



GOVERNMENT POLYTECHNIC , JAJPUR

LECTURE NOTE ON
“ MINE GEOLOGY – I ”

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Weathering :-

Weathering :- the disintegration / decaying effect of weather, climate and atmospheric agents on rock.....

→ It does not involve transport.

- Rocks are formed in different conditions but they undergo different physical & chemical condition unlike the original when they are exposed to earth's surface.
- It is important for the formation of soil, laterite, ground water, occurrences and some economical mineral deposits.
- The weathered materials accumulate to form a soft surface layer called mantle of waste / Regolith.
- Rock weathering is a phenomenon of the interface between the atmosphere and lithosphere.
- The process of removal of material from the source region is called erosion.
- When the weathered materials are eroded away from the rock surface, a fresh un-weathered part of the surface get exposed for further weathering process, which is called denudation.

→ Weathering is the initial stage in the process of denudation.

→

Agents of weathering :-

- The principle agents of transformation of rocks in the zone of weathering are water, wind, gases like O_2 , CO_2 etc, acids, gravity, variation of temperature, organisms etc.

Factors affecting weathering:-

1. Endogenetic factors (geological)

→ These factors are related to rock character.

- a) Rock strength
- b) Colour
- c) Structure
- d) Texture
- e) Mineral & chemical composition

2. Exogenetic factors:-

→ Factors other than rock characteristics, pertaining to the external environment

- a) Exposed area
- b) Climate
- c) Time
- d) Temperature
- e) Rainfall
- f) Aspect / facing direction
- g) Relief / Topography
- h) Human activity

Types of weathering:- 3 types

- (i) Physical / mechanical weathering
- (ii) Chemical weathering
- (iii) Biological weathering

Physical / Mechanical weathering:-

- This process refers to physical/mechanical disintegration of rock in which the chemical composition is not affected.
- It includes the following types

- i) Fluctuation in temperature
- ii) Variation in pressure
- iii) Exfoliation
- iv) Growth of crystals
- v) Freezing of water
- vi) Frost action

(i) Fluctuation in temperature:-

- Differential expansion and contraction in rock, produces layers of weathered surface.
- The weathering due to fluctuation in temperature is called as thermal weathering.
- The intense heat of forest and bush fires is known to cause rapid flaking and scaling of rocks.

(ii) Variation in pressure:-

- Most of the rocks are formed beneath the surface with high temperature and pressure. When these rocks are exposed to the surface the temperature and pressure varies spectacularly to which the rocks results expansion.
- The removal of overburden through weathering a rock mass expands to cut-up with the pressure, change through which joints and fissures are developed which divided the rock into layers. They are also called pressure release joints or exfoliation.

→ The phenomenon of response of rocks to release of confining pressure due to unloading is known as dilatation.

→ This is often attributed to the process of exfoliation.

(iii) Exfoliation :-

→ Originates due to differential experience of temperature & pressure through different parts of rocks.

→ Exfoliation in large boulders causes onion skin weathering which is due to differential temperature absorption as dominant factor.

→ A small quantity of water and some degree of chemical activity are necessary before rock flaking will occur. This is also known as mass exfoliation.

(iv) Growth of crystals :-

→ It is the process of weathering characterised by Na, K, Ca, Mg bearing minerals.

→ As the crystal growth, they absorbed large expansive forces that results in the weakening of the rock and ultimately breaking down of rocks.

→ Along with water, most of the soluble constituents of rocks and minerals enters the rocks through its fracture.

(v) Freezing of water :-

→ Water expands by 9% in volume when it freezes.

→ Water trapped in the pores, fissures and cavities of rocks, when freezes, exerts enormous pressure on the wall of fissures.

→ Alternate freezing and thawing is the most effective process of rock disintegration. This phenomenon often termed as frost weathering.

→ This is particularly noticed on the high mountains, where during the day time the temp. rises high enough to melt some ice and snow and its subsequent freezing in the night when the temperature drops. This is also known as frost wedging.

(vi) Frost action:-

→ Water present in the ground when freezes, layers of ice tends to form and more water is drawn to the freezing layer of ice by capillary action, thus thickness of the ice-layer increases forcing the soil above it upward.

→ In this way upheaved soil is disrupted by the expansion of freezing water. This is also known as frost heaving
conditions :-

(i) presence of pores in the ground

(ii) presence of water in the pores

(iii) Appropriate temperature

Chemical weathering:-

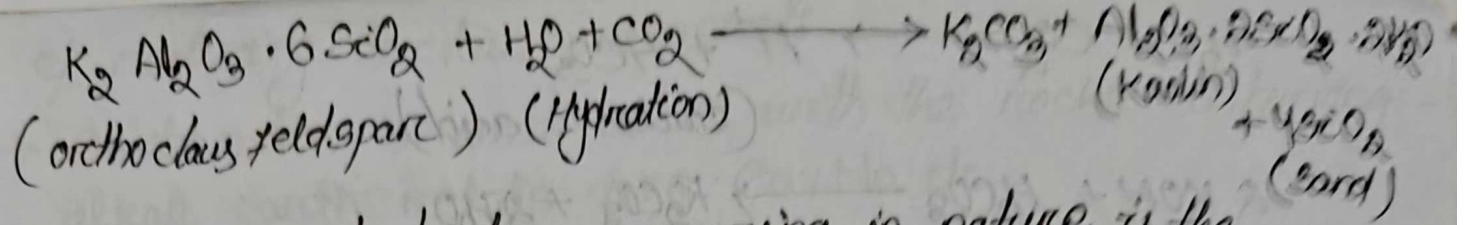
- It is a process of mineral alteration, which consists of a number of chemical reactions whereby the primary minerals (the original silicate minerals of igneous rock) are converted into new compounds, the secondary mineral which are stable in the surface environment.
- The secondary and metamorphic rocks are also substantially affected by the chemical process of weathering.
- Rocks composed primarily of quartz decompose very slowly, rocks composed mostly of ferromagnesian materials like olivine, augite etc. are highly susceptible to chemical weathering.

Types of chemical weathering:-

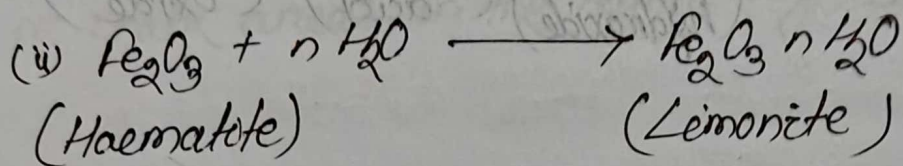
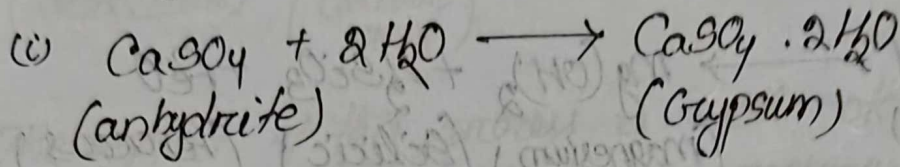
- (i) Hydration
- (ii) Hydrolysis
- (iii) Oxidation
- (iv) Carbonation

(i) Hydration:-

- This is the most powerful chemical weathering process done by water.
- Water molecules are injected into the interstices of the molecules of other minerals. Due to absorption of water minerals cause internal expansion and bringing about the decomposition of minerals.
- The most common and important is decomposition of feldspars into clay mineral i.e. kaolinite.



→ Example of hydration occurring in nature is the altering of anhydrite to gypsum, hematite to limonite.



→ When a mineral is hydrated it is the (OH⁻) ion that is built into the new crystal lattice.

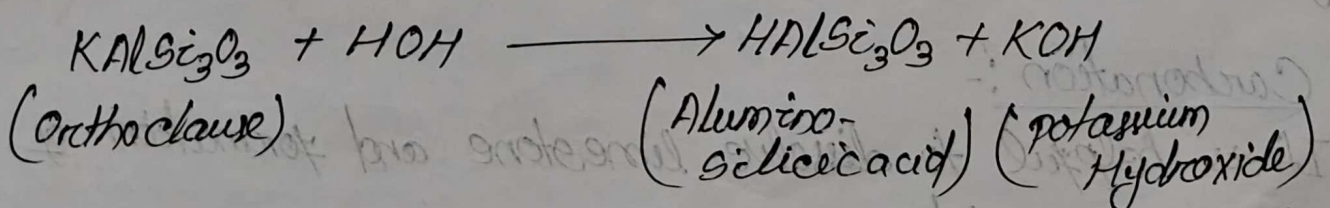
(ii) Hydrolysis:-

→ It is the process of exchange reaction between the bases of minerals and the hydrogen ions of the electrolytically dissociated part of the water.

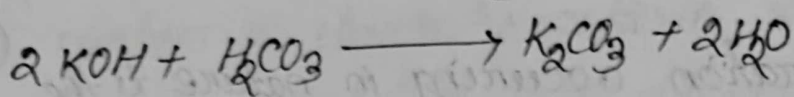
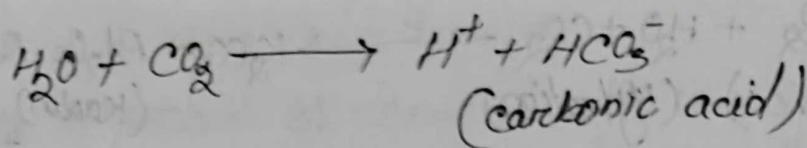
→ Water is an active chemical agent because it is always to some extent dissociated into H⁺ & OH⁻ ions.

→ Acidity is measured by the concentration of hydrogen ions i.e. the pH value.

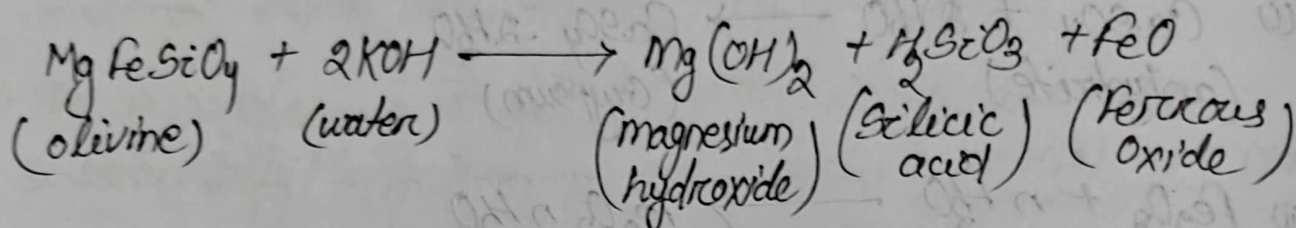
→ The higher the pH value, the more dissociated is the water and the stronger its action as a chemical weathering agent.



→ Rain water usually contains dissolved CO₂. Water is dissociated when it contains free CO₂. This reacts with the potassium hydroxide giving rise to potassium carbonate & water.



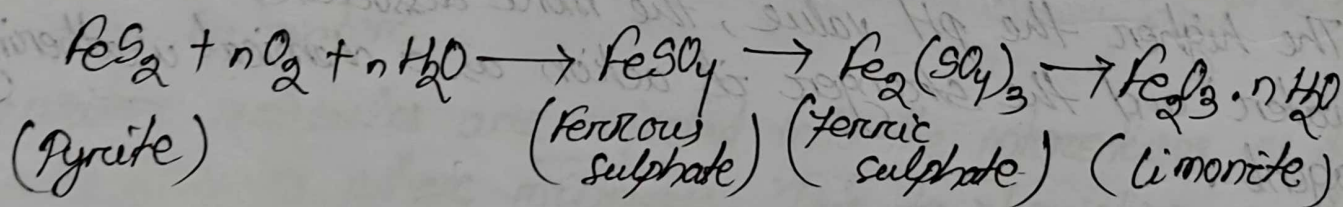
ex:- formation of magnesium hydroxide from olivine



(iii) Oxidation:-

- Chemical combination with oxygen is known as oxidation.
- Combination of water and oxygen produces hydroxides of different elements which are then leached out.
- The ferromagnesian minerals like pyroxenes and amphiboles rapidly undergo oxidation under normal atmospheric conditions producing a brown crust consisting largely of oxides of iron.
- The oxidation effects are more atmospheric in warm, moist climates.

ex:- oxidation of pyrite

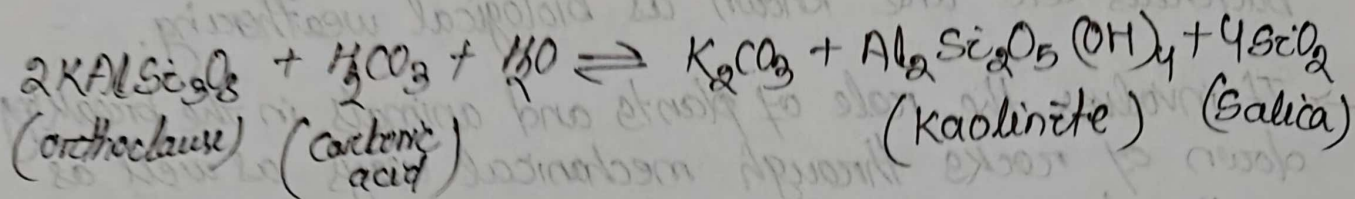


(iv) Carbonation:-

- It is helpful to dissolve limestone and formation of clay from feldspars.
- Rain water dissolves some of the atmospheric carbon-dioxide forming carbonic acid and that is capable

of reducing certain minerals.

→ Carbonation is most active with the rocks containing alkali earth metals like Ca, Na etc.



The effect of this process is well noticed in the limestone or chalk areas in the humid regions of the world.

* Elephant skin weathering:

→ Rainwater which is slightly acidic due to carbon dioxide dissolution, causes solution of some carbonates like in limestone and forms polygonal or irregular opening looking similar to elephant skin.

* Spheroidal weathering:

→ Originates due to chemical reaction of upper surface of rounded and/or jointed blocks.

→ Temperature acts as a catalyst to the alternation.

→ Upper surface of the blocks alters to clay minerals, after which the exposed surface is then altered to the same continuous alteration process layers in spheroidal shape called as spheroidal weathering.

Biological Weathering:-

- The process of weathering which are mainly related to the activities of plants, animals and organisms like bacteria etc are known as biological weathering.
- It involves the role of plants and animals in the breaking down of rocks through mechanical ways as well as in the decomposition rocks.

* Biophysical weathering:-

- Plants and root penetration through the rock joints fissures, loosens the rock.
- Insects and burrowing animals provides suitable exposure of the rock surface by loosening the soil cover.

* Biochemical weathering:-

- Certain group of bacteria, algae breaks down silica directly.
- Acids secreted by plant roots.
- Animal excretions
- Formation of chemically active acids from dead animals decaying.

Wind :-

- Wind is moving air.
- Its activity is particularly intensive in the deserts and semi-deserts which constitute about 20% of the surface of continents.
- The geological action of wind is particularly effective in areas that lack plant cover, have a considerable diurnal and seasonal temperature variation and low precipitation.
- Effective in areas i.e. desert, arid & semiarid.
- The geological action of wind can conveniently be divided into three stages

- (i) Erosion
- (ii) Transportation
- (iii) Deposition

- The geological action of wind is largely governed by its velocity.

(i) Erosion :-

- Wind erosion manifests itself in 3 forms
 - (i) deflation
 - (ii) Abrasion (corrasion)
 - (iii) attrition

* Deflation :-

- A strong wind can transport very coarse sand, lifting it from ground and carry it for great distances. This process of removal of loose soil or rock particles, along the course of the blowing wind is known as deflation (deflate = to blow off)
- This process operates well in dry regions with little or no rainfall.

→ The rate of deflation depends on the force of wind, the nature of rock and degree of weathering it has suffered.

→ Features produced by deflation

a) Hamada

b) Blow outs / deflation hollows

c) Lag deposits

a) Hamada:-

→ When the loose particles are swept away the hard mantle left behind is known as hamada.

→ The term has been applied to the stone strewn surface on the sahara desert, left after the finer materials are removed by wind. This is a form of lag deposits.

b) Blow outs / deflation hollows:-

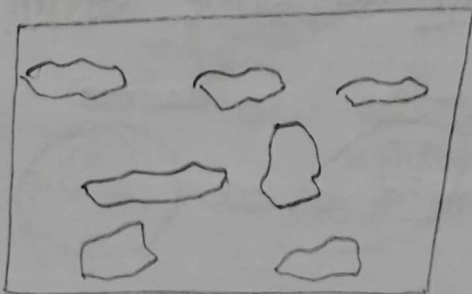
→ The depression formed in the desert due to removal of sands.

→ These are also known as blow outs.

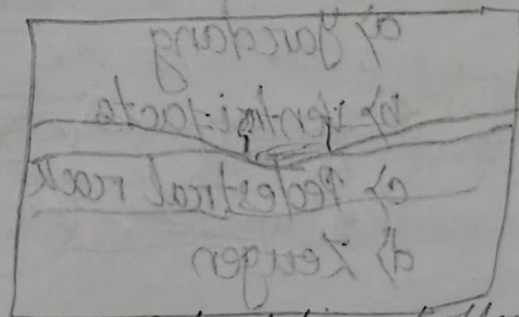
→ When the deflation basin is filled with water, it forms a typical shallow ponds is called "Oasis".

ex:- OASIS, Sahara desert

→ The position of the oasis is quickly stabilized by the growth of vegetation - commonly palm trees.



