UNIT III

Definition of Soil

"Soil is a natural body synthesized in a profile form from a variable mixture of broken and weathered minerals and decaying organic matter, which covers the earth in a thin layer and which supplies, when containing proper amounts of air and water, mechanical support and in part sustenance to plants".

"Soil is a natural body composed of inorganic and organic constituents, having a definite genesis and a distinct nature of its own"-- Dokuchaev (1900).

Branches of Soil Science

Pedology:- The Science dealing with the genesis, survey and classification and the laws of geographical distribution of soils as a body in nature. Pedology is the study of soil as a natural body and does not focus primarily on the soil's immediate practical use.

Edaphology:- The science that deals with the influence of soils on living things, particularly plants, including man's use of land for plant growth. Edaphology is the study of soil from the stand point of higher plants.

Soil Fertility:- The quality of the soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants.

Soil Chemistry:- Deals with the chemical constituents , the chemical properties and the chemical reactions of soil in relation to crop needs.

Soil Physics:- Study of various physical processes that are taking place in and through the soils.

Soil Microbiology:- Deals with microscopic population of the soil, its role in various transformations and its importance in plant nutrition and crop production.

Soil Conservation:- Deals with the protection of soil against physical loss by erosion and against chemical deterioration.

Soil Genesis:- The study of the mode of origin of soils, with special reference to the processes responsible for the development of Solum or true soil from the unconsolidated parent material.

Soil Survey:- The systematic examination, description, classification and mapping of soils in an area.

Difference between surface soil and sub-surface soil

S.No.	SURFACE SOIL	SUB-SURFACE SOIL
1	Soil up to a depth 30cm	Soil layers beyond 30cm depth
2	Physically loose and granular	Comparatively compact
3	More porosity	Less porosity
4	More organic matter content	Less organic matter content
5	Biological activity is more	Microbial activity is less
6	Mostly manipulated zone	Relatively un manipulated
7	Root activity is more	Comparatively less excepting in cases of long duration / perennial crops
8	It is completely weathered	It is partially weathered
9	Most of the essential nutrients are present in available form	Less content of essential nutrients in available form.

ROCKS: Rock may be defined as a hard mass of mineral matter comprising two or more rock forming minerals. The materials of earths crust are nothing but rocks and minerals.

Earth crust - Igneous rocks 95% and Sedimentary rocks 5%

Upper 5km of earth crust : Igneous rocks 18%

Sedimentary rocks 74%

Others 8%

Formation of Rocks: - The various processes that lead to the formation of rocks are:

1. Cooling and consolidation of Magma:- Rocks are formed by cooling and consolidation of molten magma with in or on the surface of the earth e.g. igneous or primary rocks. (Magma is defined as the complex hot solution of silicates containing water vapour and gases having a temperature ranging from 700 – 1400°C and originating at great depths in the earth crust).

2. Transportation and Cementation of Fragmentary Material:- Disintegration and decomposition lead to the breaking down of pre-existing rocks. The resulting fragmentary (broken) material is either compacted in the same place or transported in solution by the natural agencies of wind, water and ice to low lying areas like oceans. Consolidation of these materials after their deposition results in the formation of rocks called sedimentary or secondary rocks.

3. Alteration of Pre-existing rocks:- The primary and secondary rocks when subjected to earth's movement and to high temperature and pressure are partially or wholly reconstituted or altered to new rocks called metamorphic rocks.

Igneous rocks: They are the source of parent material for the others rocks. Igneous rocks can be classified based on the mode of origin and chemical composition.

Classification of Igneous rocks

Based on the mode of origin they are classified as Extrusive or Volcanic rocks and Intrusive or Plutonic rocks.

S.No.	Volcanic rocks	Plutonic Rocks
1	Formed on the surface of earth	Formed with in earth's crust
2	Cooling of magma is quick	Cooling of magma is slow and the time taken for crystallization is quite long
3	Fine size crystals are formed	Coarse crystals are formed
4	Mineral grains can be observed only under a microscope or magnifying lenses	Mineral grains can be seen with naked eye
5	Rocks have a glassy structure Ex:- Basalt, Andesite	Rocks have hard and massive structure Ex: Granite & syenite
6	These are called extrusive rocks.	These are called intrusive rocks

Igneous rocks are further classified based on the relative amounts of acid and basic components. An acid component is silicic acid or silica. Basic components are soda, potash, alumina, lime, manganese and iron oxides.

