LECTURE NOTES

MINE GEOLOGY - I

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3rd Semester Diploma

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GEOLOGY-I

1.0 PHYSICAL GEOLOGY

1.1. Define weathering and erosion :-

WEATHERING:- Weathering is the general term applied to the combined action of all processes causing rocks to be disintegrated physically and decomposed chemically because of exposure at or near the earth's surface.

TYPES OF WEATHERING:- There are three main types of weathering:

1. Physical weathering, 2. Chemical weathering, 3. Biological weathering

PROCESS OF WEATHERING:-

Physical weathering process:- This process refers to the mechanical disintegration of rocks in which their mineralogical composition is not changed. This is brought about chiefly by temperature changes. The following are some of the important processes of physical weathering.

(a) Exfoliation: - In this case thin sheets of rocks split off owing to differential expansion and contraction during heating and cooling over the diurnal temperature range.
(b) Crystal growth: - The soluble constituents of the rocks or minerals, enter the rocks through fractures and joints, along with water. With the evaporation of water the solution is precipitated to form crystals or crystalline aggregates and as they grow, they exert large expansive stresses, which help in breaking up some rocks.
(c) Freezing of water: - By freezing the pressure exerted on the walls becomes more and more intense. Which results in widening the existing fracture and new fractures form. This is the dominant mode of weathering in climates where there is repeated freezing and thawing.
(d) Differential expansion: - Rock-forming minerals expand when heated but contract when cooled. Where rock surfaces are exposed daily to intense heating by direct solar rays, alternating with intense cooling by long wave radiation at might, the resulting expansion and contraction of mineral-grains tends to break them apart

Chemical processes of weathering. Three processes are notably responsible for chemical weathering.

(a) Oxidation: - The presence of dissolved oxygen in water in contact with mineral surfaces leads to oxidation, which is the chemical union of oxygen atoms with atoms of other metallic elements. Oxygen has a particular affinity for iron compounds and these are among the most commonly oxidized materials.
(b) Hydration: - The chemical union of water with a mineral is called hydration. The process of hydration is particularly effective on some aluminum bearing minerals, such as feldspar.

(c) Carbonation: - Carbonic acid is the most common solvent acting on the crust. The effect of this process is well noticed in the lime stones or chalk areas in the humid regions of the world.

Biological weathering. This process of weathering is mainly related to the activities of various organisms. Organisms, mainly plants and bacteria, take part in the transformation of rocks at the surface in the following ways.

(a) Bio-physical processes: - Plants-roots, growing between joint blocks along minute fractures between mineral grains, exert an expansive force tending to widen those opening and sometimes create new fractures.
(b) Bio-chemical processes: - Sometimes certain groups of bacteria, algae and mosses break rock-forming silicates down directly, removing from them elements like silicon, potassium, phosphorous, calcium, magnesium, that they need as nutrients. This transformation occasionally occurs on a large scale is decisive in the alteration of parent rocks and facilitate rock weathering.

EROSION: - The force of the blowing wind or that of the dashing waves may cause a mechanical wear and tear of the rocks exposed to their fury. The rocks are therefore, gradually broken down into smaller fragments and can be conveniently removed from their home. Such breaking down or disintegration of rocks, due to the physical forces associated with the natural agencies is followed by transportation of the dislodged rock-fragments and particles and the sumtotal of the process is defined as erosion.

1.2 Explain the erosional and depositional landforms produced by wind:-

Erosional: - The wind accomplishes erosion by three means:-

(i) Deflation: - Deflation is the process of removal of loose soil or rock particles, along the course of the blowing wind. This process operates well in dry regions with little or no rainfall.
(ii) Abrasion: - Abrasion is the sand blast action of wind with sand against the rocks. The loose particles that are blown away by the wind serve as tools of destruction and when move on some rock surface they bring about a scraping of the surface.
(iii) Attrition: - Attrition is the grinding action, while on transit wind born particles often collide with one another. Such mutual collision brings about a further grinding of the particles.

Depositional: - Wind formed deposits are called Aeolian deposits. Wind is an excellent agent for sorting of materials according to their size, shape or weight. Pebbles and boulders cannot be carried away and are left back to form lag deposits. The clayey and silty fractions are deposited as loess, which does not show any stratification. Wind deposits take two general forms as:

(i) Sheets, (ii) Piles

Sheet deposits are the dust deposits laid down on large area. Piles deposits include the various types of dunes which accumulate from san and silt carried in saltation.

1.3 Explain the erosional and depositional landforms produced by river :-

Erosional: The erosion caused by the running water is of two types:

(i) Mechanical erosion and (ii) Chemical erosion.

Mechanical erosion: - It is because of the physical forces associated with the running water and it takes place in four distinct manners like :

(a) Hydraulic action: - Forces inherent in the flow of running water, can do a great deal of erosion of the bank and the bed-rock. It is mostly due to surface relief.
(b) Abrasion: - The materials which are being carried away by the running water acts as tools of destruction, and during their transportation, because of their rubbing against the surface of the bed-rock, they bring about a scraping of the surface. This process of erosion is also known as Carrasion.
(c) Attrition: - Materials during their transit often collide among themselves and in turn get themselves teared and this is the process, through which big boulders are gradually reduced in size and finally reach the size-grade of sand and silt.
(d) Cavitation: - This is because of the presence of the air bubbles which creat a whirling action at the time of penetration of water through the existing pores and fissures, and the small sand particles along with the air bubbles play a major role in widening the cavities.

Chemical erosion: - It is also known as solution or Corrosion during which process the materials get dissolved in the water of the river and are transported in solution.

Depositional: - It is the last geological action by the river, whereby materials transported get accumulated in an appropriate site where the following factors play major roles :

(i) Decrease in velocity of the transporting medium
(ii) Decrease in slope
(iii) Decrease in volume
(iv) Change in channels
(v) Chemical precipitation

1.4 Differentiate between Glacier and Iceberg

GLACIER:-Upon level surface, snow-fields slowly gain in thickness and do no, ordinarily cause the ice to move. Along slopes of hills, on the other hand, the increasing weight of the growing mass of ice is at length sufficient to make the ice flow or creep downwards. Such bodies of slowly moving ice are known as glacier. They smoothly, however a portion of the creeption mass of ice may break off and slide down under gravity, forming an available. Glacier are of common occurrence within the Himalayan region are Zamu, Kanchanjanga, Gangotri, Biafo, Saichen, Baltora, Hisapar, Bature etc.