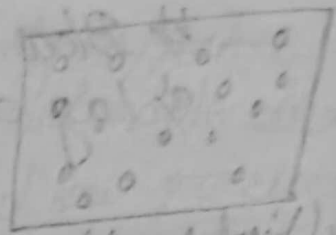
(Hamada)



(deflation hollow)

c) Lag deposits:-

- Layer of cobbles and pebbles left after removal of finer particles by wind deflation is known as 'lag deposits'.
- Formation of desert pavement and desert varnish.
- Variety name -
 - reg in Algeria
 - rig in Iran
 - Serir in Libya
 - gibbers in Australia

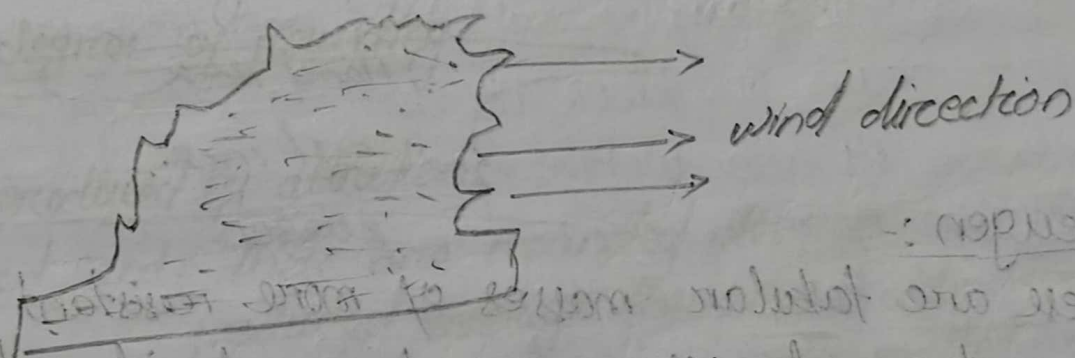


* Abrasion:-

- The loose particles that are blown by the wind serve as tools of destruction wearing away the surface with which it comes in contact. This process is known as corrosion/Abrasion.
- It is mainly effective as part of saltation.
- Its main effect is mainly seen in undercutting and fluting at the base of upstanding rock masses.
- Depending upon the hardness of the rock and the character of the material borne by the wind, the surface of the rock is polished covered with striations furrows or grooves.
- Features produced by abrasion
 - a) Yardang
 - b) Ventifacts
 - c) Pedestal rock
 - d) Zeugen

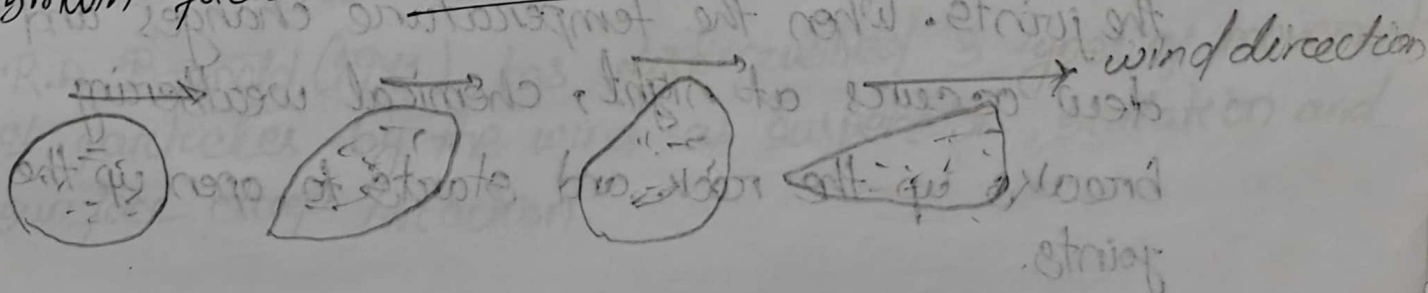
☆ Yardang:-

- Developed in vertical layers of alternating hard and soft rock.
- A vertical elongated ridge and furrows develops due to differential erosion.
- When the winds are steady and blow in one direction the softer strata are scored away more rapidly than the hard and resistant strata, there develops a topographic features consisting of elongated ridges & furrows depending on the original rock characteristics. These are usually under-cut.
- These are common in parts of Asiatic deserts.



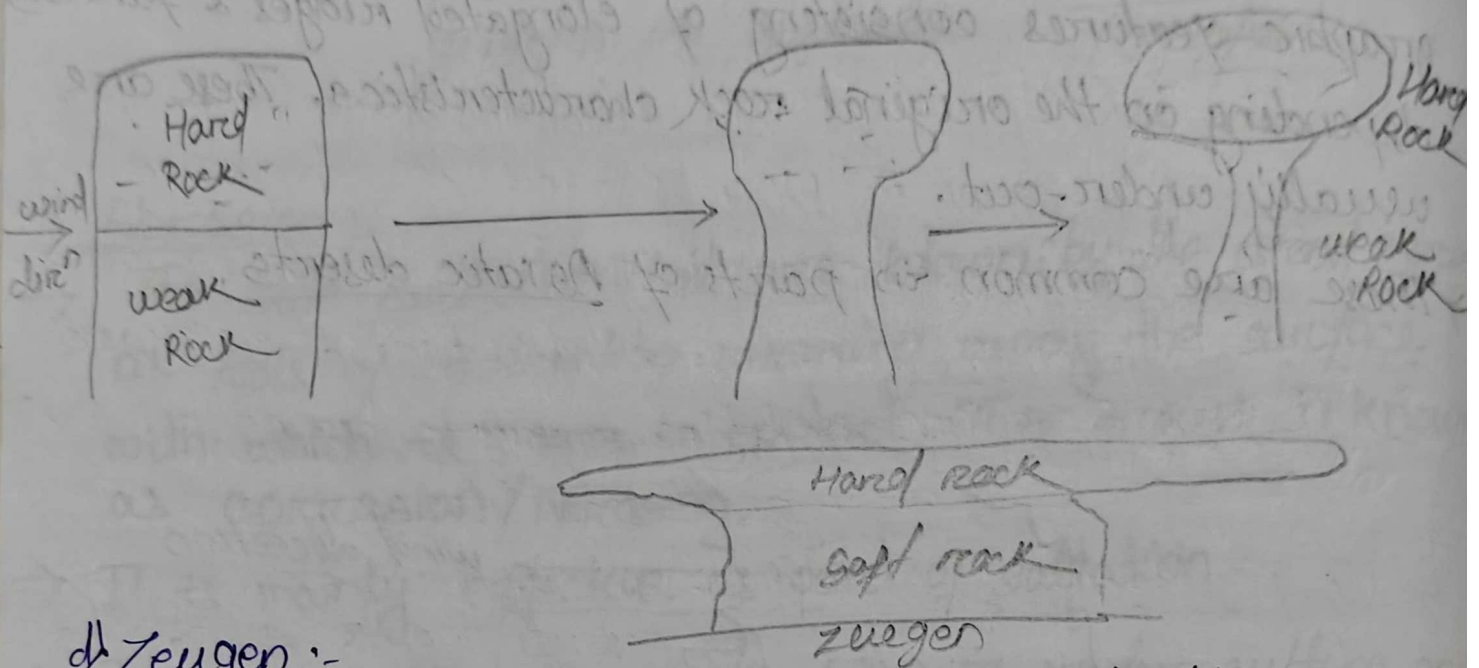
☆ Ventifacts:-

- Development of smooth polished surface on pebbles due to abrasion effect for a long time.
- Wind faceted pebbles
- Ventifacts with one smooth surface is called Einkanter with 2 broadened surface as zweikanter and with three smooth faces as Dreikanter.



c) Pedestal rock :-

- A wide hard rock cap resting over a thin column of soft rock.
- Developed in horizontal layers of hard & soft rocks.
- Abrasion action is more near the surface and decreases with increase in altitude.
- It is also known as mushroom rock.



d) Zeugen :-

- These are tabular masses of more resistant rock rising on under-cut pillars of softer material and are very often elongated in the direction of prevailing wind besides the strata are horizontal.

Formation of Zeugen :-

Stage-1 :- when there are alternating layers of hard and soft rock there can sometimes be weaknesses in the joints. When the temperature changes and dew occurs at night, chemical weathering breaks up the rock and starts to open up the joints.

stage-2:- Once the joints are opened up they are then eroded away further by wind.

→ This form ridges and hollows. At this stage the erosion starts to reach into the soft rock.

* Attrition:-

→ While a transit wind born particles often collide with one another and such mutual collision brings about some degree of grinding of the particles.

→ Thus rounding of grains becomes perfect to a great extent and the grains are reduced to smaller dimension.

→ The more the length of transmit and velocity the greater is the degree of rounding.

Features produced by attrition:-

Millet seed sand:- These are rounded deserts and grains produced through the process of attrition and have resemblance with millet seed grains.

(ii) Transportation:-

→ Wind transportation is mainly dependent on wind velocity.

→ Transport of dust from the sahara by trade wind to a distance of 2000 - 2500 km across the atlantic ocean.

→ R.A. Bagnold (1941) has distinguished 3 types of movement of particles by the wind as suspension, saltation and surface creep / traction.

Suspension:-

The finest mineral derived from silt and clays having a diameter of less than 0.5mm like dust, cloud, smoke etc. move with wind quickly and remain in suspension in the air for quite some time and settle very slowly.

Saltation:-

- Medium sized particles having diameters betⁿ 0.05-2 mm are moved in a leaping manner.
- The minimum wind velocity needed to start the saltation process is 20 km/h.
- A high speed grain in saltation can move by impact, a surface grain six times its own diameter or more than 200 times its own weight.

Surface creep:-

Through rolling and creeping ^{also} is known as traction.

suspension

saltation

creep

(iii) Deposition :-

- The power of the wind to transport the particles which are made available it by the erosional process largely depend on its speed.
- Drifting material carried by the wind tends to be heaped up by the slightest obstacle and eventually leads to the formation of what is known as aeolian deposits.
- Accumulation of rock particles etc. transported by the wind may begin due to various factors as

i) Relief of the locality

ii) Prevailing wind velocity

iii) Amount of distributing of vegetation cover

- wind deposits are classified into 2 types

i) Sheet deposits

ii) Hills deposits

- Sheet deposits are the accumulation of dusty particles over a large area, where as the Hills deposits includes various types of dune which accumulate from sand and silt carried in station.

Deposits of sand :-

There are small scale as well as large scale features usually of sand deposits. Small ripples and ridges found on sand surface are the small scale feature where as the sand hills and various types of sand dunes are the large scale feature.

a) Loess :-

- It is a deposit of wind blown silt and clay particles. 70 to 85% of these particles are in the range of 0.007 to 0.003 in diameters.
- It has a high porosity and is unstratified fertile.
- Loess deposits are usually yellow or buff colour.
- Loess deposits in the Mississippi - valley are called adobe.
- Loess deposits are quite conspicuous in North China.
(easily seen)

(b) Ripples :-

These are small low asymmetrical ridges about 2-5 cm high and stretching parallel to one another.

- Ripples are formed at right angles to the wind direction and transverse to the wind direction.
- Ridges are larger than ripples and have a maximum height of 15 cm they consist of coarse, sand granules and small pebbles.

c) Sand hills :-

Mounds of sand whose surface are irregular are called sand hills.

d) Sand dunes :-

- It is an accumulation of sand shaped by the wind usually in the form of a round hillock or ridge with a crest.
As Arthur Holmes put it any mound or ridge of sand with a crest or definite summit is called a dune.
- Dunes are of various types and their str^u is controlled

by intensity and direction of prevailing wind.

→ It generally develops in strong wind region.

→ Most of the sand dunes are asymmetric in cross-section.

→ Dunes can migrate and increase their direction.

→ Formation of dunes is controlled by

1. amount of sand supply

2. wind velocity

3. constancy of wind direction

4. amount and distribution of vegetation cover

→ The dunes which constantly change from under wind currents are known as live dunes / active dunes, while the inactive dunes which have become more or less stabilised.

→ Types of dunes

a) Barchan,

b) longitudinal / seif dunes

c) Transverse dunes

d) Parabolic dunes

e) whale-back dunes

f) Pyramidal / star shaped dunes

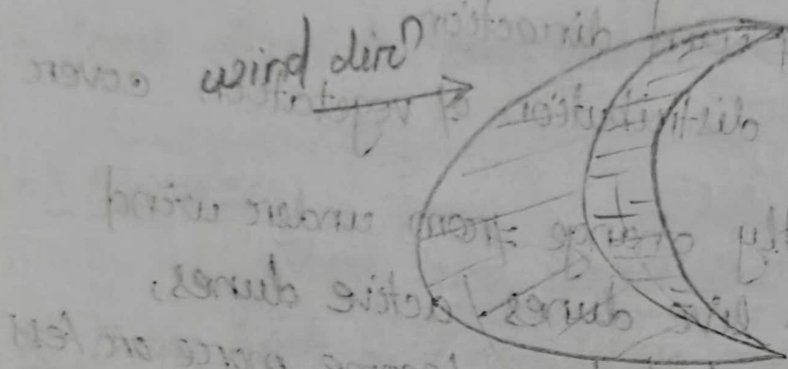
a) Barchan :-

→ These are asymmetrical crescent shaped dunes in which the points or wings of the crescent are directed down wind.

→ Formed perpendicular to the wind direction.

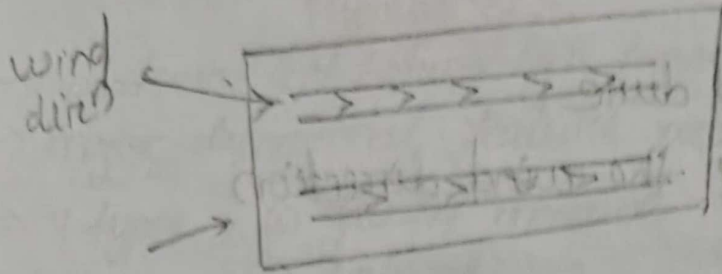
→ Developed in constant wind direction limited sand supply and a flat substrate.

- Formation of barchans is initiated by presence of an obstacle.
- Barchans are usually separated from one another & their heights vary between 1-2 meters to about 20-30 mtr.
- Speed of their movement as great as 47m/year been recorded in peru.



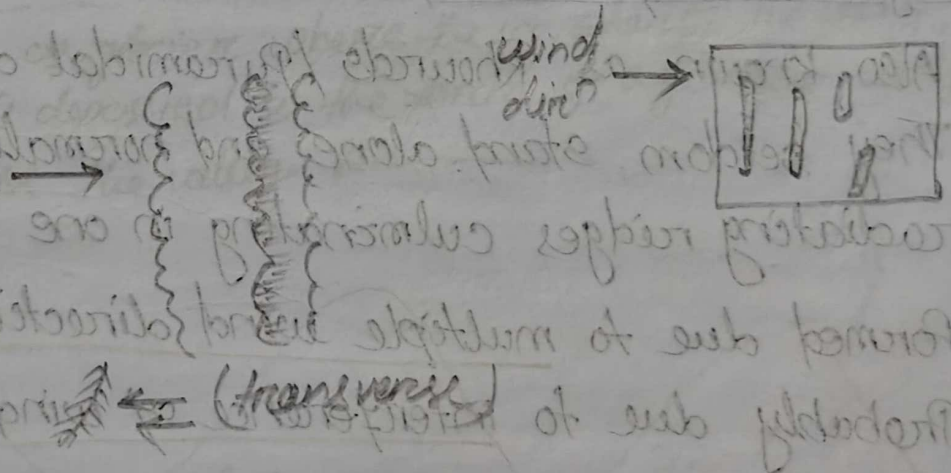
↳ Longitudinal/seif dunes :-

- Large symmetrical ridges of sand formed parallel to the wind direction.
- According to E.W spencer the seif are dunes similar to the barchans except one wing is missing which is caused by an occasional shift in wind direction from which sand is being supplied.
- It is formed in short sand supply and with a constant wind direction.
- There are about 100 km. in length and 100mtr/more in height.
- Long axis transverse to wind direction.
- It shows sheparding effect.



→ Transverse dunes :-

- These are elongated dunes form at right angles to the wind direction.
- They develop where sand supply is abundant and there is no vegetation to interfere with the growth of dunes.
- These are relatively straight and take the form of wave like ridges separated by trough like furrows.
- These dunes may be very long but commonly low heights.
- They are of common occurrence along coast and lake shores.