1. Acid rocks - >65% silica Ex:- Granite, Pitchstone
2. Sub acid rocks - 60-65% silica Ex:- Syenite, Trachyte
3. Sub basic rocks - 55-60% silica Ex:- Deorite, Andesite
4. Basic rocks - 45-55% silica Ex:- Gabbrose, Basalt
5. Ultra basic rocks - < 45% silica

Sedimentary rocks:- The sedimentary rocks are formed from sediments, derived from the breaking down of pre-existing rocks. The sediments are transported to new places and deposited in new arrangements and cemented to form secondary rocks. These rocks are also called as stratified rocks or aqueous rocks.

Formation of Sedimentary rocks:- Four stages are recognized in the formation of sedimentary rocks.

1. **Weathering**:- The igneous rocks (Primary rocks) disintegrate owing to physical, chemical and biological weathering and provide basic materials for the formation of sedimentary rocks.
2. **Transportation**:- The disintegrated material is transported by the agencies, such as water, wind, glaciers, runoff and gravity. Transportation is a function of speed of water
3. **Deposition or Sedimentation**:- The weathered materials, comprising minerals and rock fragments are deposited when the carrying agent (like water, wind) has low velocity to carry. In this process, coarser particles settle first and the finer particles later. This kind of deposition is called 'graded bedding'.
4. **Digenesis**:- It refers to the transformation of unconsolidated sediments to hard rock. It involves compaction and cementation.

a) **Compaction**:- The weight of the upper layers with thousands of meters thickness, causes compression of the lower layers or deposits.

b) **Cementation**:- The most common materials that serve as cementing agents are lime, silica, iron oxide. Water that percolates, carries the binding minerals / materials in solution deposits these in the voids of the loose sediments and binds the sediments together.

Classification of sedimentary rocks

Based on origin, sedimentary rocks are classified in to different groups

Residual:- When the products of weathering settle at that place where they have been formed, they form in to hard mass Ex:- Bauxite

Mechanical or Detrietal:- Weathered fragments are transported, deposited in beds of varying thickness and cemented. Ex: Sand Stone, Shale, Conglomerate

Inorganic or Chemically Formed:- These are formed by evaporation or precipitation of material in sea or lake water.

a. **Formed through evaporation:-** Halite (Rock salt) , Gypsum
b. **Formed through precipitation and flocculation:-** Lime stone, Dolomite

Organic Sedimentary rocks or bio-chemically formed rocks

These are formed by the accumulation and partial decomposition of organic remains under anaerobic conditions. When the plants decompose under restricted air supply in lower layers

of earth, a greater portion of their carbon content is retained and the material is slowly converted in to coal. Ex: - Peat, Lignite and anthracite (hard coal).

METAMORPHIC ROCKS:

The word 'metamorphic' means "change in form" .

FORMATION of METAMORPHIC ROCKS : Igneous and sedimentary rocks subjected to tremendous pressures and high temperatures give way to metamorphism.

1. Changes brought about by chemically activated waters – **Hydro-metamorphism**
   Ex: Sand stone to Quartzite; Granite or Basalt to Laterite.
1. Changes brought about by Heat -- **Thermo-metamorphism**
   Ex: Limestone to crystalline marble
2. Changes brought about by Pressure -- **Dynamo –metamorphism**
   Ex: Granite - Granite-gneiss (Partial foliation)
   Gneiss - Schist (Complete foliation); Shale - Slate
3. Changes brought about by Heat & Pressure - **Dynamo-thermal metamorphism**.
   Many crystalline gneisses, schists and marbles are formed.

Pre – Existing or Original Rock	**Metamorphic Rock**
Granite or Syenite	Gneiss, Mica-schist
Conglomerate	Gneiss
Sand Stone	Quartzite, Quartz-schist
Clayey Sandstone	Quartzite, Mica-schist
Shale	Slate, Phyllite, Mica-schist
Limestone	Marble
Dolomite	Dolomite marble ? Soap stone or serpentine
Iron ores	Haematite – Schists
Coal	Graphite

Classification of Metamorphic Rocks: Based on the texture and structure of minerals, the metamorphic rocks are divided in to three groups i.e. foliated, unfoliated and granulated.