ICEBERG: - When at length the glacier recede from either of the valleys, the tributary valley appears to hand above the floor of the main valley are commonly encountered in glaciated regions and are characteristic products of glacial erosion. During later periods, however, such hanging valleys are often destroyed due to fluvial erosion and consequent grading of the slopes. Glaciations is commonly more extensive in high latitudes than in the tropical or sub-tropical regions. At high latitude, the glaciers often excavate their valleys upto the sea level. These glacial valleys, occurring along the coasts and occupied subsequently by the sea itself, are known as fiords. Within fiords, glaciers come in contact with morine water and blocks of ice are found to break off from the mass of the glacier. This process of wastage of glacier ice is known as calving and the dislodged blocks of ice float on the sea in the form of icebergs.

1.4.1 Describe the erosional and deposional features produced by glacier.

EROSIONAL FEATURES PRODUCED BY GLACIER :-

1. Cirques: - These are circular depressions formed by plucking and grinding on the upper parts of the mountain slopes.
2. Arete: - This name is applied to the sharp ridges produced by glacial erosion. Where two cirque-walls intersect from opposite sides, a jagged, knife-like ridge, called an arete results.
3. Horn: - Where three or more cirques grow together, a sharp-pointed peak is formed by the intersection of the arêtes. Such peaks are known as horns.
4. Col: - Where opposed cirques have intersected deeply, a pass or notch, called a col is formed.
5. Glacial-trough: - Glacier flow constantly deepens and widen its channel so that after the ice has finally disappeared there remains a deep, steep walled, ‘U’ shaped valley, known as glacial trough.
6. Hanging valley: - Tributary glaciers also carve ‘U’ shaped troughs. But they are smaller in cross-section, with floors lying high above the floor-level of the main-trough. Such valleys are called hanging valleys.
7. Fiords: - When the floor of a glacial trough open to the sea lies below sea-level, the sea-water will enter as the ice-front recedes, producing a narrow estuary, known as a fiord or fiords.
8. Tarns: - the bed-rock is not always evenly excavated under a glacier, so that floors of troughs and cirques may contain rock-basin and rock-steps. Cirques and upper parts of throughs thus are occupied by small lakes, called tarns.

DEPOSITIONAL FEATURES PRODUCED BY GLACIER :-

Depositional by a glacier takes place when the ice begins to melt and the glacier slows down and vanishes, loosing its transporting power. The unstratified, unsorted debris dropped more or less in a random fashion by glacier form deposits known as morains. Three types of morains are known, lateral, medial or median and terminal or end. These three types are differentiated on the basis of their location in the valley.

1.4.2 Define moraine. Describe the different types of moraine.

MORAINE :- Depositional by a glacier takes place when the ice begins to melt and the glacier slows down and vanishes, loosing its transporting power. The unstratified, unsorted debris dropped more or less in a random fashion by glacier form deposits known as morains.

TYPES OF MORAINE :-

(1) Lateral Moraine :- Deposits of ridge-like pattern formed along the margins of the glaciated valley are known as lateral morains.
(2) Medial Moraine :- It results due to coalescence of two lateral morains, where two ice streams join.
(3) Terminal Moraine :- These are accumulation of rock-debris at the terminus of a glacier.
(4) Recessional Moraine :- Where glacier retreats in a halting manner, a series of concentric morains is formed, known as recessional moraine.

2.0 STRUCTURAL GEOLOGY

2.1 Define Dip. Distinguish between true dip and apparent dip.

DIP:- It is essentially an angle of inclination of the bed. It is defined as the amount of inclination of a bed with respect to a horizontal plane, measured on a vertical plane lying at right angles to the strike of the bedding.

TYPES OF DIP :- There are two types of dip as

(1) True dip :- It is the maximum amount of slope along a line perpendicular to the strike, in other words, it is the maximum slope with respect to the horizon. It may also be stated as the geographical direction along which the line of quickest descent slopes down.
(2) Apparent dip :- Along any direction other than that of the true dip, the gradient is scheduled to be much less and therefore it is defined as the apparent dip. The apparent dip of any bed towards any direction must always be less than its true dip.

2.2 Define strike.

STRIKE :- The direction of the line along which an inclined bed intersects a horizontal plane is known as the strike of the bed. It is a scalar quantity, as it has got only one component. The strike of the bed is independent of its amount of dip.

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RELATION BETWEEN DIP AND STRIKE :- The direction of dip and strike of any inclined bed must lie at right angles to each other. True dip is in the direction along a perpendicular to the strike.

IMPORTANCE OF STRIKE AND DIP :- In structural geology, strike and dip are quite important for the following purposes :

(a) To determine the younger bed or formation. It is well known that younger beds will always be found in he direction of dip. If we go in the direction of dip relatively beds of younger age will be found to out crop and older beds in the opposite direction.
(b) In the classification, and nomenclature of folds, faults, joints and unconformities the nature of dip and strike is of paramount significance.

2.3 Define folds. Classify folds and describe them.

FOLDS :- The bending of rock-strata due to compressional forces acting tangentially or horizontally towards a common point or plane from opposite directions is known as folding. It results in the crumbling of strata, forming wavy undulations on the surface of the earth, which are known as folds.

CLASSIFICATION OF FOLDS :- Folds have been classified into various type, on the following basis :

(a) Appearance in cross section, The following types of folds have been recognized, on this basis.
- (i) Antiform:- Any upwardly convex structure is termed as an antiform
- (ii) Synform:- Any upwardly concave structure in the form of a trough is known as synform.
- (iii) Anticline:- It is generally convex upwards where the limbs commonly slope away from the axial plane.
- (iv) Syncline:- It is a fold which is concave upwards and the commonly dip towards the axial plane.
- (v) Anticlinorium:- A large anticline with secondary folds of smaller size developed on it.
- (vi) Synclinorium:- It is a large syncline with secondary folds of smaller size developed on it.
- (vii) Anticlinal bend or Monocline:- It is due to local steepening of a bed, whereby there occurs a sudden increase in the dip of a bed, which is originally horizontal, to a near vertical position. But the original bedding remains as before.
- (viii) Synclinal bend or structural terrace:- In case of a dipping bed, due to local flattening of the beds at a particular spot, the beds acquire horizontality and then again follow their original dip without any change in the direction of dip. These are also known as structural bench.