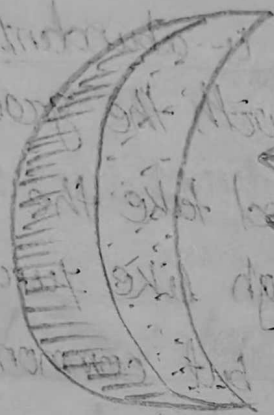


→ Whale back dunes :-

- These are very large longitudinal dune with flat tops.
- They are also known as "sand levels."
- Some times on the top of the whale-back dunes barchans or seifs may occur.

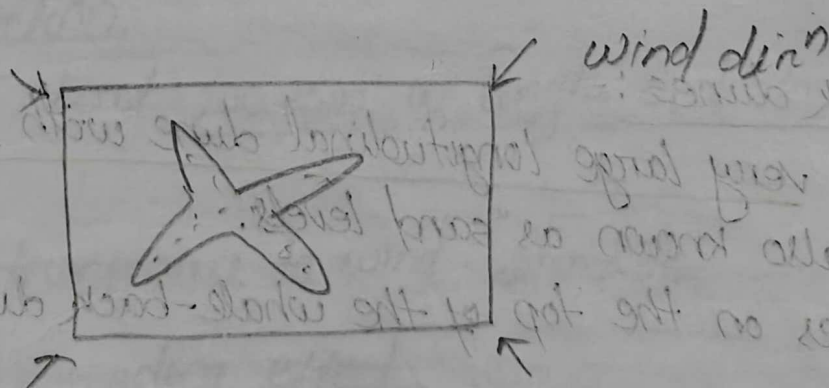
⇒ Parabolic dunes :-

- Asymmetric crescent shaped dune
- wing pointing downwards of the wind direction
- Concave upwind
- Commonly initiates around blowouts
- Abundant sand supply with steady wind direction.
- Presence of vegetation
- Hence the slip face on the downwind side is quite steep



#) Pyramidal / star shaped dunes :-

- Also known as Rhounds / Pyramidal dunes
- They seldom stand alone and normally contain steep-radiating ridges culminating in one or several peaks.
- Formed due to multiple wind direction.
- Probably due to interference of wind waves.



Moraines:-

- material left behind by a moving glacier.
- major depositional feature produced by glaciers
- 4 types →
 - (i) ground moraine
 - (ii) Lateral
 - (iii) Terminal
 - (iv) Medial

Ground moraine:-

- a layer of fill deposited beneath the moving ice, on the ground.
- It fill low spots and old stream channels thereby creating a levelling effect.

Lateral moraine:-

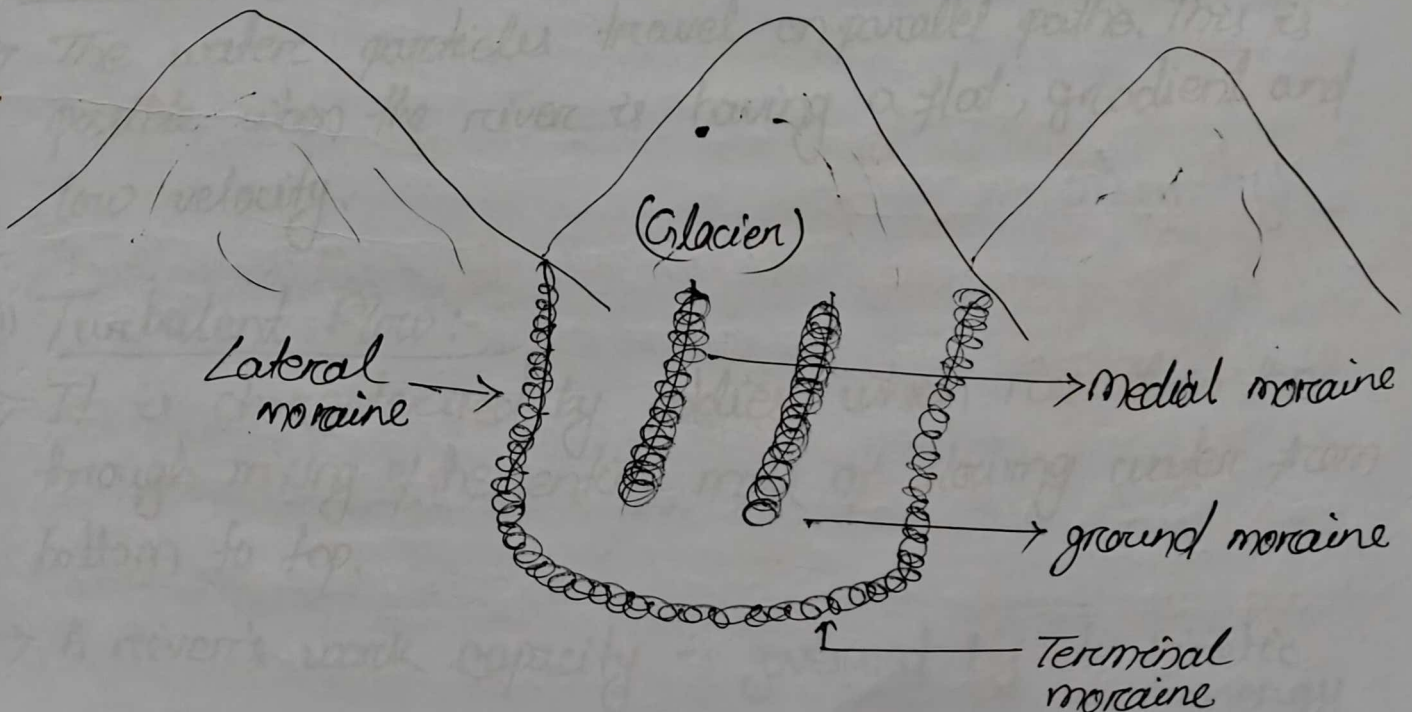
- the material that falls from the valley walls, accumulates on the sides of a glacier. When the glacier disappears, these materials are left ridges along the sides of the valley. Such -----

Medial moraine:-

- when 2 glaciers meet a "medial moraine" is formed by the union of 2 lateral moraines.

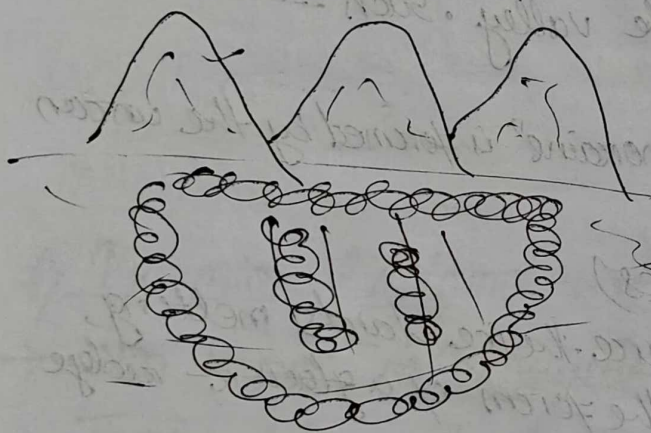
Terminal moraines:- (end moraines)

- At the terminus of glacier where the ice starts melting, the rock debris is deposited in the form of a glacier ridge which extends across the valley. -----



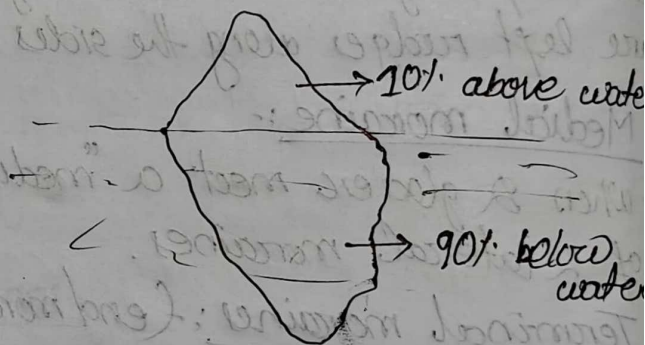
Glacier

- It is a large mass of ice that forms on land usually in mountainous areas and moves slowly downhill.
- It is larger in size
- Entirely above water level & fully visible
- Glaciers are more permanent in nature
- Remain in a fixed place
- It continues to grow with time as long as the snow keeps depositing



Iceberg

- An iceberg is a piece of ice that has broken off from a glacier
- It is smaller in size
- 90% below water & 10% above water
- Icebergs are temporary bodies of ice in the water
- Float with ocean currents and wind
- It doesn't grow with time & may melt away with time



River:-

→ River:- It is defined as a body of running water carrying sediments which flows along a definite path. The path of the river is the river valley.

Run off in river = precipitation - loss

Loss = Evaporation + infiltration

Discharge:-

The flow of water in a river or stream is expressed in terms of volume passing through a point at a given time known as discharge.

Discharge = velocity $\times$ channel cross-section area

→ In rivers the nature of flow of water is characterised mostly by the gradient & velocity.

→ There are 2 types of flow

(i) Laminar / filamented flow

(ii) turbulent flow

(i) Laminar (stream line flow):-

→ The water particles travel on parallel paths. This is possible when the river is having a flat, gradient and low velocity.

(ii) Turbulent Flow:-

→ It is characterised by eddies, which result in the through mixing of the entire mass of flowing water from bottom to top.

→ A river's work capacity is governed by its kinetic energy

$$K = \frac{1}{2}mv^2$$

where, K = kinetic energy of river

m = mass of water

v = velocity of stream flow

→ The river's work capacity is directly proportional to the mass of water and velocity of stream flow.

Geological work of river is divided into 3 types

(i) Erosion

(ii) Transportation

(iii) Deposition

(i) Erosion :-

(i) Hydraulic action

(ii) Abrasion

(iii) Attrition

(iv) Cavitation

(v) Corrosion

→ First 4 are mechanical erosion and last one is chemical erosion.

Hydraulic erosion :-

→ It is the process of mechanical loosening or removal of the material by the action of the water alone.

→ It is the turbulent flow of water which can loosen rock and soil particles along the river channel.

→ Maximum turbulence gives max^m capacity for erosion.

→ Depends on gradient, velocity of the stream, width depth

and shape of the channel discharge.

Abrasion :-

- The process of weathering away of surface by mechanical process such as rubbing, cutting, scratching, grinding, polishing etc is known as abrasion/corrasion.
- The rock wastes which are being carried in the river current as load are responsible for the abrasion action of river.
- If the rock waste is hard and bed rock is soft abrasion of the bed rock is more pronounced.
- If the rock waste is hard and bed rock is hard, abrasion of the bed rock is not remarkable.
- Abrasion may be vertical or lateral. Vertical abrasion causes deepening of the channel, lateral abrasion gives rise to valley widening.

Attrition :-

- The process of mechanical wear and tear of the transported rock fragments through which big boulders are gradually reduced in size and finally reach the size-grade of sand and silt is known as attrition.
- The inter collision between the grains that are carried away by the river irregularities and angularities are worn out they become spherical and rounded.

Cavitation :-

- It is particularly observed where river water suddenly acquires exceptionally a high velocity such as water fall.

- Rapid decrease of velocity reduce the internal pressure in the water.
- where stream velocity exceeds 12-14 m/s the water pressure at that point equals to vapour pressure of water.
- The hammering effect produced by the turbulent water due to sudden variation in velocity.

Corrosion:-

- It is the dissolving capacity of water.
- The chemical process of rock erosion by river water are known as corrosion or solution.
- The effectiveness of the process of corrosion depends much on the composition of rock constituting the river bed and the composition of the river water.

Erosional Land forms produced by River:-

1. Pot holes
2. Water falls
3. River valley
4. Escarpments
5. Wadies
6. River terraces

1. Pot holes:-

- These are cylindrical or bowl like depression in the rocky bed of streams.
- It is produced by drilling effect of swirled round by eddies.
- Potholes may vary in dimensions ranging from a few cm to several meters.

→ large potholes - plunge pool.

2. Water falls:-

→ When a river flows over a surface with broken relief the river laterally falls down from its path from a certain height and acquires normal flow after some distance constructing a waterfall.

→ A series of fall of water is known as CASCADE.

→ Gerasoppa (Jog) waterfalls in the Sharavati River in Karnataka is the highest waterfall in India.

3. River valleys:-

→ The typical river rises in the highlands and flows down due to the pull of gravity.

→ The channels carved out by the running water are known as river valley.

→ These are negative land forms of varying size and shape.

→ Three process such as valley deepening
valley widening
valley lengthening are mainly responsible for development of valleys.

(a) Valley deepening:-

→ Takes place in the youth stage

→ Gorges and canyons are created in which confined water rushes with tremendous force.

→ The process of valley deepening or down cutting generally stops when the base level of erosion is reached.

(b) Valley widening:-

→ The lateral cutting of the river results in valley widening. Due to lateral erosion and rain wasting, weathering and mass wasting.

→ Rivers starts cutting sideways with wide swinging curves and meanders.

(c) Valley Lengthening :-

→ Takes place due to head ward erosion. The valley gets lengthened due to erosion in frontal area.

U shaped & V shaped :-

→ A river's discharge is low in the upper course and the river only has enough energy to erode downwards. This is called vertical erosion.

→ The valley's sides are slowly broken down through weathering.

V-Shaped :-

→ The weathered material is transported via gravity and rainfall towards the river channel. This process steepens the valley side.

→ The steep sided and narrow valley shapes that is created is typical of upland rivers.

4. Escarpments :-

→ Presence of alternating layers of hard and soft rock.

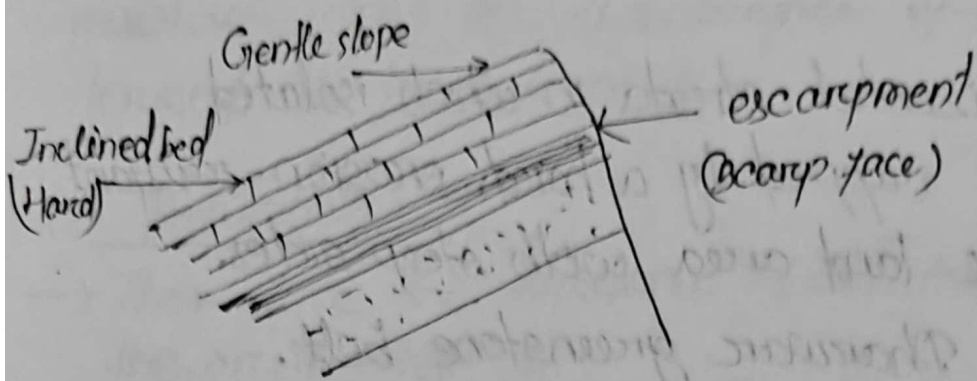
→ This is usually developed in dipping beds with harder rocks overlaying the soft ones.

→ The differential erosion gives rise to a steep slope forming an escarpment.

→ Referred to as homoclinical structure.

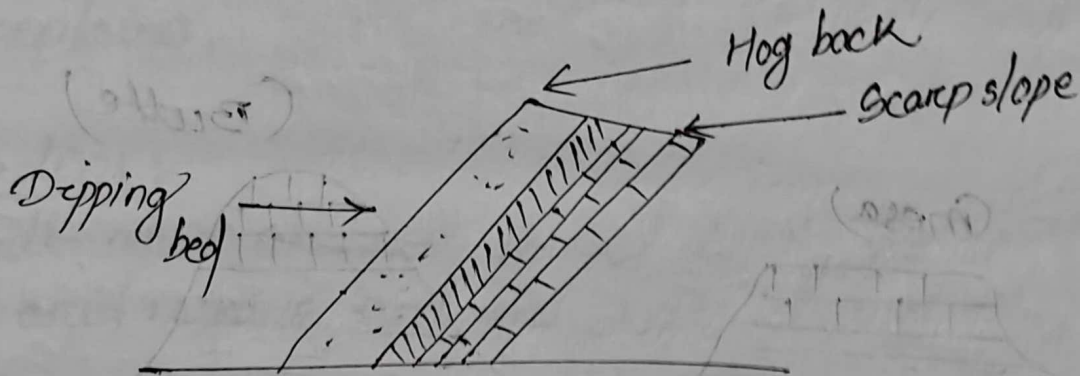
→ This gives rise to a steep slope on one side of the structure and a gentle slope on the other.

The steep side is known as escarpments or scarp face.



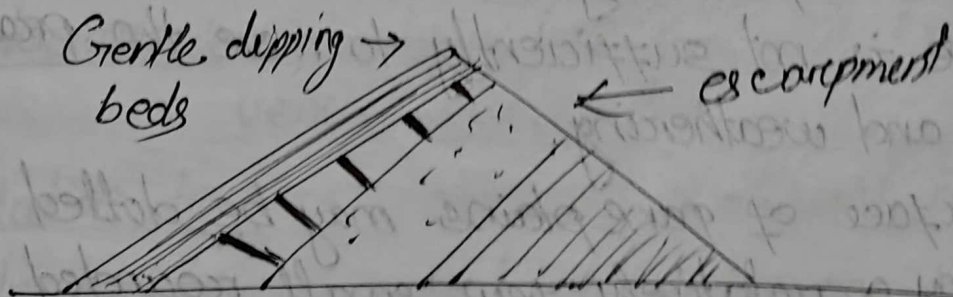
(a) Hogbacks :-

- sharp crested steep, dip of the beds at about 45° on both sides.
- steep slopes on both side



(b) Westeras :-

- Having low to moderate dip
- Seen in coastal plains
- This has the shape of an asymmetric low ridge or hill belt with a steep scarp on one side and a gentle slope on the other.