Foliated (Parallel structure) (Leaved or leafy)**:** These rocks contain micas and ferro-magnesian minerals and show foliation as the minerals are flattened and arranged in parallel layers.

Ex: Gneiss, Schist (Coarse grained); Phyllite (medium grained); Slate (Very fine grained)

Unfoliated (massive structure): These rocks contain quartz and feldspars and do not show foliation even under pressure because of large sized crystals.

Ex; Talc-schist, amphibolite and graphite.

Granular: These consisting of mostly equidimensional grains. Ex: Quartzite, Marble

Weatherability of rocks: Rocks made up of ferromagnesian minerals like olivines, pyroxenes etc., are more weatherable than rocks with non ferromagnesian minerals.

WEATHERING

Weathering is the process of disintegration and decomposition of rocks and minerals, brought about by physical and chemical means, respectively, leading to the formation of regolith (Unconsolidated residues of the weathering rock on the earth's surface or above the solid rocks)

Types of Weathering

1. Physical / Mechanical Weathering (Disintegration)
2. Chemical Weathering (Decomposition)
3. Biological Weathering (Disintegration and decomposition)

Physical Weathering

Physical weathering is a mechanical process, causing disintegration of consolidated massive rocks in to smaller pieces. In this weathering rock size will be reduced without any change in chemical composition of rock. The agents responsible for physical weathering are: the physical condition of rock, changes in temperature, action of water, action of wind and atmospheric electric phenomena.

Physical condition of rock:- The permeability of rock is probably the most important single factor which determines the rate at which the rocks weather Ex:- Coarse textured sand stone (porous) weathers more rapidly than a fine textured (almost solid) basalt.

Temperature : As a result of diurnal temperature changes the rocks heated during day and cooled during night. The temperature of rocks at its surface is very different from that of the underneath part. This creates stress and strain between heated surfaces and the cooled unexpanded parts, resulting in fragmentation of rocks. This process with time may cause the surface layer to peel of from the parent mass and the rock may ultimately disintegrate. This phenomenon is called 'Exfoliation'.

Water: Of all the agents of physical weathering the effect of water is more pronounced and widespread. Water acts as disintegrating, transporting and depositing agent. A current moving at a speed of 15cm, 30cm, 1.2m and 9.0m per second can carry fine sand, gravel, stones, and boulders of several tonnes respectively. In colder regions, the moving glaciers cause great deal of cutting and crushing of bed rocks.

Wind : Wind has both erosive and transporting effect on broken fine rock material.

Chemical Weathering

Chemical weathering is more complex in nature and involves the transformation of the original material in to some new compounds by bringing about alteration in minerals.

Solution : Water is a universal solvent. Its solubility action is enhanced when it contains dissolved CO_2, organic and inorganic acids or salts in it. Most of the minerals are affected by solubilizing action of water, though by varying degrees. Solubilization of rock minerals under the influence

$NaCl + H_2O \longrightarrow Na^+ , Cl^-, H_2O$

$CO_2 + H_2O \longrightarrow H_2CO_3$

$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$

Hydration : It is the chemical combination of water molecules with a mineral to form a new mineral. Owing to hydration, the mineral swells, looses luster, becomes softer and tend to fall apart. This is a major chemical weathering process in secondary minerals

$2Fe_2O_3$ (Haematite) + $3\ H_2O \longrightarrow 2Fe_2O_3.\ 3\ H_2O$ (Limonite)

Al_2O_3 (Bauxite) + $3\ H_2O \longrightarrow Al_2O_3.\ 3\ H_2O$ (Gibbsite)

$Ca\ SO_4$ (Anhydrite) + $2\ H_2O \longrightarrow Ca\ SO_4.\ 2\ H_2O$ (Gypsum)

Hydrolysis : Hydrolysis involves the partial dissociation of water in to H^+ and OH^- ions, which combine with minerals and bring about changes such as exchange, decomposition of crystalline structure and formation of new minerals. It is a major chemical process in primary minerals. For example hydrolysis reactions may be considered as the indications of the clay formation.