(b) Symmetry of fold. Six types of folds have been recognized on the basis of symmetry of fold, as follows :
- (i) Symmetrical fold:- When the axial plane is vertical and bisects the fold, the fold is said to be a symmetrical or upright fold.
- (ii) Asymmetrical fold:- If the axial plane has dip, the fold is described as inclined or asymmetrical fold.
- (iii) Recumbent fold:- It is an overturned fold, in which the axial plane is horizontal or more nearly.
- (iv) Isoclinal fold:- In an over-turned fold when both the limbs have the same amount of dip, towards the same direction, it is known as isoclinal fold.
- (v) Over-turned fold:- Here the axial plane is inclined and both the limbs dip in the same direction, usually at different angles.
- (vi) Homocline:- These can well be said as tilted beds, where all the beds have the same amount of dip in the same direction.

(c) Thickness of limb. Three important types of folds have been identified on the basis of thickness of the limb, as follows:
- (i) Parallel fold:- These are also known as concentric folds, where the successive semicircles have a constant centre and a regularly increasing radius.

(ii) Similar folds:- In this case the shape of the folds may vary along the axial plane and at right angles to the fold axis. Here every bed is thinner in the limbs and thicker near the hinges.

(iii) Suprateneous folds:- Here the strata are thinnest at the crest of the anticlines and thickest at the troght of the synclines.

(d) Inter-limb angle. On this basis folds have been classified into the following types:

(i) Open or gentle fold:- Where the inter-limb-angle is greater then 70°.

(ii) Closed fold:- Where the inter-limb-angle is between 30° to 70°.

(iii) Tight fold:- Where the inter-limn-angle is below 30°.

(iv) Cylindrical fold:- When the profile is essentially semicircular and remains constant when traced along their axes.

(e) Attitude of the fold. Chiefly five types of folds have been recognized on this basis,

(i) Plunging fold:- A fold is said to plunge if the axis is not horizontal

(ii) Non plunging fold:- When the exis of the fold does not dip in any direction, it is said to be a non-plunging fold.

(iii) Doubly plunging fold:- Here the fold reverse its derection of plunge within the limits of the area under consideration.

(iv) Periclinal structure:- It commonly includes two structures namely, dome and basin.

(v) Reclined fold:- Here the axis plunges directly down the dip of the axial plane

(f) Mechanism of folding. On this basis, there are dhiefly four types of folds, like:

(i) Drag fold :- During folding, where a bedding-plane-slip occurs beween competent and incompetent layers, it is commonly found that the incompetent strata are deformed into small subsidiary folds, termed as drag fold or parasitic fold

(ii) Flexure fold:- It is mostly referred as true-folding. As it is well known that when compressive force acts on a series of flat beds, there occurs bending, and the convex side is subjected to tension and the concave side is subjected to compression.

(iii) Shear folding:- It is also known as slip folding or Gleit-bretter folding. It results from minute displacement along closely spaced fractures.

(iv) Flow folding:- It develops in highly incompetent beds which behave more as a viscous fluid than a solid rock. These are highly disharmonic in nature.

(g) On the basis of origin. Folds may be of tectonic as well as non-tectonic in origin.

(i) Folds caused by orogenic movements:- If an area has been subjected to more than one phases of folding, there results cross-folding, in which the axial planes and axes of the folds intersects one another at an angle.

(ii) Folds of non-tectonic origin:-

(1) Cambering and valley bulging: Cambering occurs where competent beds form the capping of hills, overlying incompetent beds.
In case of valley bulging the incompetent material is forced up into a valley by the weight of the hill masses on either side, which becomes turned up at the edges in the process.

(2) Diapiric or piercement folds: These are formed during the upward movement of the mass of rock forming a diaper. Salt domes are best examples of this type.

(h) Special types of folds.

(i) Chevron folds:- These are angular folds having straight limbs and sharp hings.

(ii) Fan folding:- If, in any fold, both the limbs are overturned the fold assumes the shape of a fan where the crests and troughs are sufficiently rounded.

(iii) Box fold:- These are rectangular in cross-section. In this crest is broad and flat, two hinges are present, one on either side of the flat crest.

(iv) Kink-bands:- These are narrow bands, usually, a few inches or few feet wide, in which the beds assume a dip which is steeper or gentler then the adjacent beds.

(v) Ge'anticline:- It is the broad uplifted area bordering a geosyncline, which supplies sediments for its filling.

(vi) Geosyncline:- These are elongated large basins which are found submerged beneath the sea-water and contain very great thickness of sediments.

2.4 Define faults. Describe the various types of fault.

FAULTS:- Faults are well-defined cracks along which the rock-masses on either side have relative displacement. The attitude of faults are defined in terms of their strike and dip. The strike and dip of a fault are measured in the same way as they are for bedding.

TYPES OF FAULTS:- There are two types of classification of fault.

(1) Geometric classification. (2) Genetic classification

(1) Geometric classification: This classification is strictly based on the attitude of the faults. There are five bases of geometric classification, which are as

(i) Rake of the net-slip:- On this basis folds are classified as

(a) Strike slip fault: Where the net slip is parallel to the fault and rake of the net slip is equal to zero.

(b) Dip slip fault:- Here the net slip is equal to the dip slip. Rake of the net slip is therefore 90°.

(c) Diagonal slip fault:- Where there is both a strike-slip and dip-slip component and rake of the net slip is more than 0° but less than 90°.

(ii) Attitude of the fault:- Six types of faults have been recognized on this basis, which are

(a) Strike-fault:- Where strike of the fault is parallel to the strike of the rock-beds forming the country.
(b) Dip-fault:- Where the strike of the fault is parallel to the dip of the country rocks.
(c) Diagonal fault:- It is also known as oblique fault, which strikes diagonally to the strike of the adjacent rocks.
(d) Bedding fault:- In this case the fault plane is parallel to the bedding planes of the adjacent rocks.
(e) Longitudinal fault:- Here the fault strikes parallel to the strike of the regional structure.
(f) Transverse fault:- It strikes perpendicularly or diagonally to the strike of the regional structure.

(iii) Fault-pattern:- On the basis the following types of faults have been recognized :

(a) Parallel faults:- It consists of a series of faults having the same dip and strike.
(b) Step-faults:- If in a series of parallel faults the successive blocks are down-thrown more and more towards a particular direction, the resulting structure will be a step-fault.
(c) Arcuate fault:- These are also known as peripheral faults which have circular or arc-like out-crop on a level surface.
(d) Radial faults:- Here a number of faults belonging to the same system, radiate out from a point.

(e) Enechelon faults:- There are relatively short faults which overlap each other.

(iv) On the basis of dip value:- Two important types of faults have been recognized on this basis. They are as

(a) High-angle fault:- Where dip amount is more than 45°.
(b) Low-angle fault:- These faults dip less then 45°.

(v) Apparent movement:- On this basis faults can be classified into :

(a) Normal faults:- Which are inclined faults in which the hanging wall side appears to have moved relatively downwards in comparison to the adjoining foot wall side.