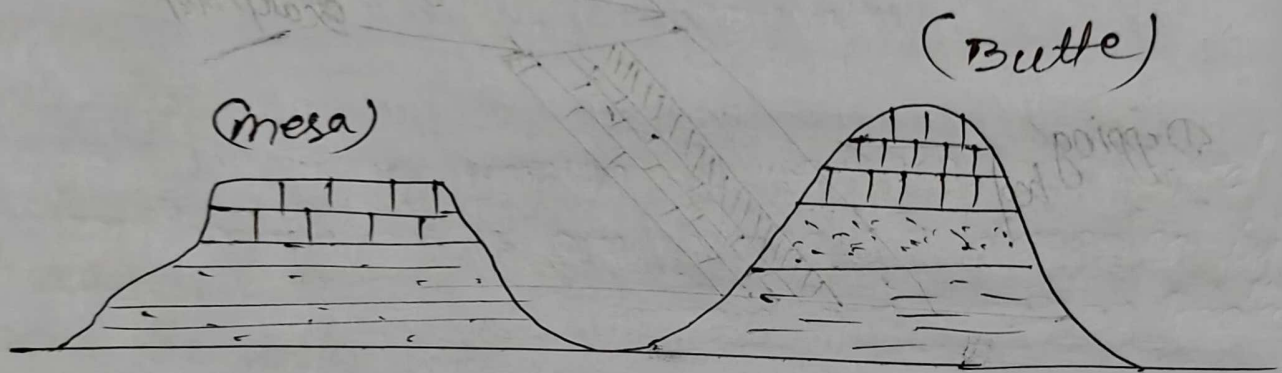


(c) Mesa:-

- In regions of horizontal strata in which isolated portion of land is capped by a hard, erosion-resistant bed, isolated table land area with steep sides.
- Mesa are common throughout greenstone belt.

(d) Butte:-

- Reduction of mesa with continued erosion with a smaller flat topped hill.
- Such features in South Africa are called kopjes.



(e) Pene plain:-

- It is the term used for the nearly smooth erosion surface or relatively low relief and altitude which covers a large area.
- It involves a temperate-humid climate.
- Hence the slope is gentle that the river's velocity down the slope is not sufficiently to move the products of erosion and weathering.
- The surface of pene plains may be dotted here and there by a relatively few small rounded hills, underlain by resistant rocks.
- These hillocks made up of harder, durable and

resistant rocks on the surface of the peneplain are termed as Monadnocks.

(4) Pediments:-

- These are the erosional land forms mostly formed in the arid regions.
- The land form is a gently sloping plain worn down by scarp retreat.
- The vast plains formed by the convergence of many pediments are termed as pediplains.
- Pediplains are often considered as analogous to peneplains.

5. Wadies:-

- Small river channels formed during the rains in deserts and arid regions and also known as washes.

6. River - terraces:-

- Erosional features consisting several step like plains along the river side.
- Occurs with Rejuvenation - attainment of youth stage in mature and old stage.
- Development of youthful topographic features in a landmass having stable features is known as Rejuvenation.

a) Erosion terraces:- Entirely of bed rock with thin alluvium veneer (bed-rock)

b) Accumulative terrace:- composed of alluvial deposit

c) Composite terrace:- consist of the terrace-bench composed of alluvium while the bed-rock lies at the base of their cusp.

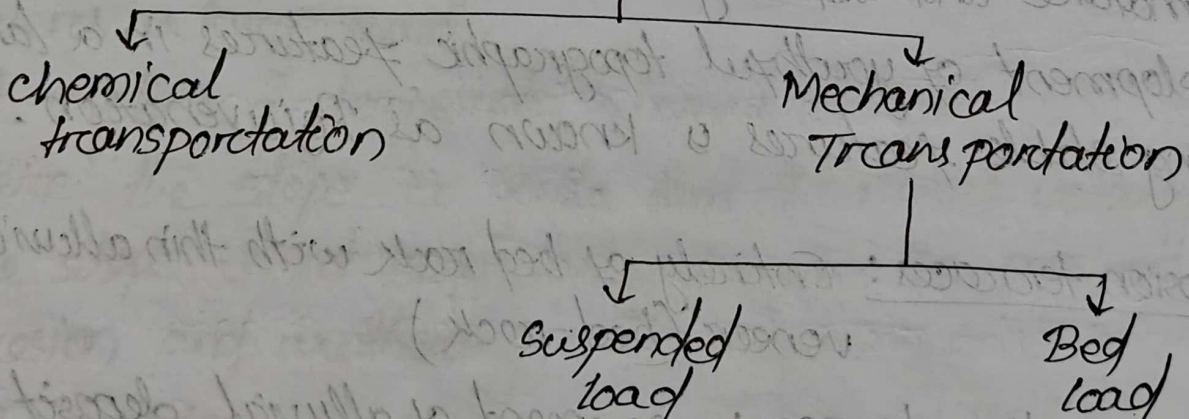
- The erosion terraces are also known as bed-rock terraces.
- Accumulative terraces are also known as alluvial terraces and the composite terraces are rock-defended terraces.
- The winding gorge digs deep into the solid rock beneath such gorges are called incised meanders.
- If the rock of an incised meander is narrow, the intervening ridge of rock may be cut through down below from both the sides forming ultimately what is called a natural bridge.

Badlands:-

- Due to pronounced erosion the terrain constituted of argillaceous rocks are intricately dissected by gullies and ravines such terrain are known as Badlands.

(ii) Transportation:-

Transportation of load of a river



Chemical transportation:-

- Limestone, dolomites and salts are very soluble and some compounds of iron, manganese, phosphorous etc. are transported in the form of colloidal solution.

Mechanical transportation:-

- This is influenced by 3 main factors as follows

i) Velocity of the river - current

ii) Nature of the river - current

iii) Density of rock material to be transported

(a) Suspended load:-

- Fine particles of clay and silt are transported in suspension.

- The intensity of turbulence and the velocity of the river flow determines the length of time a particle remains in suspension.

(b) Bed load:-

- It comprises the heavier particles of sand, pebbles, gravels and cobbles.

Saltation:-

- Lifted up by the eddies and is carried to some distance
- The smaller the particles the higher the lift and longer than jump.
- This process of saltation is mostly effective in the transportation of sand grains.

Traction:-

- The transportation of sediments by creeping is known as traction.

- Bigger fragments of rocks like boulders, cobbles and pebbles.
- The weight of fragments that can be rolled along the bottom is proportional to the sixth power of the stream velocity, according to the Airy's law.

(iii) Deposition :-

Occurs due to

- a) decrease in the velocity of river
- b) decrease in slope or gradient
- c) decrease in volume of water i.e. discharge
- d) change in channels
- e) chemical precipitation

Depositional features :-

1. Alluvial Fans and cones :-

- when streams flow abruptly from steeper to gentle gradients as at the base of a mountain or ridge, If its velocity is checked and the huge quantities of materials carried by the river are dropped there giving rise to a broad, low-cone shaped deposit called an alluvial fan.
- when the slope of the fan is greater than 10° , it is called as alluvial cone.
- A series of adjacent fans may in time coalesce to form an extensive piedmont alluvial plain also known as Bayada.

2. Flood - plain deposits:-

- Flood plains are areas of low and relatively flat and bordering the channel on one or both the sides at bank level. These areas are readily submerged under water during flood time, when the water over tops the banks of the channels and rises above the channel at low water.
- Deposits formed on flood plain by flood water outside the actual channel are known as overbank deposits.

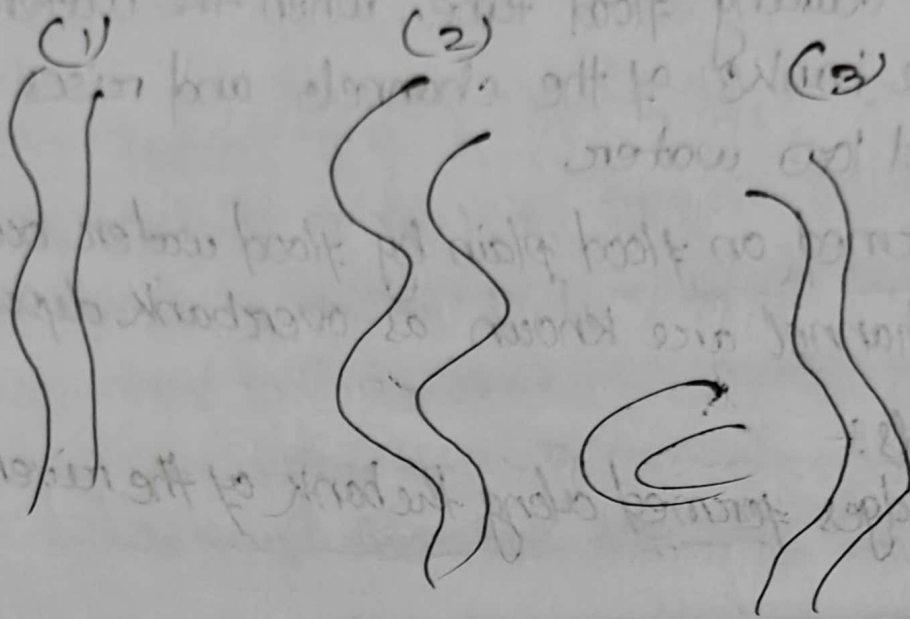
3. Natural levels:-

- Broad low ridges formed along the bank of the river during floods.

4. Meanders or ox-bow lake:-

- The sweeping in to curved sinus path of river generally in flood plains are known as meandering of river.
- It develops due to
 - * presence of any obstacle
 - * different erosion on the river banks
 - * development of ox-bow lake
 - * point bar deposits are found
- Erosion becomes more towards the outside of each bend and the channel depends along the downstream part of the bend which is also termed as under cut side.
- At the same time there starts deposition towards the inner side of each bend forming that is known as the slip off slope.
- A meander grows until it becomes bulb shaped with a narrow neck.

- The deposits formed at the steep off slope of a meandering river is known as point-bar.
- It is also known as oxbow lake or horse shoe shaped lake.
- River sinuosity = $\frac{\text{length of the channel}}{\text{absolute length of the channel}}$.



Braided Rivers :-

- It is a phenomenon of dividing and reuniting the river channels.
- Deposition starts near the centre of the channel.
- Generally developed due to steeper slopes $> 0.1^\circ$, unstable banks, High bed load.

Delta :-

- Formed at the last stage of river where it meets a sea / lake.
- Formed where strong wave currents are absent.
- Delta are considered to be the submerged equivalent of alluvial fans.
- Sometimes the tides and currents may be sufficiently strong to prevent any considerable deposition and the mouth of the river remains open forming that is

called as estuary.

→ On top of forest beds, the layers of sediments lie which have a gentle sea ward slope. These are known as top-set beds.

→ On the basis of shape of the deltas are classified as

i) arcuate delta

ii) bird-foot delta

iii) Cuspate delta

→ Deltas provide extensive flat fertile land which support dense agricultural population.

Ex :- the ganges delta,

the Nile delta

the mississippi delta

Cycle of erosion:-

The concept of cycle of erosion was formulated by William Morris Davis an American geomorphologist towards the end of the 19th century.

(Top set beds)

(Bottomset beds)

(Forest beds)

(Bedding of a Delta)

→ In a normal cycle there are 3 stages.

i) Youth stage

ii) Mature stage

iii) Old stage

(i) Youth stage:-

→ There is intensive bottom erosion, the gradients are steep and the erosion is rapid.

→ The rapid deepening of the channel leads to the formation of V-shaped valleys.

→ Lakes, rapids, water falls, steep sided valley and gorge are of common occurrence during this stage. The phenomenon of river capture / river piracy takes place in this stage.

River capture:-

→ process of diversion of a river by the headward migration of another river is known as river capture / river piracy.

→ The point where the course of second river is diverted is known as Elbow of capture.

→ The capture river is known as Misfit and the deserted part of its channel through which no water flows is termed as the wind-gap.

(ii) Mature stage:-

→ rivers flow with a graded profile i.e. it attains a profile of equilibrium.

→ Ridges and valleys develop prominently flood plain develop and river-meandering takes place.

→ Hog backs, Cuestas, mesa, butte, meanders, oxbow lakes, natural bridge, flood plains, alluvial fans etc.

(iii) Old stage:-

→ the gradients are gentle and the velocity is low. In old stage a river has maximum meandering.

→ Features like peneplains, natural levees, delta.

→ Bhangera is the name of the oldest alluvium.

* Playas:-

→ the lake bed in many deserts

→ (shore or beach) also called pan, flat or dry lake, flat bottom depression found interior desert basin and adjacent to coasts with in arid and semi arid regions, periodically cover by waters that slowly filters into the ground water system or evaporates into the atmosphere

→ Namada doesn't form a delta.

* Knick point:-

→ It is a part of a river or channel where there is sharp changes in channel slope such as waterfall or lake.

* Sag pond:-

→ It is a body of water that has collected in a depression formed betⁿ the two sides of an active strike slip fault zone, such as the San-Andreas.

* Strath:-

→ It is a large valley typically a river valley that is wide and shallow.

→ Fining upward sequence indicates decreasing depositional

energy which is evident in all the rivers (fluvial environment)
As the depositional energy decreases, coarser grains
settle first.

* Largest delta → Ganga - Brahmaputra

→ The lake bed in many deserts (shore or beach) also called pan, flat or dry lake flat
bottom depression found interior desert basin and
adjacent to coasts with in arid and semi arid regions
periodically cover by water that slowly filters into
the ground water system or evaporates into the atmosphere
→ Horns of a delta

Knick point: It is a part of a river or channel where there is
sharp change in channel slope such as waterfall or lake

Bad land: It is a body of water that has collected in a depression
formed betⁿ the two sides of an active strike slip fault
zone, such as the San Andreas.

Strath: It is a large valley typically a river valley that is eroded
and shallow.

→ Finding upward sequence indicates decreasing depositional

Igneous Rock

- Rocks are aggregates of minerals that constitutes a unit structure of the earth's crust.
- Petrology is the science of geology that deals with the study of the rocks and it includes.

(a) petrogenesis:- the origin and mode of occurrence as well as natural history of rocks.

(b) Petrography:- dealing with classification & description of rock.

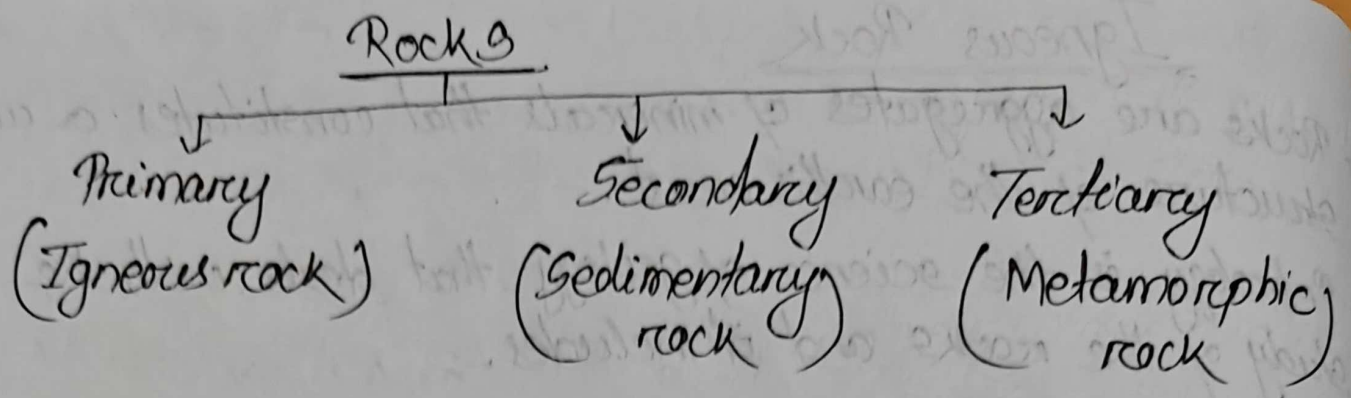
The Earth zone :-

- Bary sphere → inaccessible heavy interior of earth
This is followed outwardly by lithosphere; the thin rock crust of earth then by more or less continuous.
- The earth zone of igneous rock activity and lava formation situated betⁿ the lithosphere and the barysphere is known as "pyrosphere"
- A zone towards the base of the lithosphere which can sustain a little or no stress has been called the "asthenosphere" (sphere of weakness) by Barroel.
- The zone in which crustal movements originate has been named as "tektoisphere"

Classification of rocks :-

Rocks formed a major part of the earth crust. They may be defined as aggregates of minerals.

Some rocks such as quartzite (Quartz) and marble (calcite) contains grains of one mineral only. But most are composed of a variety of different minerals.