$KAlSi_3O_8 + HOH \longrightarrow HAlSi_3O_8 + KOH$

Orthoclase Acid silicate clay

$2HAlSi_3O_8 + 14\ HOH \longrightarrow Al_2O_3.\ 3\ H_2O + 6\ H\ 4SiO_4$

Recombination Silicic acid

Muscovite $\longrightarrow$ Illite : Muscovite is a 2:1 primary mineral with a non-expandable crystal structure and with a formula of $KAl_3Si_3O_{10}(OH)_2$. As weathering occurs, the mineral is broken down in size to the colloidal range; part of K is lost and some silica is added from weathering solutions. The net result is illite mineral with a less rigid crystal structure and an electronegative charge.

Oxidation: The process of combination of oxygen is known as oxidation. Moisture aids in oxidation process and this process mostly occur after hydrolysis

$4FeO + O_2^- \longrightarrow 2Fe_2O_3$

$Fe^{2+-} \longrightarrow Fe^{3+} + e-$

Oxidation of iron reduces its size and increased the electrical charge and creates electrical and structural imbalance in iron containing minerals such as pyroxenes, amphiboles and biotite.

Reduction:

The process of removal or loss of oxygen is called reduction. It occurs in submerged areas. In reduction reaction iron reduces to highly soluble ferrous form.

$Fe^{3+} + e^- \longrightarrow Fe^{2+}$

$2Fe_2O_3 \longrightarrow 4FeO + O_2$

Oxidation and reduction are more common in minerals with Fe, Mn and S.

Carbonation:

Combination of carbon dioxide with any base. This effectively decompose the minerals of rocks and organic matter accelerates this due to more CO_2 production.

$CO_2 + KOH \longrightarrow K_2CO_3$

$K_2CO_3 + H_2O + CO_2 \longrightarrow 2KHCO_3$

In this way the bases present in rocks can be solubilized and removed making the rock weak.

$CO_2 + H_2O \longrightarrow H_2CO_3$

$CaCO_3 + H_2CO_3 \longrightarrow Ca(HCO_3)_2$

The carbonic acid or carbonated water has an etching effect on rocks like limestone or other rocks containing calcium or magnesium carbonates as cementing materials leading to their breakage and formation of new minerals.

It may be concluded that chemical weathering involves destruction of rocks and minerals in to simple new compounds.

Biological Weathering

Unlike physical and chemical weathering, the biological or living agents are responsible for both decomposition and disintegration of rocks and minerals. The biological life is controlled largely by the prevailing environments.

Man, animals, higher plants, earth worms, termites and micro-organisms are responsible for biological weathering.

FAUNA:

1. The disintegration of rocks by cutting action of hills and rocks to build dams, roads etc., by humans
2. The animals, insects live in rocks make burrows and holes in rocks leading to weakening of rocks. Their excreta and other materials lead to chemical decomposition of rocks.

FLORA :

1. The roots of the plants penetrate into small cracks of rocks. As they grow they exert disruptive force due to which even hard rocks break into pieces.
2. Some roots grow deep in to soil and make open channels for percolation of water in to deeper layers.
3. Roots produce acids, which have solubilizing action of constituents of rocks making them weak.

SOIL FORMING FACTORS

Soil formation is a process of two consecutive but overlapping stages

1. The weathering of rock (R) in to parent material,
2. The formation of the soil from parent material

Weathering Soil forming processes

Rock ⟶ Parent material ⟶ Soil

Dokuchaev (1889) was the first person to show that soils usually form a pattern in the landscape and established that they develop as a result of the interplay of soil forming factors viz: parent material, climate and organism, which he put forward in the form of an equation:

$$S = f(P,Cl,O)$$

Jenny (1941) formulated the following equation

$$S = F(Cl, B, R, P, T, etc)$$

S= any soil property, Cl = Climate, B = Biosphere, R = Relief / topography, P =Parent Material T= Time, etc: additional unspecified factors.

Soil can be defined in terms of soil forming factors. "Soil is a dynamic natural body having properties derived from the combined effect of climate and biotic activities as modified by topography acting on parent materials over a period of time.