(b) Reverse faults:- In this case the foot wall side appears to have been shifted downwards in comparison to the hanging walls.

(2) Genetic classification:- It is well known that along the shear fractures the displacement is parallel to the walls and there is no movement perpendicular to the fracture. It is assumed that the displacement are caused by some stresses. Three types of principal stresses have been assumed.

Three main types of faults have been recognized basing on the orientation of the three principal stresses.

(a) Normal faults: In this case,
  (1) Maximum stress ------------ Vertical (M_1)
  (2) Mean stress ------------------ Horizontal (M_2)
  (3) Minimum stress ------------- Horizontal (M_3)

Here the hanging wall has moved relatively downward. It is also known as gravity fault as well as tensional faults.

(b) Strike-slip fault: In this case,
  (1) Maximum stress ------------ Horizontal (M_1)
  (2) Minimum stress ------------- Horizontal (M_3)
  (3) Mean stress ------------------ Vertical (M_2)

Here displacement remains essentially parallel to the strike of the fault. These are also known as transcurrent, transform, wrench as well as tear faults.

(c) Thrust fault: Here,
  (1) Maximum stress ------------ Horizontal (M_1)
  (2) Mean stress ------------------ Horizontal (M_2)
  (3) Minimum stress ------------- Vertical (M_3)

In this case, the hanging wall moves relatively over the footwall. It includes the following types of faults :

(a) Reverse fault : Where the dip of the fault is more than 45°.
(b) Thrust fault : Where the fault has a dip less than 45°.
Thrusts are again subdivided into two types :

i. Over thrust: In which the initial dip is 10° or less and the net-slip is measured in terms of miles.
ii. Under thrust: In this case, the foot-wall side actually moved and pushed itself underneath the hanging wall side.

(c) Nappes.
(d) Imbricate or Schuppen structures, etc.

2.5 Define unconformity. Describe the various types of unconformity.

UNCONFORMITY:- An unconformity is a plane of discontinuity that separates two rocks, which differ notably in age. The younger of these rocks are nearly always of sedimentary origin and must have been deposited on the surface of the older rock, which is a surface of erosion.

TYPES OF UNCONFORMITY:- The various types of unconformities may be enumerated as follows :

(a) Angular unconformity:- If the beds beneath the erosion surface are folded or tilted so that there is an angular discordance between the younger and older beds, the contact is called an angular unconformity.
(b) Disconformity:- It is also known as Parallel-unconformity in view of the fact that the bedding above and below the plane of discontinuity. The lower and upper series of beds dip at the same amount and in the same direction, thus this type or unconformity is formed when there is a lesser magnitude of diastrophism, or disturbance between the deposition of the two sucession strata.
(c) Local-unconformity:- It is also known as a non-depositional unconformity. It is similar to disconformity, but it is local in extent and hence the name. the time involved is also short. Thus it represents a short period of non-deposition. So the age difference between the overlying and underlying beds is very less.
(d) Non-conformity:- It is commonly applied to structures in which the older formation made up essentially of plutonic rocks, is overlain unconformably by sedimentary rocks or lava flows. The essential concept being that prolonged erosion must have occurred to expose the intrusive before burial.
(e) Blended unconformity:- It is a surface of erosion, which may be covered by a thick residual soil that grades into the underlying bed rock. Younger sediments deposited above the surface may incorporate some of the residual-soil and a sharp contact may be lacking. Such a contact may be called as Blended unconformity.

2.6 Define joints. Describe various joints.

JOINTS:- A joint is defined as a fracture in a rock between the sides of which there is no observable relative movement. They are present in most consolidated rocks of igneous, metamorphic and sedimentary origin. Joints may form as a result of either diastrophism or contraction.

TYPES OF JOINTS:-

1. According to the mode of origin, three types of joints have been recognized, as follows :

(a) Tensional joints:- These are also known as shrinkage joints. In igneous rocks, they are produced as a consequence of contraction due to cooling. Columnar structure which characterizes many basic extrusive and intrusives, consists of long hexagonal blocks closely packed together.
(b) Sheet joints:- These joint develop in sets and are more or less parallel to the surface of the ground, especially in plutonic igneous intrusion such as granite. They may originate due to unloading of the rock mass when the cover is removed through the processes of erosion.

(c) Tectonic joints:- These are also known as shear joint. They are formed in a rock under compression. They originate as a direct result of folding or thrusting in rocks. Generally they are of three types :

   i. Strike set : Longitudinal joints parallel to the fold axis.
   ii. Dip set : Also known as cross joints, perpendicular to the longitudinal joints.
   iii. Diagonal set : Which is a conjugate set of oblique joints, which lie at rather less than 45° to the direction of tectonic axis.

2. According to the geometric classification of joints, there are three important varieties, like strike-joints, dip joints and diagonal joints, which is totoally with respect to the regional strike and dip of the country rocks.
   Joints may be open or closed. The closed joints are also knoen as latent, blind or incilient joints. They may become open as a result of weathering, which is commonly found in joined lime stones.

3.0 ELEMENTS OF CRYSTALLOGRAPHY

3.1 Define a crystal.

CRYSTAL:- Crystals are solid geometric figures which are bounded by well defined more or less plane surfaces called faces. Crystals show the following general characteristics.

1. Crystals are polyhedral bodies.
2. It possesses a typical internal atomic structure and accordingly the faces of a crystal are arranged in a regular pattern.
3. The regular-chemical condition. Crystals are formed due to slow-cooling.
4. A crystal which possesses both external form as well as internal atomic structure is said to be a perfect crystal but if it possesses only the internal atomic structure without the development of corresponding external form, it is said to be crystalline, when there is neither internal atomic structure nor external form, it will be known as an amorphous substance.

3.2 Describe the symmetry elements and forms present in the normalmetric system.

ELEMENTS OF SYMMETRY :- Crystals also show certain regularity of positions of faces, edges, corners, solid-angles etc. the geometric locus about which a group of repeating operations act is known as a symmetry element. Sometimes the repetition is with respect to a point, in which case it has centre of symmetry, sometimes it is with respect to a line in which case, it has an axis of symmetry and when the repetition is with respect to a plane, it is said to have a plane of symmetry.

1. Centre of symmetry:- The point within a crystal through which straight lines can be drawn so that on either side and at the same distance from the centre similar faces, edges and solid angles are encountered, is known as the centre of symmetry. In other words, a crystal

is said to possess a centre of symmetry, when for each face, edge, corner etc. On one side of the crystal, there is a similar face, edge or corner, directly on the opposite side of the centre point.