Igneous rock :-

- It is formed by the cooling and solidification of magma.
- e.g. granite, basalt, diorite, gabbro, pegmatite and peridotite

Sedimentary rock :-

- It is formed by consolidation and cementation of sediments deposited under water
- e.g. sandstone, dolomite
limestone, laterite
Chalk

Metamorphic Rock :-

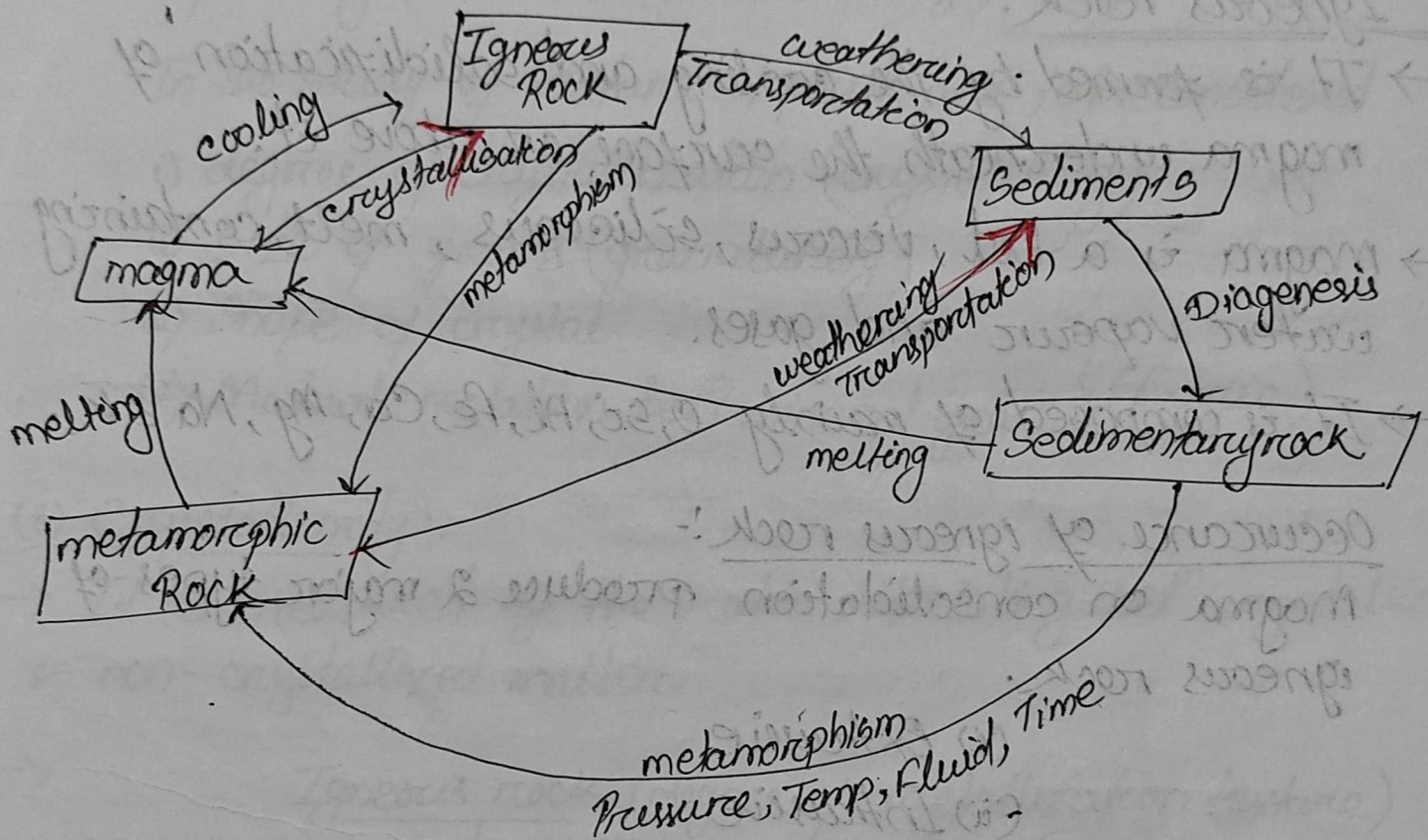
- It is formed when pre-existing rock have been changed in texture and composition by increased temp. & pressure.

e.g. slate Gneiss hornfels
phyllite Quartzite
Schist Marble

Characters of rock:

- i) A mass of mineral matter
- ii) It must be a unit of earth's crust
- iii) It must be consolidated solid substance
- iv) It may be made up of 1 mineral in large quantities (monomineralic rock) or may be made up of several minerals in different quantities.

Rock cycle :-



→ The rock cycle shows relationship betⁿ 3 types of rocks. Erosion produces sediments which is transported and deposited in to deep basins under the sea. Then it hardens to form "sedimentary rock".

→ If these rocks are deeply buried, then temp. & pressure turn them into metamorphic rock.

- Intense heat at great depth melts metamorphic rock and produces magma. The magma may rise up and reach the earth's surface where it cools to form "Igneous rock".
- At the surface igneous rocks are exposed to weathering and erosion and the cycle begins again.

Igneous rock:-

- It is formed by the cooling and solidification of magma underneath the surface or above it.
- Magma is a hot, viscous, siliceous, melt, containing water vapour and gases.
- It is composed of mainly O, Si, Al, Fe, Ca, Mg, Na & K.

Occurrence of igneous rock:-

Magma on consolidation produce 2 major types of igneous rock.

(i) Extrusive

(ii) Intrusive

(i) Extrusive :-

- The rocks formed due to solidification of lava are called "extrusive rocks"/"volcanic rocks"
- Texture of volcanic rocks are generally fine grained and crystallization of lava.
- It contains gas & cavities

Texture of igneous rock:-

→ Texture means mutual relationship betⁿ crystal and glassy material present within igneous rock.

Also it means size, shape, arrangement of mineral grains in rock.

The grain size of an igneous rock depends on the rate of cooling of magma. In general slower is the rate of cooling, the coarser is the grain of rock.

In the study of texture 4 points are to be considered

i) degree of crystallization (crystallinity)

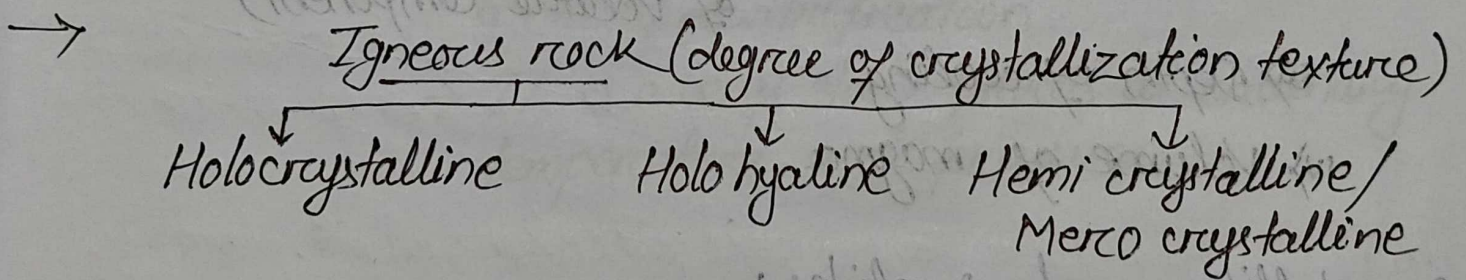
ii) Size of grains (granularity)

iii) Shape of crystal

iv) Mutual relation betⁿ mineral grain } (Fabric)

(i) Crystallinity:-

→ It is measured by the ratio subsisting betⁿ crystallized & non-crystallized matter.



a) Holocrystalline:-

→ when an igneous rock is made up of entirely of crystals.

→ Slow cooling always favours the formation of crystals so the igneous rock that formed at greater depth (i.e. plutonic) are holocrystalline.

(b) Holohyaline :-

- when a rock is composed entirely of glassy material, its texture is called "holohyaline".
- Hence the magma comes out to the surface and suddenly cools down to form a glassy matter.
- They occur mostly as marginal faces of rock bodies and also occur as loaves (obsidian) or as dykes or sills (pitch stone).

(c) Microcrystalline / Hemi crystalline :-

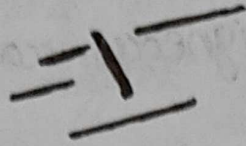
- when a rock is composed partly of crystals and partly of glass, the texture is called microcrystalline.
- These are that have consolidated on/near the surface.
- Degree of crystallisation depends on:
 - i) Rate of cooling
 - ii) Viscosity of magma (composition of magma & presence of volatile component)
 - iii) Depth of cooling
 - iv) Volume of magma

Crystallites and microlites :-

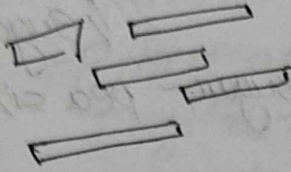
- Crystallites are embryo crystals not yet organised to full crystalline structure.
- Crystallites have more varied form
 - a) Globulites :- minute spherical drops probably consisting of iron oxide.



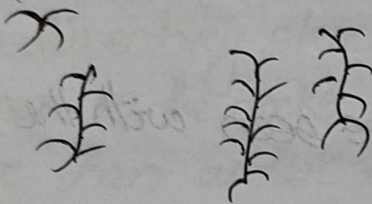
b) margarite :- when globulites elonged and contact like string the resulting form is called margarite.



c) Longulites :- cylindrical rods with rounded ends



d) Trichites :- hair like forms which often start from common centre



e) Scopulites :- rods carrying branches



* Microclites :- larger bodies and are usually rod shaped.)

* Devitrification :- transformation of glassy to crystalline matter is called devitrification

→ It is a very slow process at ordinary temperature and pressure.

✓ (ii) Granularity :-

→ It refers to the grain size of the crystal present in the igneous rock.

→ 2 broad terms are used for the description

a) Phaneritic / phanero crystalline

b) Aphanitic

a) Phaneritic :-

- when individual crystals are visible to the naked eye
- The texture of phaneritic igneous rocks can be further subdivided as

- i) fine grained → grains are smaller than 1mm ($< 1\text{mm}$)
(sugar granules)
- ii) medium grained → 1-5mm diameter (sugar - pea size)
- iii) Coarse grained → 5-50 mm diameter
- iv) Very coarse " → $> 50\text{ mm}$ diameter

b) Aphanitic :-

- when the grains are too small to be seen with the naked eyes are called "Aphanitic"

Types :-

- i) micro crystalline :- when individual crystals are distinguishable only under microscope
- ii) Mero crystalline :- partly distinguished
- iii) Crypto crystalline :- when the individual crystals are too small to be distinguished separately under microscope
- iv) Glassy :- when there is no crystallization at all.

In general, pegmatitic and plutonic rocks are coarse grained and volcanic rocks are either fine grained or glassy.

The grain size of crystals depends on the rate of cooling and on the viscosity of the magma.

(iii) Shape of crystal :-

- The fabric or pattern of a rock depends on the shapes & on the relative sizes and arrangement of crystals.
- It refers to the degree of development of crystal faces.

of Euhedral :- when the mineral grains have perfect crystal outline.

- These are known as idiomorphic / automorphic crystals.

e.g. Lamprophyre

Long Structure of sedimentary rock :-

- The sedimentary structure may be defined as those large features in the rocks which can be studied in the field rather than under thin section.
- Sedimentary rocks structures are both organic & in-organic in nature.
- Depending upon the mechanism of formation, the in-organic structures are classified into primary & secondary structure.

Inorganic structure :-

(i) Primary structure :-

It is due to mechanical action of current & show the following characteristics.

- i) These structure show palaeo-current direction
- ii) Rate of supply of sediments
- iii) mode of transportation
- iv) top & bottom of beds

- The primary structures include the following

of Bedding / Stratification :-

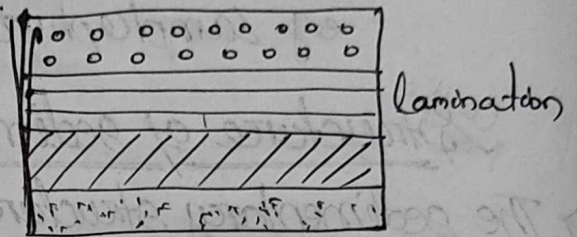
- Deposition of insoluble material or sediment into layers or beds on the surface of accumulation is called "stratification".

→ The planes dividing different beds are called the "bedding planes".

→ Different beds are distinguished from each other by

- i) difference in mineral composition
- ii) variation in grain size or texture
- iii) difference in colour
- iv) variation in thickness

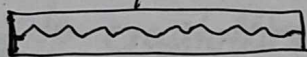
→ If the individual layers are extremely thin ($< 1\text{cm}$), the structure is known as "lamination" and the layers are "laminae".



→ Lamination

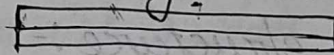
↓
Diplectic
Lamination

* contact betⁿ 2 laminae
is sharp



↓
Symplectic
Lamination

* contact betⁿ 2 laminae
is rough



→ Lamination is usually found in very fine grained rock like shale.

→ The plane of contact is known as laminating plane i.e.

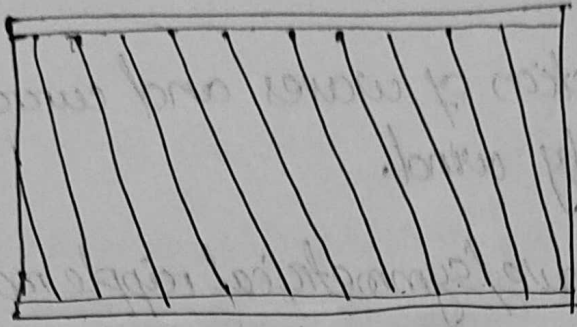
b) Cross bedding/cross stratification :-

→ The minor beds/lamination lie at an angle to the plane of general stratification.

→ It is formed due to change in the velocity and direction of flow of stream.

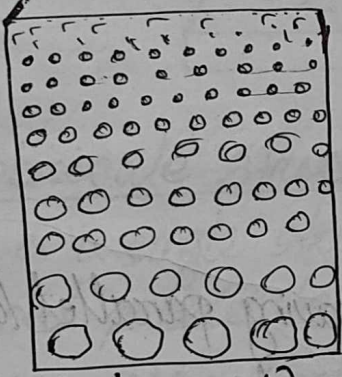
→ It also known as current bedding/false bedding.

→ It is commonly found in shallow water and wind formed deposition.

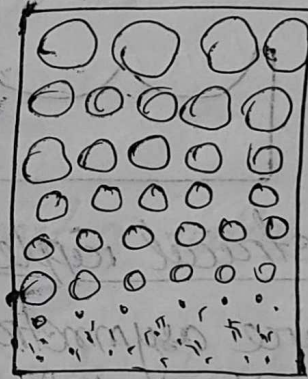


c) Graded bedding:-

- There is a gradation of grain size from coarser at the bottom to finer at the top.
- The graded bedding results from rapid sedimentation in water.
- Graded bedding are seen in "gray wackes"



(Normal)



(Reverse).

d) Torrential bedding:-

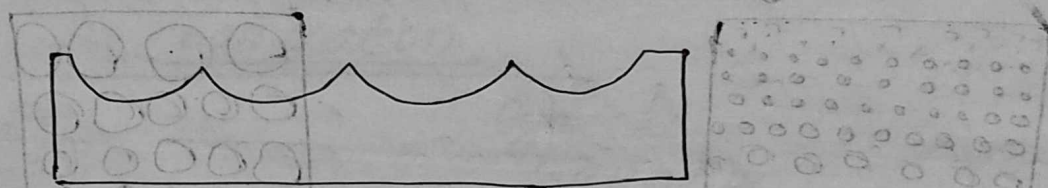
- It shows an alternation of coarser current bedded materials and their finer horizontal laminae.
- When deposition takes place in such a manner that thin horizontal beds made up of fine material are found to lie in alternation with coarse and current bedded deposits the resulting structure is known as torrential bedding.
- Here the finest beds are straight and they characteristically develop in alluvial fans.

→ Ripple marks :-

- These are minute/wavy undulation seen on the surface of bedding planes.
- They produced by the action of waves and currents in shallow water and also by wind.
- 2 types (i) Oscillation/wave/symmetrical ripple mark
(ii) Current/asymmetrical ripple mark

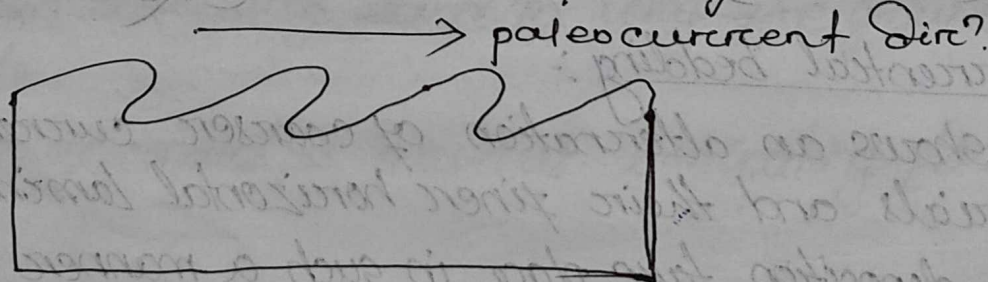
(i) Symmetrical ripple mark :-

- These are symmetrical with sharp and broad rounded trough.
- This structure is used to determine tops and bottoms of bed.