Joffe divided the soil forming factors into active and passive factors.

1. Parent material, Relief / Topography and Time -- Passive factors
2. Climate, Vegetation & Organisms ------- Active factors

PEDOGENIC OR SOIL FORMING PROCESSES

The geological weathering produces weathered rock material i.e. the parent material and when the genetic factors set the stage for soil development . The pedogenic processes change the parent material in to soil with varying horizonations.

BASIC / FUNDAMENTAL PEDOGENIC PROCESSES:

1. **HUMIFICATION:** Humification is the process of decomposition of raw organic matter in to 'HUMUS'. It is an extremely complex process involving various organisms such as bacteria, fungi, actinomycetes, earth worms and termites. The decomposition of organic matter takes place in two phases: **mineralization and humification.** Mineralization is a biochemical breakdown of dead plant tissues by soil microorganisms to produce simple structured soluble organic substances. During the second phase, that is humification, soluble organic substances regroup themselves in to large molecules by polymerization and become poorly soluble. The activities of microorganisms and soil formation are as under:

Mor : It refers to surface soil horizon developed under acid litter and humus from coniferous and heath vegetation, where fungi activity predominates.

Mull : Designated as forest soil horizon (A1). It is slightly acid and is best developed under base rich litter, where bacterial activity predominates.

2. **ELUVIATION :** Eluviation means "Washing out". It is the process of removal of constituents in suspension or solution by the percolating water from the upper to lower layers. The eluviations encompasses mobilization and translocation of mobile constituents resulting in textural differences. Leaching refers to the movement and removal of material in solution from the soil.
3. **Illuvation:** The process of deposition of soil materials (removed from the eluvial horizon "E") in the lower layer (or horizon of gains having the property of stabilizing translocated clay materials) is termed as "illuviation". The horizons formed by this process are termed as illuvial horizons (B-horizon especially Bt).
4. **Calcification**

The process of precipitation and accumulation of calcium carbonate in some part of the profile is called calcification. This is a common process in arid and semi-arid regions, which are low in rainfall (Rainfall<PET). The illuviated horizon of $CaCO_3$ is designated as 'calcic horizon'.

5. **PODZOLIZATION :** (Russian term) Pod = under and zola = ashlike

It is the process of accumulation of silica and eluviation of sesquioxides. The favourable conditions for podzolization are: 1. cool and humid climate and 2. Siliceous (sandy) or acidic parent material, having poor reserves of weatherable minerals. As the materials move out, it gives a bleached appearance (E-horizon) below the surface. The eluviated materials deposit in B horizon as dark coloured Bh (precipitated humus), reddish brown Bs (deposition of sesquioxides) and a yellowishish brown (silicate clay) layer which gradually merges with parent material.

6. **LATERIZATION :**

The term laterite is derived from the word "later" means "brick" or "tile". In laterization, unlike podzolisation, silica is removed leaving sesquioxides to remain in solum. This soil forming process is called "laterization" or "Lotozation" Eg: Soils of Malabar hills of Kerala. The favorable conditions are: 1. Warm and humid (tropical) climate with 2000 to 2500 mm rainfall and continuous high temperature (>25°C) throughout the year. 2. Basic parent materials, having sufficient ferro-mangnesion minerals (Pyroxenes, amphiboles, biotite and chlorite) are favourable for the development of laterites.

7. GLEIZATION

"Glei" means blue, grey or green clay. The gleization is a process of soil formation resulting in the development of a glei (or gley) horizon in the lower part of the profile above the parent material due to poor drainage conditions or water logged conditions.

8. SALINIZATION

It is the process of accumulation of salts such as sulphates, chlorides of calcium, magnesium, sodium and potassium in soils in the form of salty (salic) horizon. As a result of the accumulation of salts, solon chalks or saline soils develop with an electrical conductivity of > 4 dSm^{-1}. The soils are called saline soils, which have ESP less than 15 per cent and pH between 7 and 8.5.