2. Axis of symmetry:- It is an imaginary line about which if the crystal is allowed to rotate through an angle of 360° similar faces, edges and solid angles will come to the space for more than once. If it comes twice, the axis is an axis of two fold symmetry, if it occurs thrice, it is an axis of three fold symmetry.
   The maximum number of axis of symmetry is 13 and it is found in Isometric system.

3. Plane of symmetry:- It is an imaginary plane which passes through the centre of the cystal and divides it into two parts, such that one part is the mirror image of the other. These planes of symmetry may be diagonal, horizontal as well as vertical.
   There are maximum nine planes of symmetry, which is the normal class of isometric system.

   Symmetry elements have a particular relationship with the internal atomic structure of the crystals. Accordingly, they form the basis for the classification of crystals into thirty-two symmetry classes.

   It is quite significant to note that the normal classes of all the systems show maximum number of symmetry elements, but the other classes consisting of hemi-hedral, hemi-morphic, tetarohedral and enantimorphic forms show minimum number of symmetry elements in mal class which consists of the holohedral forms.

4.0 ELEMENTS OF MINERALOGY

4.1 Define a mineral

MINERAL:- Minerals generally occur in aggregates of more or less imperfectly developed crystals. Structure is the usual term used to denote the state of aggregation or shape of the minerals.

4.2 Enumerate and describe the physical properties of minerals.

Minerals possess definite physical properties by virtue of which they can be distinguished from one another. The most important physical properties are as follows :

Colour : Some minerals possess a characteristic colour, e.g. galena, magnetic, olivine, etc; but in some others the colour is variable, e.g. quartz.

Specific gravity : Most rock-forming minerals have a specific gravity between 2 and 4.

Lusre : The luster may be metallic (like galena or iron pyrites), pearly (like talc) or silky.

Taste and Smell : Rock salt, alum and some other minerals can be recognized by their taste.

Streak: A few minerals, when drawn over paper or over an unglazed porcelain plate, leave a coloured mark known as the streak; for example, graphite gives a black streak; hematite leaves a cherry red streak.

Crystalline: A crystal is geometrical solid bounded by smooth plain surfaces called faces and capable of increasing in size by the deposit of fresh material on the outside of these surfaces. The faces in a crystal show a definite geometrical pattern and the angles between the faces are constant; for example, quartz crystallizes in the hexagonal system, while mica or muscovite crystallizes in what is called the monoclinic system, and rock salt, in the cubic system. The crystallization may take place by : (a) deposition from solution (b) slow cooling from the molten stat, or (c) direct change from a vapour to a solid.

Cleavage: Many crystals have tendency to split along one or more direction parallel to an actual or possible crystal face. This splitting gives plane surfaces known as cleavage planes. For example, mica cleaves in one direction only; galena (lead sulphide) cleaves in three planes at right angles, forming perfect cubes.

Fracture: When a crystal breaks independently of the cleavage plane, it is said to fracture. The property is prominent in minerals with poor cleavage.

Hardness : This term gives the relative ease with which minerals can be scratched. In practice hardness is measured by reference to a set of minerals given below so arranged that the first member can be scratched by all the others, the second by all except the first, and so on.

4.3 Explain briefly the silicate structures.

The silicate structures, so far recognized are of the following types :

1. Neso-silicates :These are independent or isolated SiO_4 tetrahedral which are bound to each other only by ionic bonds through interstitial cations. Their structures depend chiefly on the size and charge of the interstitial cations.
2. Soro-silicates : The soro-silicates are characterized by isolated double tetrahedral groups formed by two SiO_4 tetrahedral sharing a single apical oxygen. the resulting ratio of silicon to oxygen is 2:7. they have a net charge of '-6'. As the charge is '-6', three divalent ions are needed to balance it.
3. Cyclosilicates : When each SiO_4 tetrahedron shares two of its oxygen with neighboring tetrahedral they may be linked into rings. They have a ratio of Si : O = 1:3. three possible closed cyclic configurations of this kind may exist as
   (a) Each of the three tetrahedral shares an oxygen atom.
   (b) Each of the four tetrahedral shares an oxygen atom.
   (c) Each of the four tetrahedral shares an oxygen atom.
4. Chain structures : These are also known as ino-silicates. Here SiO_4 tetrahedral are joined together to form chains of indefinite extent.
   There are two principal modifications of this structure yielding somewhat different composition :
   (a) Single chains, in which Si : O is 1 : 3 characterized by the pyroxenes and pyroxenoids.
   (b) Double chains, where alternate tetrahedral in two parallel single chains are cross linked and the Si : O ratio is 4 : 11, characterized by the amphiboles.

5. Sheet structures (Si_4O_{10}) : It is also known as phyllosilicates. It is formed when the SiO_4 tetrahedral are linked by three of their corners and extend indefinitely in a two dimensional net-work orsheet, which has a silicon and oxygen ratio of 45 : 10. this is the fundamental unit-in allmica and clay-structure.
6. Tectosilicates : It is also known as framework structure. When each of the four oxygen atoms of each tetrahedral ᵢs shared by another tetrahedron, it results in the formation of tectosilicates. Here every SiO_4 tetrahedron shares all its corners with other tetrahedral giving a three dimensional net-sork in which Si : O = 1 : 2.

4.4 Classify Minerals.

CLASSIFICATION OF COMMON MINERALS:

(a) Essential Minerals : these make up the bulk of the rocks and are always silicates with the exception of quartz and the carbonates.
(b) Accessory Minerals : These are present only in small quantities in a rock
(c) Secondary Minerals : These are derived from the break-down of the others.

CLASSIFICATION OF ECONOMIC MINERALS:

(a) Metallic minerals : Minerals that yield metals :
Precious metals : gold, silver, platinum.

Base metals : copper, lead, zinc, tin.

Steel industry metals : iron, nickel, chromium, manganese, cobalt, molybdenum, tungesen, vanadium, titanium, ec.

Light metals : aluminium, magnesium, titanium, ec.

Electronic industry metals : cadmium, bismuth, germanium, mercury, selenium.

Radioactive metals : uranium, radium, caesium, zirconium, beryllium, rare earths, etc.

(b) Non-metallic minerals :
Insulating materials : Mica, asbestos, silimanite.

Refractory materials : Silica, alumina, zircon, graphite, etc.

Abrasives : corundum, emery.

Gems : garnet, diamond, topaz, emerald, salphire, etc.

General industrial minerals : phosphate rock, lime stone, rock-salt, barite, borates, felspars, magnesia, gypsum, poash, clays, sulphur.