(ii) Asymmetrical ripple mark :-

- These are asymmetric in nature, having parallel long ridges. Hence both the crest and troughs are rounded.



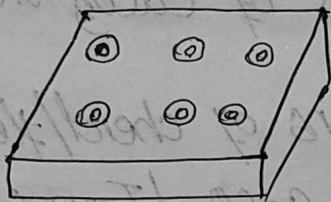
(7) Mud Cracks :-

- These cracks typically develop in clayey sediments as a result of drying.
- These are also known as "shrinkage cracks" or "sun cracks".

→ They are the widest at the top but tapers towards the bottom.

(g) Rain prints :-

→ These are small circular to elliptical depression in wet muds also in fine grained rocks by the impact of rain/hailstone bubbles etc.



(h) Imbricate structure :-

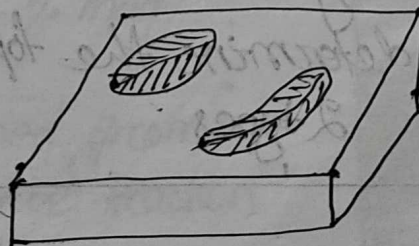
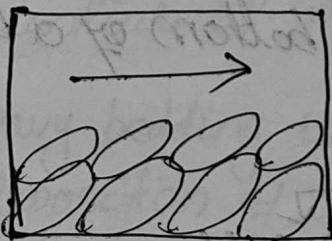
→ It is a single structure in a deposit of flattened/disk-shaped pebbles/cobbles.

→ Some pebbles beds show an imbricate structure with the pebbles leaning in the direction of the current.

(i) Tracks and trails :-

→ These are marking indicative of the some animal over soft sediments.

→ Trails are the winding passages through which long/short bodied animals moved.



(ii) Secondary structure:-
→ These are the products of chemical action within the sediments after their deposition and before consolidation.

(a) Concretions:-

- These are various shaped masses and nodules of mineral matter found within a sedimentary rock.
- Their shape may be spherical, ellipsoidal, lenticular or irregular.
- Their chemical composition different from the enclosing rock.
- Concretions generally consists of CaCO_3 or Silica.

Ex:- In limestone (concretions of chert/flint)
Clays (concretion of CaCO_3 / Iron sulfide)
Sandstones (concretion of iron oxide / CaCO_3)

b) Solution structure:-

- These are irregular openings in calcareous rocks and are produced by groundwater action.

ex:- Vugs

Graded bedding:-

- characterised by distinct vertical gradation in grain size.
- Formed by turbidity current
- It is used to determine the top and bottom of a bed.

2 types

Normal
(vertical fining up sequence)

Reverse
(vertical coarsening up sequence)

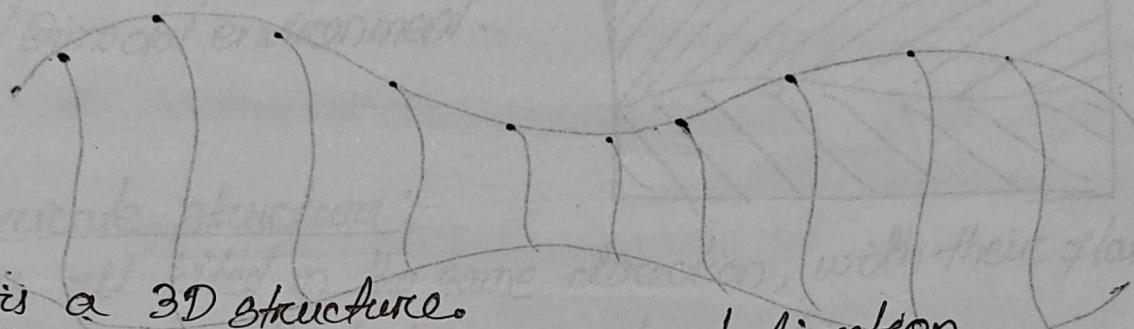
→ Reverse bedding has been attributed by 2 process.

Dispersive pressure:-

- It is directly proportional to grain size.
- It is always slows the settling velocity.
- So finer grains settled first than coarser.

Kinetic sieving:-

- In this mechanism, finer grains fall down through the spaces of larger grains to be deposited at the bottom.



- It is a 3D structure.
- used to determine ~~place~~ current direction.
- Used to determine top and bottom of a bed.

Flaser, wavy, lenticular bedding:-

- These types of bedding are formed under fluctuating hydraulic activity (are under which alternating flowing water and stagnant water)
- During stagnant condition mud is depositing and during flowing condition sand is deposited.

- * Flaser $\Rightarrow$ % sand $>$ % mud
- * wavy $\Rightarrow$ % sand = % mud
- * Lenticular $\Rightarrow$ % sand $<$ % mud

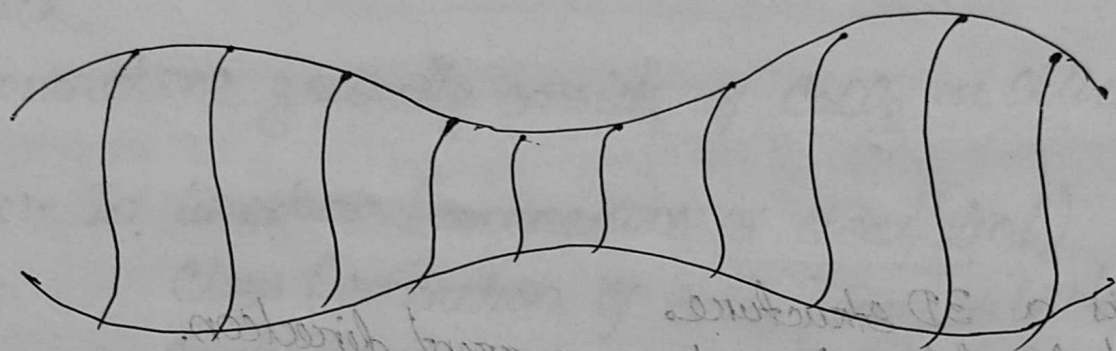
- wavy bedding is formed from deposition of alternative traction and suspension load.



→ Seen in total and intertidal environment.

Hummocky cross-stratification:-

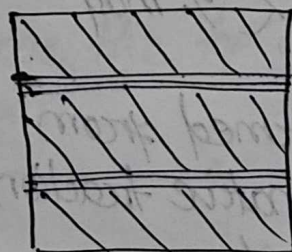
- It is characterised by undulating sets of cross-laminae that are both concave up (swales) and convex up (hummocks)
- Formed by both unidirectional and oscillatory current flow.
- Steps are 15-30 cm thick
- Formed during storm activity
- Commonly confined to shallow marine or lacustrine sedimentary rock.



- These are typically occurring fine sandstone to coarser siltstone that commonly contains abundant mica and fine carbonaceous plant debris.
- Cross bed cuts gently into each other with curved erosion surface.
- Dip angle $< 12^\circ$

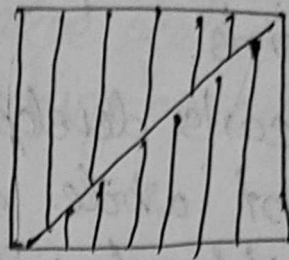
Torrential bedding:-

- It shows an alternation of coarse current bedded material and finer horizontal laminae.



Wedge shaped cross bedding:-

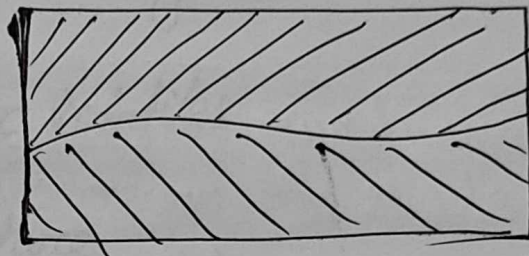
- When top and bottom converge at a point, it is called wedge shaped cross bedding.



Herringbone cross stratification:-

- Type of sedimentary structure formed in tidal areas, where the current periodically flows in the opposite direction.

- Tidal / Bimodal environment.



Imbricate structure:-

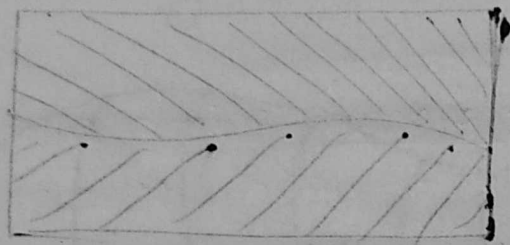
- Pebbles all tilted in the same direction, with their flat sides commonly displaying an upstream dip.
- Long axis of the pebbles lying more or less parallel to one another. Leaning in the direction of current flow.
- Useful in paleocurrent analysis.

Slump structure:-

- This term have been applied to structures produced by penecontemporaneous (immediate after deposition) deformation resulting from movement and displacement of unconsolidated / semi-consolidated sediments mainly under influence of gravity.
- Typically occur in mudstones and sandy shales.

Load casts :-

- A bulbous depression formed on the base of a bed of sediments.
- Load casts develop by the differential sinking of the sediment while still soft into less dense sediment below.
- Gravitational instability
- They commonly occur in the sole of sandstone beds that overlie mudstone or shale.
- Load casts are not strictly casts as they do not infill an existing depression as in the case of flute casts.



Intricate structure :-
Pebbles all tilted in the same direction, with their flat sides commonly displaying an upstream dip.
Long axis of the pebbles lying more or less parallel to one another, leaning in the direction of current flow.
Bed in paleocurrent analysis.

Shallow structure :-
This term has been applied to structures produced by erosion of soft sediments (immediate after deposition) consisting from movement and displacement of unconsolidated, semi-consolidated sediments mainly under influence of gravity.

Typically occur in mudstones and sandy shales.

Structure of Igneous Rock:-

- The term structure refers to the large scale feature / field characters of rocks such as bedding or columnar structure or pillow structure.
- The factors on which structure of igneous rock depends are given below
 - i) Composition of magma
 - ii) Viscosity of magma
 - iii) temp. & pressure at which cooling and consolidation takes place
 - iv) Presence of glass and other volatiles

Igneous structure

Mega structure

Minor structure

Micro structure

(a) Mega structure:-

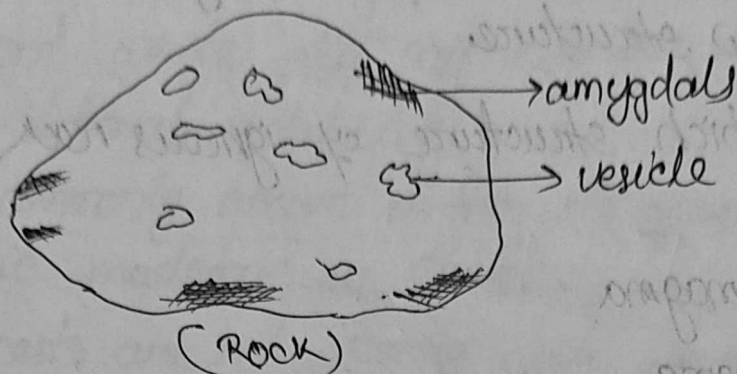
- These are formed in the flow stage of the magma (i.e. in extrusive rocks) and it includes

(i) Vesicular and amygdaloidal structure:-

- Most lava contain large amounts of gas and volatiles. These gas and volatiles escape into the atmosphere when they solidify on the earth's surface. As a result numerous gas cavities are formed near tops of lava flows.
- These gas cavities are called the vesicles and the volcanic rock which contain vesicles is said to have "vesicular structure".
- The vesicles are subsequently filled by secondary minerals such as calcite, zeolite, these are called

amygdales and the rock is said to have an amygdaloidal str^u.

→ These are the usual characteristics of basic lava flows.



(ii) Lava drains tunnels :-

→ Sometimes the upper surface of lava consolidates the interior may still remain fluid. When the enclosed lava drains out through some weak spot the resulting structure is known as lava drain tunnels.

(iii) Cellular / scoriaceous structure :-

→ If the lava is heavily charged with volatile and gaseous constituents, then numerous cavities are formed with the solidification of lava.

→ When the cavities are very much abundant, the term "pumice" or rock-froth is applied.

→ Such structures are known as cellular or scoriaceous structure.

→ These are characteristic of highly siliceous lava.

→ Scoria, pumice → float in water.
(rock name)

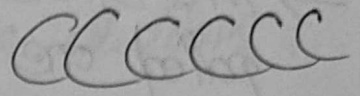
Block lava :-

→ Lavas of acidic composition due to their high viscosity, don't flow to greater distance. They after solidification gives rise to a rough and clinkery like surface. Such lava flows are known as "block lava."

→ It is also known as "aa" structure.

→ Block lava issues at a lower temperature.

→ In block lava the cavities are larger and irregular in shape.



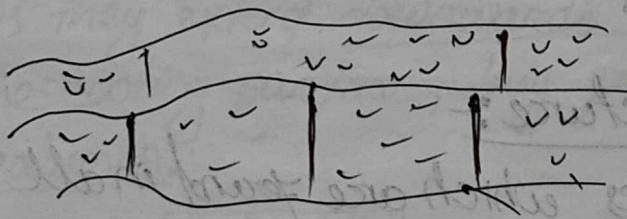
Ropy Lava :-

→ Lavas of basic composition due to their low viscosity, they can flow to greater distance and after solidification offers a smooth surface and exhibit wrinkled. Such lava flows are known as "Ropy lava".

→ It issues at a high temp.

→ In ropy lava the cavities are smaller and regular in shape.

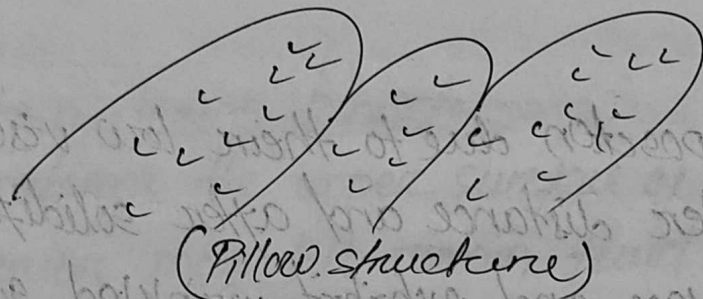
→ It is also known as "Pahoehoe" structure.



(Blocky lava)

(v) Pillow structure:-

- When lava of basaltic composition flows over sea floor after solidification it gives to a pillow like structure on the lava surface.
 - This structure consist of isolated pillow shaped masses piled one upon another.
 - These pillow are commonly glassy outside and finely crystalline inside.
- ex:- Spilitite, a lava rich in albite exhibits pillow structure



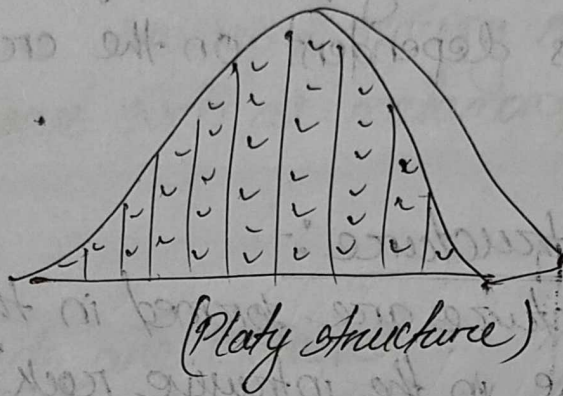
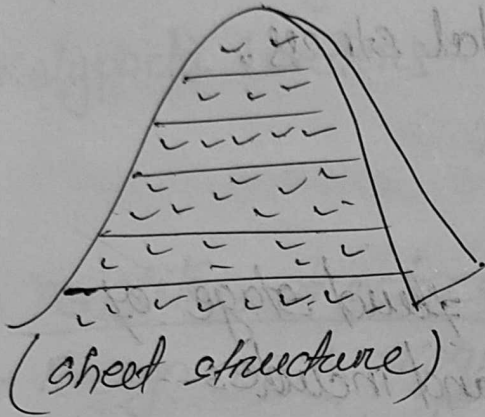
Flow structure:-

- A structure in igneous rock in which the stream line or flow lines of the magma / lava are revealed by parallel / sub parallel, bands / streaks of different composition.
 - These are formed during cooling and crystallization of lava.
 - Such structure are called flow structure.
- ex:- Rhyolites, trachytes

Jointing, sheet and platy structure:-

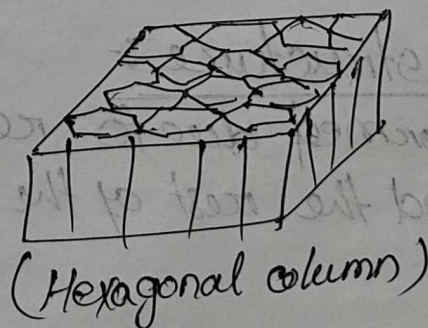
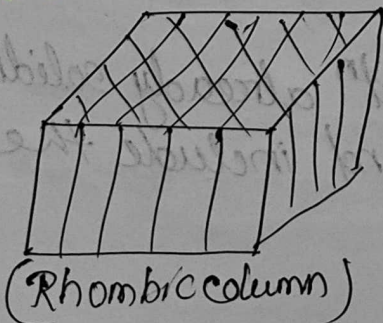
- Joints are divisional planes which are found in all kinds of igneous rock.
- In granites, it is common to find 3 set of joints, One is horizontal & 2 are vertical and $\perp$ to each other.

