by elaborate chemical or x-ray investigations.

Kaolinite, Nacrite, **Dickite,** china clay, Kaolin :-

Cryst : Triclinic; Form crystals, usually very soft, crumbling to powder; cleav: perfect; col: white when pure; Lust : dull; Feel: greasy; H : 2-2.5; Sp.gr;2.6

Opt.prop :- R.I-slightly higher; brief-weak;

Varieties :- Nacrite, Dickite, crystallized varieties; kaolin or china clay; Lithomarge.

Occur :- Kaolinite and laolin results from the alteration of the feldspars of granites (wearing and pneumatolysis)

Uses for the manufacture of fine porcelain and china, porcelain fittings, as fillers in paper, rubber, and paint manufacture.

Halloysite : Kaolin-like mineral, occurring with laolinite in kaolin deposits. Bole-red clay.

Montmorillonite :- a soft, white clay mineral occurring as an alteration-product of Al-silicates. Montmorillinite, together with beidellite constitutes a large proportion of the clay **"Bentonite".** it is believed to result from the decomposition of volcanic ash, and is employed for various purposes such as the decolourizing of oils, water-softening, as a filler, for the thickening of drilling muds in sinking oil-wells, and as an absorbent in many processes.

Beidellite :- occurs on thin plates, white in colour and usually results from the alteration of micas.

Illite :- formed by the decay of muscovite or feldspar, either by weathering or hydrothermal processes. Illite is a dominant mineral in many shales.

Phyrophyllite :- A mineral with many of the physical properties of talc; it occurs as foliated masses in crystalline schists. It is used for the same purposes as talc.

Allophane :- Hydrous aluminium silicates. The name is now used to denote the non-crystalline part of a clay that is soluble in dilute Hcl (Grim)

Fuller's Earth : it is a greenish-brown material, soft and earthy in texture, with a soapy feel; it yields to the fingernail with shining streak, and adheres to the tongue placed in water it falls to powder, but does not form a paste; it has been suggested that fuller's earth is composed dominantly of montmonrillonite; its modern use is in the refining of oils and fats. It occurs chiefly as beds delivered from weathered basic volcanic or pyroclastic rocks.

Sphen, Titanite :- Ca Tio (SiO_4). The comp. is variable. Cryst. Struct: independent SiO_4-tetrahedra with groups of (Cao_7) and (TiO_6).

Crst : Monoclinic; Form: crystals, massive: Twinning rather common; cleav: good: col : Brown ,green grey; lust:Adamantine; Fract: imperfect conchoidal; H : 5-5.5; Sp.gr: 3.54.

Opt.pro :- R.I very high; brief-very strong ; biaxia optically positive.

Varieties : Greenovite; Leucoxene.

Occur : In acid igneous rock, contact-metamorphosed limestone.

Topaz :-$Al_2F_2SiO_4$; part of F may be replaced by OH. Cryst: Orthorhombic; Form: Crystals, columnar; Cleav : perfect; Col: wine-yellow; pink, white;

Lust: Vitreous; Fract: Sub-conchoidal to uneven; H : 8, Sp.gr : 3.5-3.6.

Opt.prop:- colourless; R.I-much higher; Relief-distinct; Brief-low; Biaxial; optically positive.

Occur : in acid igneous rocks, Tin-bearing pegmatites; Uses : as a gemstone.

Staurolite :- $(Mg,Fe^2)_2(Al,Fe^3)_9O_6(SiO_4)_4(O.OH)_2$

The structure is composed of alternate layers of kyanite and iron hydroxide.

Cryst : Monoclinic/orthorhombic; Form: Prismatic crystals; Twinning: Cruciform twins, Pyramid and dome; cleav: Interrupted; Col: Reddish-Brown; Lust: Subvitreous to resinous; Fract : Conchoidal; H: 7-7.5; Sp.gr:3.7.

Opt.prop :- Pleochroic; twinning common; R.I-high, Brief-low; biaxial; optically positive.

Occur :- Metamorphic rocks, associated with garnet and kyanite.

Tourmaline :- Complex borosilicate of Al, together with alkali metals or iron and Mg. The general formula can be written $X\ Y_3\ B_3\ (Al,Fe^3)_6\ O_{27}(OH,F)_4$

Where x=Na, Ca and Y=Mg,Fe^2Li. The structure is $Si_6\ O_{18}$-rings (cyclosilicate).

Cryst : Hexagonal; Form: Prismatic crystals, massive, columnar; cleav: difficult; col: black; Lust: vitreous;

Fract : Subconchoidal or uneven; H : 7-7.5; Sp.gr: 2.98-3 2.

Opt.prop :- Strong Pleochroic, Pleochroic halas common; R.I-high; Brief-moderate; elongation negative; uniaxial, optically negative.

Varieties : Rubellite, Indicolite, Brazilian Sapdhire, Brazilian Emerald, peridot of Ceylon, Schorl.

Occur :- As an accessory mineral in acid igneous rocks, pegmatites, as a product of pneumatolytic action, metamorphic rocks, as heavy-residue in sedimentary rocks.

Uses : As gemstone.

Cordierite, lolite, Dichroite :-

Comp : $(Mg,Fe)_2$ Al_3 (AL Si_5O_{18}). The ratio of Mg : Fe varies. Cryst : Orthorhombic, Form : Pseudohexagonal crystals, massive; Cleav : poor; Col : shades of blue; Lust ; vitreous; Fract : subconchoidal; H : 7-7.5; Sp.gr : 2.6-2.7.

Opt.prop :- R.I-near to quartz; biaxial, usually optically negative.

Occur: Metamorphic rocks (regional & contact) as a magmatic mineral in norites.

Spdumene :- Li Al Si_2 O_6

Cryst : monoclinic; Form : crystals, massive; cleav: Perfect, good parting; col; Grayish; Lust: pearly; H: 6.5-7; Sp.gr: 3.1-3.2. gemvarieties Hiddenite the emeraid-green; kunzitelilac

Occur :- Granitic pegmatites, accompanied by other lithium minerals.

Uses: Raw material for Lithium salts.

Beryl :- Be_3Al_2 (Si_6O_{18}).

Cryst : Hexagonal; Form : Prismatic crystals common;

Cleav : Indistinct; col: emerald-green, paleblue; Lust: Vitreous to resinous; Fract : Conchoidal; H: 7.5-8; Sp.gr: 2.7.

Varieties : Emerald; Aquamarine.

Occur :- An accessory mineral in acid igneous rocks metamorphic rocks.

Zircon :- Zr SiO_4

Cryst : Tetragonal : Form: Crystals; cleav : indistinct; Col: colourless, grey; Lust : Adamantine; Fract: conchoidal; H : 7.5; Sp.gr.4.7.

Opt.prop :- R.I-very high, optically positive.

Varieties : Hyacinth, Jargoon, Zirconite

Occurrence :- Igneous rocks, especially more acid and corresponding pegmatite forms, crystalline Limestones, heavy-reside of sedimentary rocks, associated with ilmenite, rutile.