(c) Fuel minerals :
Solid fuel : anthracite, coal, lignite, oil shale.

Liauid fuels : petroleum oil natural gas.

4.5 Describe mineralogy and physical properties of Olivine, Quartz, Feldspar and Pyroxene group of minerals.

OLIVINE : It is a silicate of magnesium and iron found in basic igneous rocks such as dolerite, basalt and perodote. It is greenish and looks like quartz (Sp. Gr. = 3.2 to 4.3; H = 6 to 7).

Physical properties of olivine:

1. Crystal system -------------------------------- Orthorhombic
2. Colour -- Olive green
3. Streak -- Colourless
4. Lusture --- Vitreous lusture
5. Hardness -------------------------------------- 6.5 to 7
6. Cleavage -------------------------------------- absent
7. Sp. Gravity ------------------------------------ 3.2 to 4.3
8. Fracture --------------------------------------- Conchoidal
9. Twinning -------------------------------------- Rare.

QUARTZ : It is an important constituent of the granite and other acid igneous rocks, and a chief constituent of the sandstones where it occurs in the broken form (Sp. Gr. = 2.65 ; H = 7).

Physical properties of quartz:

1. Form : White quartz is a member of the Hexagonal system. Tridymite belongs to Orthorhombic system and Cristobalite belongs to Isometric system.
2. Streak : White.
3. Lusture : Vitreous to sub-vitreous.
4. Hardness : 7 (seven)
5. Cleavage : No cleavage (an important characteristic).
6. Sp. Gravity : Low, i.e., 2.65.
7. Twinning : (i) Common twins are Dauphine type, a penetration twin with the 'c' –axis as the twin axis.

(ii) Brazil type, A penetration twin with (1120) as the twin plane.

(iii) Japanese law, Contact twins with (1122) as twin plane

8. Electric property : Quartz is piezo as well as pyro electric.
9. Colour : Quartz is colourless but the non-crystalline varieties are coloured.

FELDSPARS: This is the most important group of the rock-forming silicates. They constitute about $2/3^{rd}$ of the igneous rocks.

Physical properties of feldspars:

1. Crystal form: Orthoclase is monoclinil, Microline and other plagioclases are triclinic.
2. Colour : Orthoclase is flesh red in colour. Microcline is green in colour and the colour of plagioclases ranges from white to gray.
3. Lusture : Vitreous or pearly (play of colour is marked).
4. Cleavage : 2 sets – one parallel to (001) face and other to (010). The angle between the cleavages is 90° in case of orthoclase but less than 90° in other members.
5. Hardness : 6 (six)
6. Sp. Gravity : 2.5 to 3, according to calcium content.
7. Twinning : (a) (1) Carlsbad – 'c' axis is the twin axis and (010) the composition plane

   (2) Baveno : (021) is the twin plane.

   (3) Manebach : (001) is the twin plane.

   (b) Microcline :

   (1) Albite : Twin plane (001), twin axis perpendicular to this.

   (2) Pericline law : (010) composition plane, twin axis is the b-axis.

(c) Plagioclases : They show all the above twinning types.

PYROXENE: These rocks forming silicates contain the Si_2O_6 single chain structure (inosilicates). These are anhydrous silicates of Mg and Fe and thus are predominantly found in ferro-magnesian rocks, in basic and ulrabasic rocks.

Physical properties of pyroxene:

1. Colour : Nearly black or green of various shades.
2. Lusture : Vitreous to subvitreous. Hypersthene shows a kind of metallic-pearly lusture termed Schillerisation.
3. Cleavage : 2 sets, prismatic at angles 87° and 93°.
4. Hardness : 5 to 6.
5. Sp. Gravity : Low to moderate.
6. Twinning : Contact twins in case of monoclinic members.

5.0 PETROLOGY

5.1 Define a rock. Distinguish between a rock and mineral.

ROCK : The branch of petrology dealing with the study of stones alone is called lithology. Stones include the rocks that are necessarily hard, tough and compact.

Rocks are necessarily the constituents of the earth's crust. Rocks are composed of one mineral only while most of the rocks are multiminerallic consisting of more than on mineral species as essential constituents.

MINERAL:- Minerals generally occur in aggregates of more or less imperfectly developed crystals. Structure is the usual term used to denote the state of aggregation or shape of the minerals.

5.2 Define Igneous, Sedimentary and Metamorphic Rocks.

CLASSIFICATION OF ROCKS : According to the mode of origin, all rocks are categorized into three major groups :

I. Igneous Rocks or Primary Rocks.
II. Sedimentary Rocks or Secondary Rocks.
III. Metamorphic Rocks.

IGNEOUS OR PRIMARY ROCKS: These are the rocks formed by the solidification of magma either underneath the surface or above it; accordingly they are divided into two groups.

(a) Intrusive bodies: Which are formed underneath the surface of the earth. On the basis of the depth of formation, intrusive rocks are of two types. (i) Plutonic rocks, which are formed at very great depths. (ii) Hypabyssal rocks, which are formed at shallow depth.

(b) Extrusive bodies: These are due to the consolidation of magma above the surface of the earth. These are also known as Volcanic rocks

IMPORTANT FEATURES OF IGNEOUS ROCKS :

1. Generally hard, massive, compact with interlocking grains.
2. Entire absence of fossils.
3. Absence of bedding planes.
4. Enclosing rocks are baked.
5. usually contain much feldspar.

SEDIMENTARY OR SECONDARY ROCKS: These rocks have been derived from the pre-existing rocks, through the processes of erosion, transportation and deposition by various natural agencies like, wind, water, glacier, etc. the loose sediments, which are deposited, undergo the processes of compaction and the resulting products are known as sedimentary rocks.

On the basis of place of formation, sedimentary rocks are of two types :

(1) Sedentary rocks, that are the residual deposits, formed at the site of the pre-existing rocks from which they have been derived. These are not formed by the process of transportation.
(2) Transported, in which case the disintegrated and decomposed rock materials are transported from the place of their origin and get deposited at a suitable site. According to the mode of transportation of the deposits, these rocks are sub-divided into three types as :
(a) Mechanically deposited: Clastic rocks.
(b) Chemical precipitation: Chemical deposits.
(c) Organically deposits: Organic deposits.

IMPORTANT FEATURES OF SEDIMENTARY ROCKS :

1. Generally soft, stratified, i.e., characteristically bedded.
2. Fossils common.
3. Stratification, lamination, cross-bedding, ripple marks mud-cracks, etc are the usual structures.
4. No effect on the enclosing or the top and bottom rocks.
5. Quartz, clay minerals, calcite, dolomite, hematite are the common minerals.