9. SOLONIZATION OR ALKALIZATION

The process involves the accumulation of sodium ions in the soil resulting in the formation of sodic soils (solonetz) under arid and semi-arid conditions. This occurs when anions like carbonates and bicarbonates predominate in soil. When the ESP > 15 %, the soil is designated as alkali soil with a high pH of >8.5, which results in less nutrient availability. These soils are called black alkali soils.They have problems like poor aeration, low infiltration and percolation of water.

10. SOLODIZATION OR DEALKALIZATION

This process refers to the removal of Na^+ from exchange sites. The Na^+ can be eliminated by increasing the concentration of Ca^{2+} or Mg^{2+} in the water, followed by improved drainage facilities.

MINERALS

Mineral is a naturally occurring, homogenous element or inorganic compound that has a definite chemical composition and a characteristic geometric form.

Only one element – Metal – Cu, Fe, Ca. Non Metal – C, S, Si.

Two or more elements combined – Gypsum-$CaSO_4 . 2H_2O$, Olivine – $(Mg/Fe)_2 SiO_4$,Feldspar – $KAlSi_3O_8$

Formation & Distribution in the Earth's crust

When the molten magma solidifies, the different elements present there in freely arrange themselves in accordance with attractive forces and geometric form. Of the more than 2000 known minerals only a few occur in abundance in the earth crust. Silicate minerals occupy 90% of the mineral composition of rocks of the earth's crust. The is the fundamental building block of all the silicate minerals of the earth's crust.

CLASSIFICATION OF MINERALS

1. **Based on mode of origin**

a) Primary Minerals

b) Secondary Minerals

2. **Based on Chemical composition**

a) Native elements

b) Oxides and hydroxides

c) Sulphates

d) Sulphides

e) Carbonates

f) Halides

g) Silicates

3. **Based on the Quantity**

a) Essential Minerals

b) Accessory Minerals

4. **Based on Specific Gravity**

a) Light Minerals

b) Heavy Minerals

Primary Minerals : The primary minerals are those which are formed owing to the crystallization of the molten magma. Depending up on the tetrahedral linkage, the silicate minerals are divided in to six groups.

1. Orthosilicates : Olivine
2. Inosilicates: Single chained : Pyroxenes
   Double chained : Ampliboles
3. Phyllosilicates : Biotite, Muscovite
4. Tectosilicates : Quartz, Feldspars
5. Ferro - Magnesian Minerals: Olivines, Pyroxenes, Amphiboles, Biotite
6. Non Ferro Magnesian Minerals: Muscovite, Orthoclase, Albite, Anorthite, Quartz

Secondary minerals: Minerals formed due to weathering action of primary minerals.

PRIMARY SILICATE MINERALS

Quartz: The frame works of quartz is very densely packed and occurs in a high degree of purity. It is resistant to physical and chemical weathering as the structure is densely packed.

Feldspars: Its frame work is less dense than quartz. There are most abundant among rock

forming minerals in the earth's crust. These are non ferro - magenesian minerals and act as store house of sodium, calcium, potassium minerals and many trace elements in soils.

Micas: Occur most extensively in soils. Muscovite (white mica) a non- ferromagnesian mineral is resistant for weathering. Biotite (black mica) a ferro- magnesian is highly susceptible for weathering.

Pyroxenes and Amphiboles: These two minerals are two groups of ferro- magenesian minerals and their structure consists of long chains of linked silica tetrehedra (Inosilicates). Due to variety of substitutions these minerals are excellent host minerals for trace cations in soils and also for main constituent cations like Ca, Mg and Fe.

Pyroxenes - Single chain. Eg. Augite $(Ca, Na)(Mg,Fe,Al)(Si,Al)_2O_6$

Olivines: Olive green colored minerals. Olivines are relatively easily weathered. It is called island silicate. Ex: Forsterite – Mg_2SiO_4 ; Fayalite – Fe_2SiO_4

Weatherability of primary minerals.