- The horizontal joints planes are some time so closely spaced to produce a sheet structure.
- Due to the development of different sets of joints which gives rise to only plates of the rock mass on striking the rock such as feature is called platy structure.
- These type of structure developed after the plutonic rock is exposed due to erosion.



Columnar and prismatic structure:-

- With uniform cooling and contraction a few sets of vertical joints develop such joints, bring about the formation of columns which may be square, rectangular, rhombic / hexagonal in outline.
- The columns develop perpendicular to the cooling surface so that in a lava flow they stand vertically.
- As they extend downwards or upwards or laterally from the cooling surface, they produce well known prismatic columns.



Rift and grains :-

- In granites, 3 mutually $\perp^{\circ}$ equally spaced joints are taken into advantage while producing cubical blocks are known as "moral jointing".
- But for the processing of the rock down to smaller dimensions, they mutually $\parallel^{\circ}$ closely spaced joints are taken into advantages. These joints are known as rift and grain is dependent on the crustal stress.

(b) Minor structure :-

- These structures are formed in the fluid stage of the magma (i.e. in the intrusive rock) and includes --

(i) Primary foliation :-

- Plutonic rocks are characterised by foliation. These are formed by the parallel arrangement of platy and ellipsoidal mineral grains.

(ii) Banding in Rocks :-

- These are also known as layered rocks consisting of alternation bands of different.

(iii) Schlieren :-

- These are wavy, streaky, irregular sheets usually lacking sharp contact with the surrounding igneous rock.

(c) Micro structure :-

- These are formed due to reaction betⁿ already solidified crystals and the rest of the magma and include the following!

(i) Reaction Rims:-

→ When the reaction betⁿ early formed minerals frequently occurs near the boundary of the mineral grain is called the reaction rim.

→ 2 types (i) coronas

(ii) Kelyphitic borders

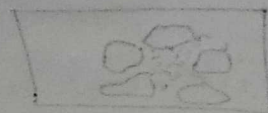
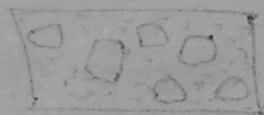
coronas:- are the reaction rims formed by primary magmatic reactions.

Kelyphitic borders:- are developed during secondary process such as metamorphism.

(ii) Xenolithic structure:-

→ Foreign rock fragments are included into the magma when it rises upwards the earth's surface if they are not digested they remain entrapped within the mass of the igneous rock.

→ Such entrapped fragments of foreign rocks are called the xenolith, and the structure is called xenolithic structure.



Texture of igneous rock

- (b) subhedral :- when crystal outlines have partially developed
→ also known as hypidimorphic crystal
- (c) Anhedral :- crystal faces are absent with reference to the 3 dimensions in space.

→ crystals are classified as

(i) equidimensional :- equally dividⁿ in all dirⁿ

eg. garnet

(ii) Tabular :- better develop in 2 dirⁿ

eg. mica, feldspar

(iii) Prismatic :- better develop in 1 direction

eg. Horn blende

(iv) Ir-regular :- crystal shaped as ragged, patches, veins and skeletons

ex :- quartz

⑨ Mutual reaction of crystal :-

→ It refers to relative size, shape, dimension of crystal and their relation to 1 another.

(a) equigranular :- minerals grains are of more or less equal size

(b) In equigranular :- igneous rock containing various of size of mineral grains

seriate

→ 2 very imp. texture fall within this group

(i) Porphyritic :- larger crystals (phenocrysts) are

surrounded by smaller (ground/mass) which may be microgranular or glassy.



(ii) Poikilitic texture :- smaller crystals are enclosed in larger ones without common orientation

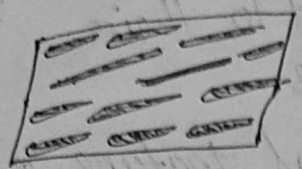
larger crystals are called → oikocrysts

smaller " " " " " "

→ chadacryst (xenocryst)



* Directive texture:- the texture produced by flow of lava during their consolidation are called --



Form in time of lava flow

Rock structure:- (shape, size & arrangement of rock masses in the earth's crust).

Primary structure:- These are resulted during the formation of rock itself.

- ex:- columnar joints, current bedding, ripple mark

Secondary structure:-

These are produced by deformation due to the weight of overlying rock & earth movement.

- ex:- fold, fault, joints.

* Why we should study structural geology?
 1) Structural geology finds application in petroleum geology because petroleum and gas are associated with structural features. Faulting is associated with a fold.

Normal faults are associated with a fold.

2) Structural geology finds application in exploration. ex:- signposts through (accumulation of mineral resources with structure)

3) Structural geology finds application in mines.

Structural Geology:-

Structural geology:- study of 3 dimensional distribution of rock units with respect to their deformational histories.

or study of the structural feature of rock masses of the earth's crust, their origin, mechanism.

Rock structure:- (shape, size & arrangement of rock masses in the earth crust.)

(i) Primary structure:-

These are resulted during the formation of rock itself.

ex:- columnar joints,
current bedding
ripple mark

(ii) Secondary structure:-

These are produced by deformation due to the weight of overlying rock / earth movement.

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* Why we should structural geology?

⇒ i) structural geology finds application in petroleum geology because petroleum and gases are associated with structural feature - bombay high is associated with a fold.

Naharkatia Assam is associated with a fold.

(ii) Structural geology finds application in exploration.

ex:- signbhum thrust (Accumulation of mineral takes place with structure)

(iii) Structural geology finds applications in mines.

- (iv) Use in ground water geology and hydrology.
- (v) Finds application in geothermal energy development.

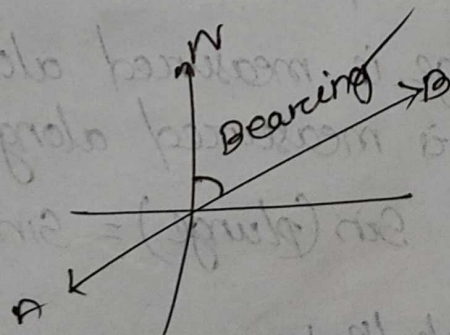
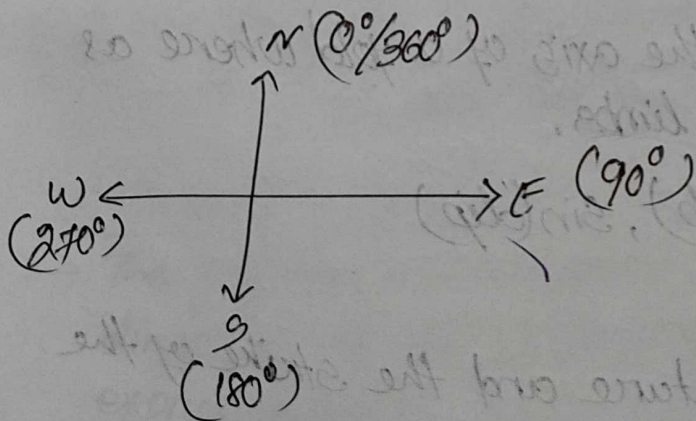
Attitude of beds:-

- It refers to the 3-D orientation of geological feature like beds.
- The rock masses especially stratified formation when subjected to tangential forces or compressive forces they get tilted or bent.
- This inclination produced two very important structural elements which define the attitude or position of rock strata i.e. dip and strike.
- The orientation is related to geographic co-ordinate i.e. east, west, north, south and horizontal.

Bearing:-

- It is the horizontal angle betⁿ an object and a specified geographic co-ordinate direction (generally north).
- The geographical co-ordinate can also be east, west or south.
ex:- an object to east would have an absolute bearing of 90° .

- In case of geology, fixed geographic direction is taken as North and the angle is measured in clockwise direction.
- Bearing is always represented in 3 digit no.



b) Inclination :-

→ It is the angle betⁿ plane/line and an imaginary horizontal line measured downward in a vertical plane.

c) Plunge :-

→ It is the vertical angle betⁿ the horizontal plane and axis or line of maximum elongation of a feature. It is measured on a vertical plane.

→ Plunge is measured along the axis of a fold where as dip is measured along the limbs.

$$\sin(\text{plunge}) = \sin(\text{pitch}), \sin(\text{dip})$$

d) Pitch / Rake :-

→ angle betⁿ the axis of feature and the strike of the plane containing the axis.

* Trend:-
→ It is the direction of its projection on a horizontal plane.

* NOTE:-
→ The attitude of a linear structure is described by its trend and plunge.
→ The attitude of a planar structure is described by its strike and dip angle / dip direction.

* Dip:-

- It is the angle of inclination of a rock bed with the horizontal plane:--
- It is measured in a plane $\perp$ to the strike.
- Dip of a bed has got 2 components like direction as well as magnitude so dip is a vector quantity.
- 2 parameters (i) direction of inclination
(ii) amount of "

(i) Direction of inclination:-

- The geographic direction i.e. the trend of the line in the direction of inclination represented by compass points expressed either in terms of

(i) Circular bearing:- $87^\circ, 120^\circ, 279^\circ, 303^\circ$ etc.

(ii) Quadrant bearing:- $N 15^\circ W, S 45^\circ E$ etc.

(ii) amount of inclination:-

→ It is expressed as

(i) Gradient:-

the tangent of the angle betⁿ the horizontal and the inclined surface line 1 in 10, 1 in 15, 1 in 20.

(ii) angle:-

The vertical angle betⁿ the downward inclined surface i.e. the top bedding plane of the strata & the horizontal express in degree & minutes of an arc like 25° , 30° , 45° etc

→ Along the direction of dip younger rocks are found in opposite direction older rocks are formed.

* True Dip & Apparent Dip:-

→ the max^m inclination of the strata in the plane of the dip i.e. steepest angle made by the bedding plane with the horizontal is called "True dip".

→ It is the max^m inclination of a inclined bed

→ Its direction is always perpendicular to the strike direction.

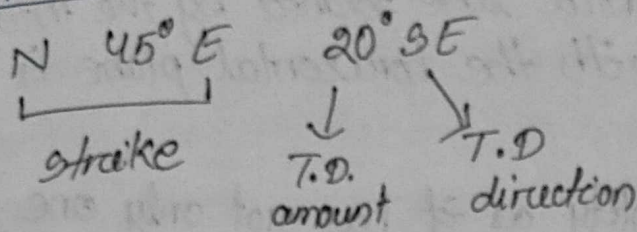
→ The inclination of strata from the horizontal in any other direction than that of the true dip is called an "apparent dip".

→ It has a value less than the true dip always.

→ Along the strike direction the dip will be zero.

NOTE:- Initial/original/Primary dip → dip due to deposition of sediments on a sloping surface.

* Attitude expression:-



calculation of true dip from apparent dip:-

$$\tan d = \tan \theta \cdot \cos \beta$$

where, d = apparent dip amount

θ = True dip amount

β = horizontal angle betⁿ true dip direction & apparent dip direction.

Q. > A limestone bed dips 30° the direction of $N 15^\circ E$ calculate its apparent dip in the direction of $N 45^\circ E$?

Ans: $\theta = 30^\circ$ $d = ?$
 $\beta = 45^\circ - 15^\circ = 30^\circ$

$$\begin{aligned} \tan d &= \tan \theta \cdot \cos \beta = \tan 30^\circ \cdot \cos 30^\circ \\ &= \frac{\sin 30^\circ}{\cos 30^\circ} \cdot \cos 30^\circ \\ &= \sin 30^\circ = \frac{1}{2} \end{aligned}$$

$$\Rightarrow \tan d = \frac{1}{2}$$

$$\Rightarrow d = \tan^{-1}\left(\frac{1}{2}\right)$$

$$= 26.56^\circ$$

Strike:-

- The direction of a horizontal line formed by the intersection of the rock beds with the horizontal plane is called strike of the beds.
- Strike is a scalar quantity as it has got only one component i.e. direction.
- The beds normally extend laterally along their strike.
- Strike is always at right angle to the true dip direction.
- Strike angle can be expressed in 2 ways
 - i) Azimuth/bearing expression → expressed in 3 digits
 - ii) Quadrantic expression → expressed within a quadrant

Measurement of dip and strike:-

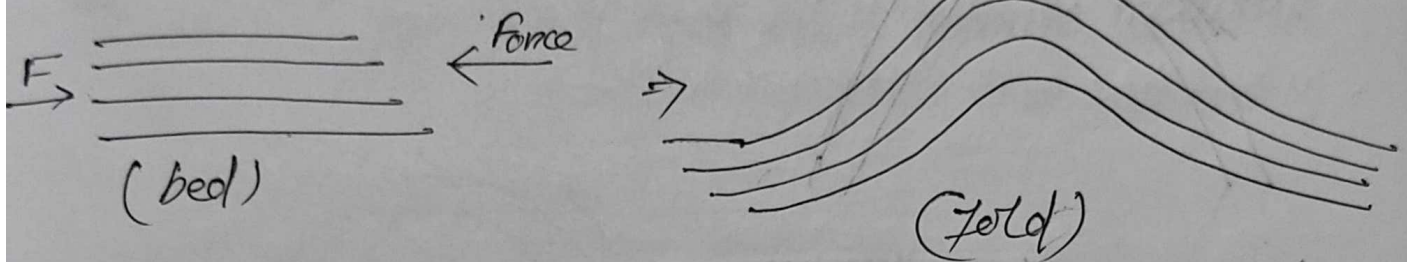
- The amount and direction of dip and strike of rock beds are measured with the help of an instrument called "clino compass" / "Brunton compass".

Clino compass:-

- The instruments consist of a large circular dial with 3 concentric graduations.
- The outermost peripheral graduation reads from 0° to 360° clockwise for reading full circle bearing.

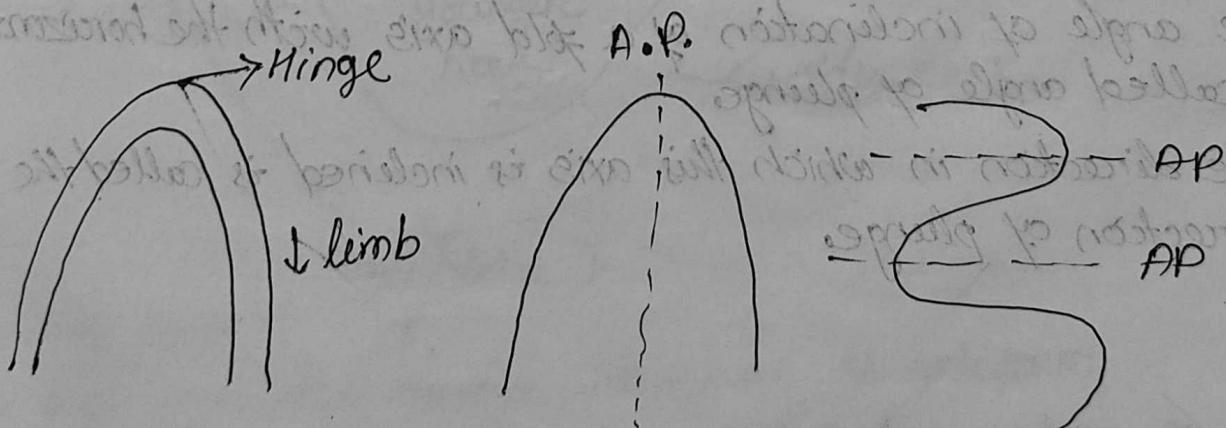
Fold :-

- The bending of rock strata due to compressional forces acting tangentially or horizontally; towards a common point/plane from opposite direction is known as "fold".
(ductile deformation).
- Folds are wavy undulation which are developed in country rocks whenever the region is subjected to severe stress.