METAMORPHIC ROCKS: These are formed by the alteration of pre-existing rocks by the action of temperature, pressure aided by sub-terranean fluids (magmatic or non-magmetic).

IMPORTANT FEATURES OF METAMORPHIC ROCKS:

1. Generally hard, interlocking grains and bedded (if derived from stratified rocks).
2. Fossils are rarely preserved in rocks of sedimentary origin except slates.
3. Foliated, gneissose, schistose, granulose, slaty, etc. are the common structures.
4. Common minerals are andalusite, sillimanite, kyanite, cordierite, wollastonite, garnet, graphite, etc.

5.3 Describe the various textures and structures found in Igneous rocks.

TEXTURE OF IGNEOUS ROCKS: Textures of igneous rocks describe the actual relations between crystals or that between the crystals and the glassy material present within igneous rocks. Rocks have been formed under diverse physicochemical environment, and textural studies indicate the cooling history of the magma. Texture of igneous rocks is a function of three important factors:

1. Crystallinity :

(a) Holocrystalline: When an igneous rock is made up of mineral grains only.

(b) Hemi-crystalline: when a rock contains both crystalline as well as glassy matter in variable proportions.

(c) Holohyaline: When the igneous rock consists wholly of glass

The degree of crystallization depends on the following factors :

(i) Rate of cooling.
(ii) Viscosity of magma
(iii) Depth of cooling.
(iv) Volume of the magma.

2. Granularity: It refers to the grain size of the crystals present in the igneous rocks. These are

(a) Phaneric: when individual crystals are visible to the naked eyes and are:

(i) Coarse grain: when the grain size is 5 mm or above.

(ii) Medium grain: Grain size is 1 mm to 5 mm.

(iii) Fine Grain: Grains are smaller than 1 mm in diameter.

(b) Aphanitic: When individual grains cannot be distinguished with unaided vision and are

(i) Micro –crystalline: when individual crystals are distinguishable under microscope.

(II) Mero-crystalline: Intermediate in range.

(iii) Crypo-crystalline: When individual crystals are too small to be separately distinguished, even under the microscope.

(iv) Glassy: when there is no crystallization at all.

3. Fabric :

(i) Shape of the grains: It refers to the degree of development of crystal faces and are :

(a) Euhedral: When the mineral grains are found to have developed a perfect crystal outline. These are known as idiomorphic or automorphic crystals.

(b) Sub-hedral: when the crystal outlines have partially developed. These are also known as hypidiomorphic or hypautomorphic crystals.

(c) Anhedral: When the crystal faces are absent.

STRUCTURE OF INGNEOUS ROCKS: The structures of igneous rocks are large scale features, which are dependent on several factors like :

(a) Composition of magma.
(b) Viscosity of magma.
(c) Temperature and pressure at which cooling and consolidation takes place.
(d) Presence of gases and other volatiles.

Igneous structures are mostly classified into three major groups, are as follows:

1. Mega-structures 2. Minor-structures. 3. Micro-structures.

1. Mega-structures: These are usually formed in the flow stage of the magma and include :

(i) Vesicular and amygdaloidal structures: When lavas heavily charged with gases and other volatiles are erupted on the surface the gaseous constituents escapes from the magma as there is a decrease in the pressure. Thus, near the top of flows, empty cavities of variable dimensions are formed. The individual openings are known as vesicles and the structure as a whole is known as vesicular structure.

If, however, the vesicles thus formed are subsequently filled in with some low-temperature secondary minerals, such as calcite, zeolite, chalcedony etc, these infilling are called amygdales.

(ii) Cellular or scoriaceous structures: By the bubbling out of the gases, from a lava heavily charged with volatile and gaseous constituents, numerous cavities are formed with the solidification of the lava. When the cavities are very much abundant, the term pumice or rock-froth is applied. Such structures are known as cellular or scoriaceous structures and are characteristic of highly siliceous lavas.

(iii) Lava-drain tunnels: Sometimes while the upper surface of the lava consolidates, the interior may still remain fluid. When the enclosed fluid lava drains out through some weak-spots lying at the periphery of the flow, the resulting structure is known as lava-drain tunnel.

(iv) Block-lava: Since lavas of acidic composition, due to their high viscosity, do not flow to greater distances, they after solidification are found to offer a very rough surface. Such lava flows are known as block lava. It is also known as ‘aa’ structure.

(v) Ropy lava: Lavas of basic composition are quite mobile because of their low viscosity and they can floe to freater distances and after solidification offers very smooth surface. Such lava flows are known as ropy lava and are also known as pahoehoe structure.

(vi) Pillow structure: It consists of isolated pillow shaped, masses piled one upon another. These are produced by extrusion of lava into rain-soaked air, beneath ice-sheets, under water logged sediments or in sea water. Spilite, a lava rich in albite characteristically exhibits pillow structure.

(vii) Sheet structure: The development of one set of well defined joints, sometimes brings about a slicing effect on the massive igneous rock body. If all such slices are horizontal, the structure is said to be sheet structure.

(viii) Platy structure: This is also due to the development of different sets of joints, which gives rise to only plates of the rock mass, on striking the rock. Such a feature is known as platy structure.

(vii) Columnar structure: As a consequence of contraction due to cooling, a few sets of vertical joints develop. Such joints, bring about the formation of columns, which may be square, rectangular, rgombic or hexagonal in outline.

(viii) Flow structure: Subsequent to eruption of lava upon the surface the viscous, varieties flow from one place to the other with great difficulty and in their attempt to do so, the dissimilar patches within the lava are drawn out in the form of elongated lenticles. Sometimes the already crystallized particles within the magma arearranged parallel to the direction of flow of the lava. They naturally indicate the direction of flowing of the mass, prior to its consolidation. These are also known as directional structure or more commonly flow structure.

(ix) Rift and grain: These are due to jointing. In granites, into mutually perpendicular, equally spaced joints, which are taken into advantage while producing cubical blocks, are known as mural joining. But for processing of the blocks down to smaller dimensions, the mutually perpendicular closely spaced joints (one horizontal and the other vertical) are taken into advantages. These joints are known as rift and grains.

2. Minor structure: These structures are formed in the fluid stage of the magma and include the following :

(i) Primary foliation: Sometimes many plutonic rocks are characterized by foliation resulting from the parallel arrangement of platy and ellipsoidal mineral grains.

(ii) Banding in rocks: These are also known as layered rocks consisting of alternating bands of different composition. It may result from lamellar flow, from settling of minerals from a crystallized magma or from successive injections.