1. Early stage of weathering

   Olivine $(Fe,Mg)_2SiO_4$; Anorthite (Calcium feldspar – $CaAl_2Si_2O_8$)
2. Intermediate weathering stage

   Orthoclase (Potassium feldspar-$KAlSi_3O_8$); Quartz SiO_2
3. Advanced stage of weathering: No primary mineral is observed in advanced stage of weathering. Hence young soils contain several primary minerals but highly weathered soils do not contain any primary minerals.
4. **Essential Minerals:** The minerals which form the chief constituents of rock and which are regarded as the characteristic components of that rock are known as "Essential Minerals" eg. Quartz, Feldspars and Micas
5. **Accessory Minerals:** These minerals occur only in small quantities and whose presence or absence is of no importance as far as the character of the rock is concerned, are called as accessory minerals eg. Tourmaline, Pyrite, Magnetite.
6. **Light Minerals:** Are the minerals which have specific gravity below 2.85. E.g:, Quartz (2.60), Feldspar (2.65), Muscovite (2.50-2.75)
7. **Heavy Minerals:** Having specific gravity above 2.85 g/cc E.g:, Haematite (5.30), Pyrite (5.0), Limonite (3.8), Augite (pyroxene) (3.1 – 3.6), Hornblende (amphiboles) (2.9 – 3.8), Olivine (3.5)

SECONDARY MINERALS: The secondary minerals are formed at the earth's surface by the weathering of the pre-existing primary minerals under variable conditions of temperature and

pressure. Due to the action of weathering processes primary minerals are altered or decomposed. They are two types. a. Silicate minerals and b. Non-silicate minerals.

Silicates: These are the minerals that contain silica along with other elements.

a) Clay minerals : Illite, Montmorillonite, Kaolinite

Non Silicates:

a) Oxides, Hydroxides of Al and Fe : Hematite, Goethite, Gibbsite
b) Carbonates: Calcite, Dolomite
c) Sulphates: Gypsum
d) Phosphates: Apatite

Basic structural units of Secondary minerals:

Silica Tetrahedron: Geometrically it is possible to arrange only four oxygen atoms around a central silicon cation, so that all are touching each other and the resultant silica tetrahedron $(SiO_4)^{4-}$ carries a net negative charge of four. This is called a silica Tetrahedron.

Weatherability of Minerals in sequence:

Early stage of weathering:

a) Gypsum ($CaSo_4.2H_2O$) b) Calcite ($CaCO_3$) and c) Dolomite ($CaCO_3.MgCO_3$)

Intermediate stage of weathering:

Secondary clay minerals like Illite, Vermiculite, Montmorillonite

Advanced stage of weathering:

Silicate minerals like Kaolinite and Halloysite.

Non silicate minerals like Gibbisite $Al_2O_3.3H_2O$;Hematite - Fe_2O_3; Goethite FeOOH

Rutile and Anatase TiO_2; Zircon $ZrSiO_4$

Formulae of Different Rock Forming Minerals:

Phosphorus containing minerals

a) Fluorapatite $Ca_{10}(PO_4)_6F_2$
b) Apatite: $Ca_{10}(PO_4)_6^{2+}$
c) Variscite $AlPO_4.2H_2O$
d) Vivianite $Fe_3(PO_4)_2$
e) Strengite $FePO_4.2H_2O$

Boron containing minerals

a) Tourmaline -$Na(Mg,Fe)_3Al_6(BO_3)_3Si_6O_{18}$

Iron containing minerals

a) Limonite – $Fe_2O_3.3H_2O$
b) Viviamite $Fe_3(PO_4)_2$

c) Ilmenite - $FeTiO_3$

d) Siderite - $FeCO_3$

e) Pyrite - FeS_2

f) Hematite: Fe_2O_3

g) Chalcopyrite - $CuFeS_2$

h) Magnetite - Fe_3O_4

Zinc containing minerals : Sphalerite - ZnS; Smithsonite - :$ZnCO_3$

Mg containing minerals :

a) Epsom - $MgSO_4.7H_2O$; Mangnesite - $MgCO_3$

b) Dolomite - $CaCO_3$. Mg CO_3; Epsomite - $MgSO_4.7H_2O$

Cu containing minerals:

a) Chalcorite - Cu_2S

b) Covellite - CuS

c) Chalcopyrite - $CuFeS_2$

Mn containing minerals:

a) Pyrolusite - MnO_2

b) Manganite - MnOOH

c) Rhodocrosite - $MnCO_3$

Mo containing minerals :

a) Molybdenite : MoS_2

b) Wulfenite : $PbMOO_4$