(iii) Schlieren: These are somewhat wavy, streaky, irregular sheets, usually lacking sharp contact with the surrounding igneous rocks. They may be altered inclusions, segregation or may represent concentration of residual fluids into layers in a rock that had otherwise crystallized.

3. Micro structures: These are formed due to reaction between already solidified crystals and the rest of the magma and include the following :

(i) Reaction rims: When the reaction between an already crystallized mineral and the rest of the magma is incomplete, the corroded crystals are found surrounded by the products of reaction, some new mineral. Such zones are known as reaction-rim. When the reaction rims are produced by primary magmatic reaction, they are known as corona structures and kelyphitic borders when secondary.

(ii) Myrmekite structure: It is produced by an intergrowth of quartz and plagioclase feldspar where quartz occurs as belbs or drops in plagioclase.

(iii) Graphic structure: It results from an intergrowth of quartz and orthoclase feldspar.

(iv) Xenolithic structure: Occurrence of foreign rock fragments within an igneous rock gives rise to xenolithic structure. He xenoliths are said to be cognate when they are genetically relatedto enclosing rocks and accidental when they are fragments of country-rocks without having any genetic relation with the enclosing rock.

(v) Orbicular structure: These are spherical segregations consisting of concentric shells of different mineral composition and texture, which occasionally occurs in granitic rocks.

(vi) Spherulitic structure: Its essential feature is simultaneous crystallization of fibres with radiation arrangement about a common centre. The large spherulites are known as

‘Lithophyse’. In basic lavas and intrusions, they are called vorioles and the rocks containing them variolites.

(vii) Perlitic-cracks: These are curved, concentric lines of fracture, often seen in volcanic glass. These are simply due to contraction of the glassy mass on cooling.

5.4 **Describe some important structures of sedimentary rocks along.**

STRUCTURES OF SEDIMENTARY ROCKS: Sedimentary structures are both organic and inorganic in origin. Depending on the mechanism of formation, the inorganic structures are classified into….

I. Primary structures. II. Secondary structures

I. Primary Strucures: The primary sedimentary structures include the following :

(I) Bedding or stratification: Insoluble mechanically transported material is deposited in layers on the surface of accumulation which may be horizonatal or inclined. Stratification may be the result of variation in composition of different layes, colour of layers, textures of the layers and porosity of the layers.

(ii) Cross-stratification: Here the beds are found to lie slightly oblique to the major bedding planes and bound by layers of concordant bedding. Mostly found in arenaceous rocks.

(iii) Torrential bedding: It shows an alternation of coarse current bedded material and finer horizontal laminae. Here the foreset beds are straight and they characteristically develop in alluvial fans.

(iv) Graded bedding: In this case there is a gradation of grain size from coarser at the bottom to finer at the bottom to finer at the top. It is having a sharp contact with the underlying strata. This in consolidated form in known as turbidies. Graded bedding are seen in Graywackes.

(v) Ripple marks: These are minute undulations formed due to current or wave action, developed on arenaceous rocks. These are of two types:

1. Oscillation or wave ripple 2. Current ripple.

(vi) Mud-cracks: these cracks typically developed in clayey sediments due to prolonged to the atmosphere. These are also known as shrinkage cracks or suncracks. They are wider at the top but tapers towards the bottom.

(vii) Rain-prints: these are shallow depressions surrounded by alow-ridge fromed by the impact of the drop, hailstones, bubbles etc.

(viii) Imbricate structure: In conglomerate and pebble beds fragments having a noticeable elongation are sometimes deposited with the long axes of the pebbles lying more or less parallel to one another, leaning in the direction of current flow.

(ix) Tracks and trails: These are markings indicative of the some animal over soft sediments. Trails are the winding passages through which long bodied and short bodied animals moved.

(x) Convolute bedding: Here, the sedimentary lamina are contorted into a series of anticlines separated by broad synclines. Distortion increase upwards but it is confirned to one bed and is often abruptly truncated by overlying sediments.

II. <u>Secondary Strucures</u>: These are the products of chemical action contemporaneous with sedimentation or shortly thereatter and includes :

(a) Concretions: they are spherical to elliptical bodies, usually small and of diverse chemical nature than the rocks in which they occur. They include nodules, oolites, pisolites, geodes etc.

(b) Solution structures: Irregular opening commonly in calcareous rocks and are produced due to gound water action.

Organic structures:- Fossils impressions, as well as petrified remain of animals or plants are the common organic structures found in sedimentary rocks.

5.5 Describe various structures found in metamorphic rocks.

<u>STRUCTURES OF METAMORPHIC ROCKS:</u> Five major types of metamorphic structures have been recognized as follows:

(i) Cataclastic texture: It is produced under stress and in absence of high temperature, whereby rocks are subjected to shearing and fragmentation. Only the durable mineral partly survive the crushing force and the less durable ones are powdered. Thus, when resistant mineral and rock fragments stand out in a pseudo porphyritic manner in the finer material, it is known as porphyroclastic structure. Phenocrysts are called porphyroclasts. Argillaceous rocks develop slaty cleavage, harder rocks may be shattered and crushed forming crush breccia and crush conglomerate. When the rocks are highly crushed into fine grained rocks, they are known as mylonites. Since these structures are formed due to cataclasis, they are as a whole known as cataclastic structure.

(ii) Maculose structure: It is produced by thermal metamorphism of argillaceous rocks like shales. Here larger crystals of andalusite, cordierite and biotite are sometimes well developed giving a spotted appearance to the rocks. The well developed crystals are known as porphyroblasts with increasing degree of metamorphic, the spotted slates pass into extremely fine grained granular rock known as hornfels.

(iii) Schistose structure: Here the party or flaky minerals like the micas and other inequidimensional minerals show a preferred orientation along parallel planes, under the effect of the stress dominating during metamorphic. The longer directions are parallel to the direction of maximum stress. Schistosity is the property or tendency of a foliated rock, whereby it can be readily split along foliation plane.

(iv) Granulose structure: This is found in the rocks composed of equidimensional minerals like quartz, feldspar and pyroxenes. They are formed by the recrystallisation of pre-existing rocks, under uniform pressure and great heat. The typical texture is coarsely granoblastic. These structures are also known as sacchroidal. Quartzites and marbles are typical examples of this xtructure.

(v) Gneissose structure: It is banded structure due to alternation of schistose and granulose bands and is produced by highest grade of metamorphism, typically by regional metamorphism. The bands differ from one another in colour, texture and mineral composition. Gneisses typically show this type of structure, hence the name.