Elements of fold :-

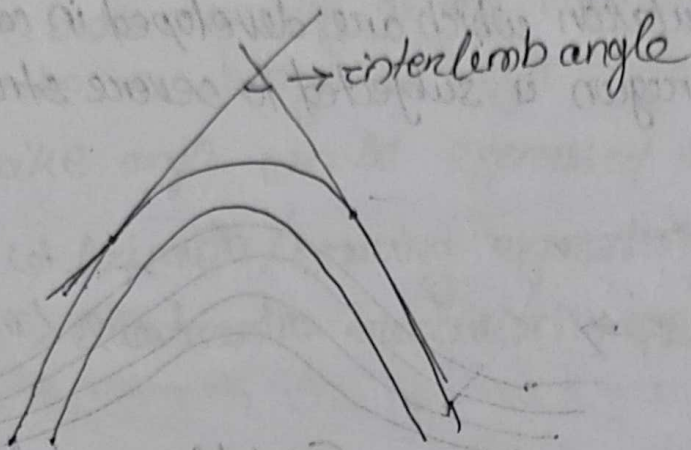
- i) Hinge :- It is the line of max^m curvature in a folded bed.
→ it may be horizontal, inclined or vertical.
- ii) Limb :- The sloping sides of a fold from crest to trough.
- iii) Axial plane :- It is an imaginary plane/surface which divides a fold into 2 equal halves.
→ It may be vertical, horizontal or inclined.



iv) Inter limb angle:-

The angle betⁿ the limbs of the fold.
→ The angle subtended by the tangents at adjacent inflection point.

→ Inflection point:- mid point of successive crest & trough



v) Axes of fold:-

- The median line about which folding has taken place.
- The axis may be vertical, horizontal or inclined.
- When horizontal it is 11° to strike of bed. When the hinge line is straight is called fold axis.

vi) Fold surface:- when the hinge line is curved

vii) Plunge of fold:-

→ folds having inclined axis are called plunge fold.

- The angle of inclination of a fold axis with the horizontal is called angle of plunge.
- The direction in which this axis is inclined is called the direction of plunge.

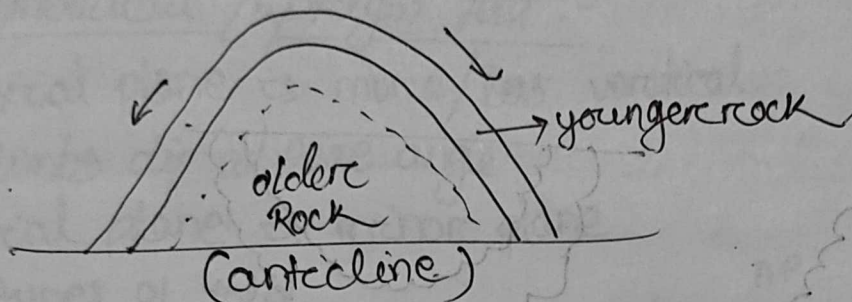
Classification of fold :-

- 2 types (i) Genetic classification
- (ii) non-genetic/Geometric classification

(i) Genetic classification :-

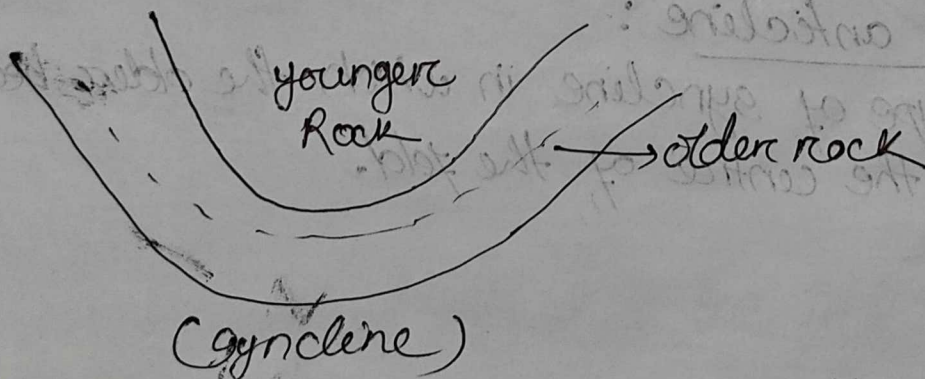
a) Anticline :-

- beds are convex upward.
- limbs are dip away from the axis of fold.
- In the centre, older rocks are found.
- The word is from greek word means opposite inclined.



b) Syncline :-

- beds are concave upward
- limbs are dip towards the axis of fold
- In the centre, younger rocks are found.
- The word is from the greek word means together inclined.



c) Antiform :-

- any upwardly convex structure is antiform.
- Hence the age relationship betⁿ bed is not known.

d) Synform:-

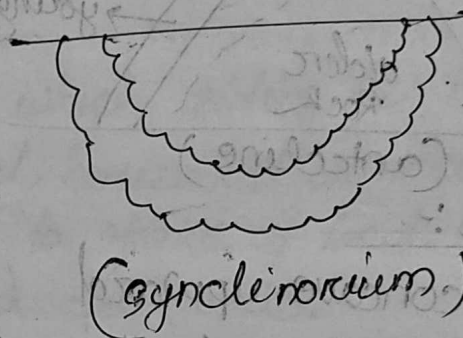
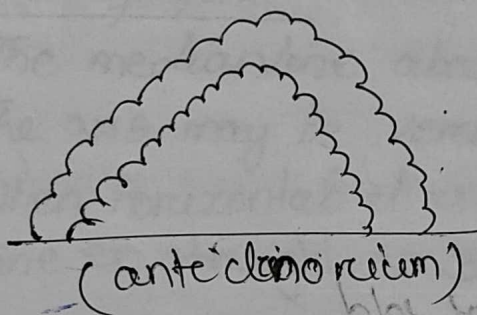
- Any upwardly concave structure is synform.
- Here the age relationship betⁿ bed is not known.

e) Anticlinorium:-

- A large anticline with a number of secondary fold of smaller size developed on it.

f) Synclinorium:-

- A large syncline with a number of secondary fold of smaller size developed on it.



g) Antiformal syncline:-

- It is a type of anticline in which the beds are found in the centre of the fold younger.

h) Synformal anticline:-

- It is a type of syncline in which the older beds are found in the centre of the fold.

(ii) Geometrical classification:-

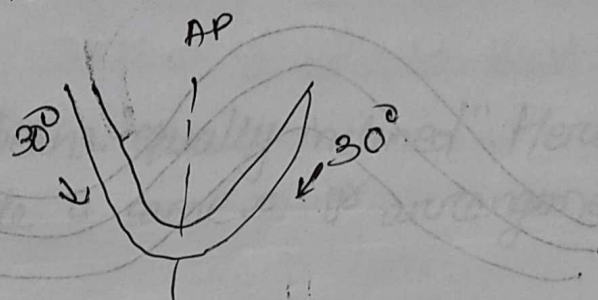
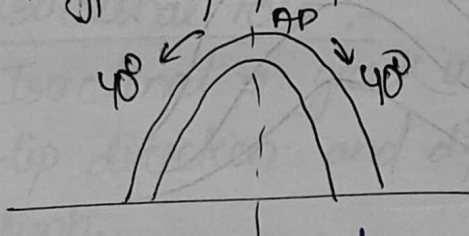
Folds can be classified on the basis of

- a) position of axial plane
- b) degree of compression
- c) behaviour with depth
- d) Relative curvature of outer and inner arc
- e) Plunge of fold
- f) Profile of outer surface
- g) mode of occurrence

a) Position of axial plane:-

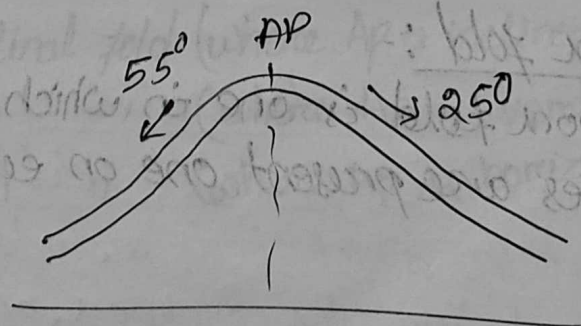
(i) Symmetrical/upright fold:-

- axial plane is more/less vertical
- 2 limbs dip at same angle
- axial plane is minor plane
- M types of fold.



(ii) Asymmetric fold:-

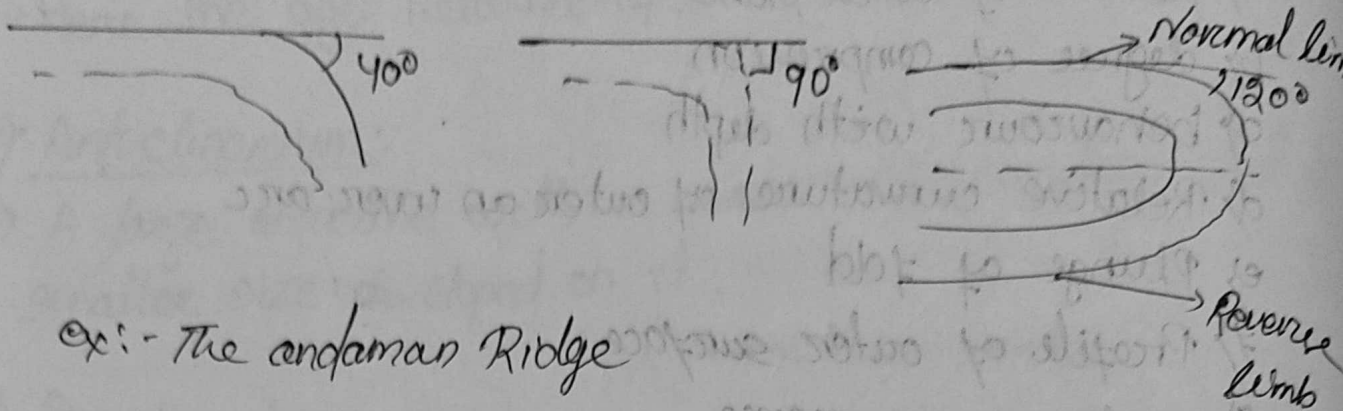
- axial plane is inclined
- dip angle is different
- Z-type, or S-type



(iii) Overturned fold:-

- It is an asymmetrical fold whose one limb is turned past the vertical.
- axial plane is inclined
- One of the limb occurs in normal position and other limb rotated more than 90° .

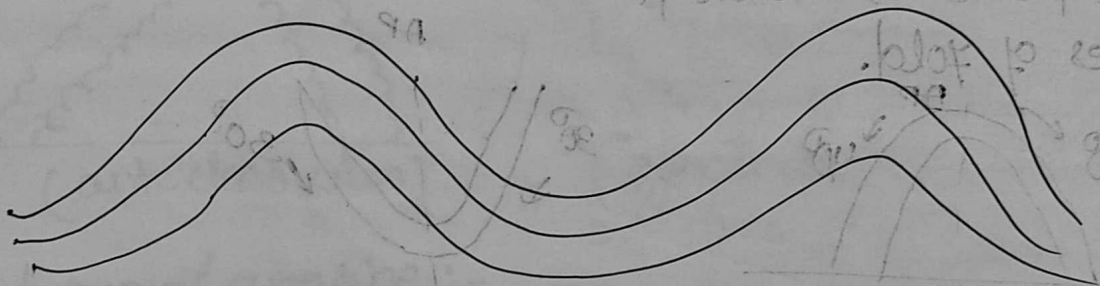
→ The limb above the axial plane is the normal limb and the limb underneath is called "Reverse limb".



ex:- The andaman Ridge

(iv) Fan fold :-

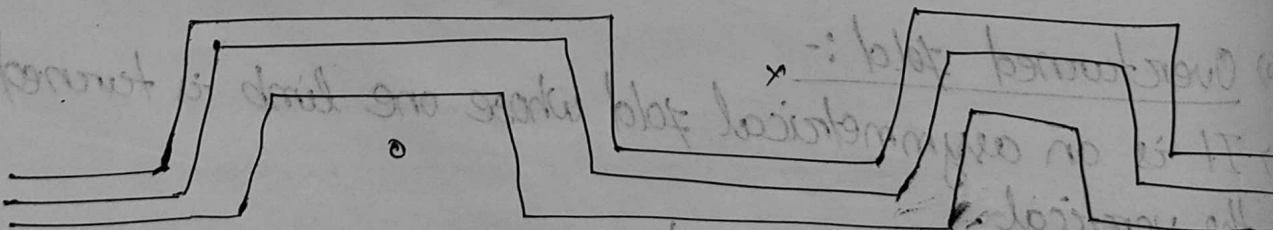
- both limbs are overturned
- In the anticlinal fan fold 2 limbs, dip towards each other and in the synclinal fan fold the 2 limbs dip away from each other -ve inter limb angle.



(v) Box fold :-

- A box fold is one in which the crest is flat, two hinges are present one on either side of the fold.

Rounded hinge



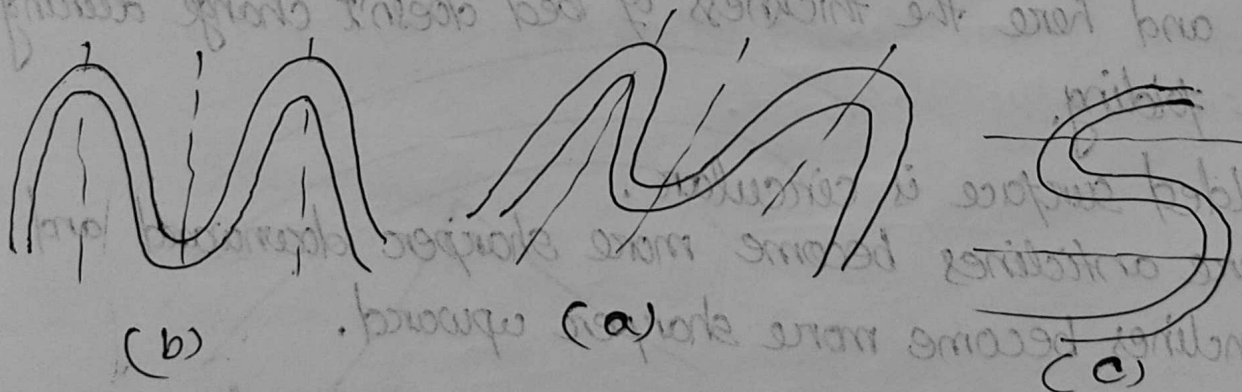
(vi) Recumbent fold:-

- It is an overturned fold in which the axial plane is horizontal.
- The curved part of the fold betⁿ the normal and inverted limb is known as arch bend.
- The outer and inner parts of the fold are known as "shell" and "core".
- Secondary folds attached to the recumbent folds are known as "digitations".
- Sometimes recumbent folds are known as "Nappes".

(vii) Isoclinal fold:-

- Isoclinal is greek word means "equally inclined". Here dip direction and dip angle is same & its arrangement of limb.

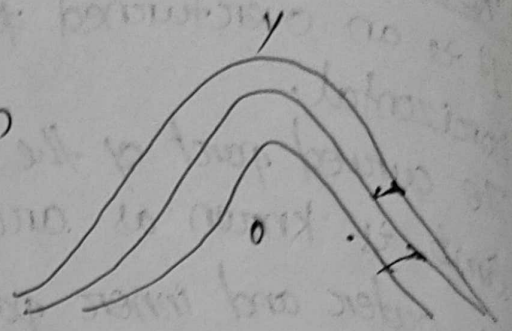
- 3 types
 - a) inclined isoclinal fold (where Ap is inclined)
 - b) Vertical " " (where Ap is vertical)
 - c) horizontal " " (where Ap is horizontal)



(b) Degree of compression:-

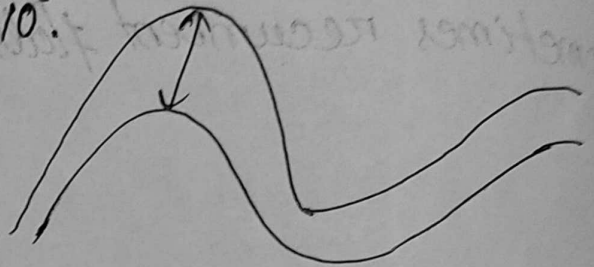
Open fold:-

- thickness of bed is uniform
- Fold angle is betⁿ 90° - 170°



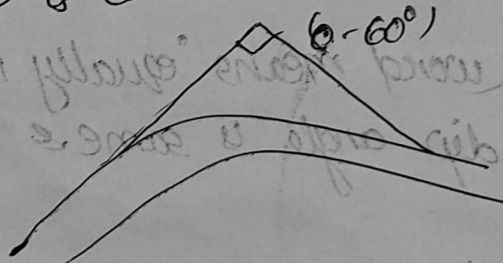
(ii) Close fold:-

- thickness of folded layers aren't uniform
- Fold angle is betⁿ 150° - 110°
 - thicker at crest
 - thinner at trough



(iii) Gentle fold:-

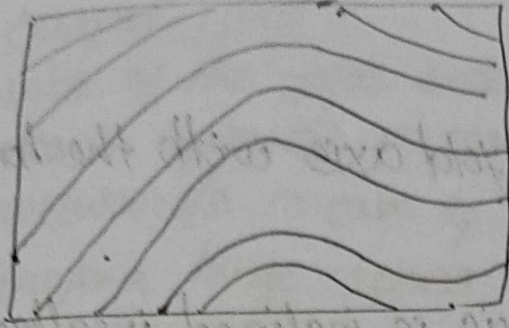
- Here, fold angle is betⁿ 0° - 60°
- thickness of limb is constant



(c) Behaviour with depth:-

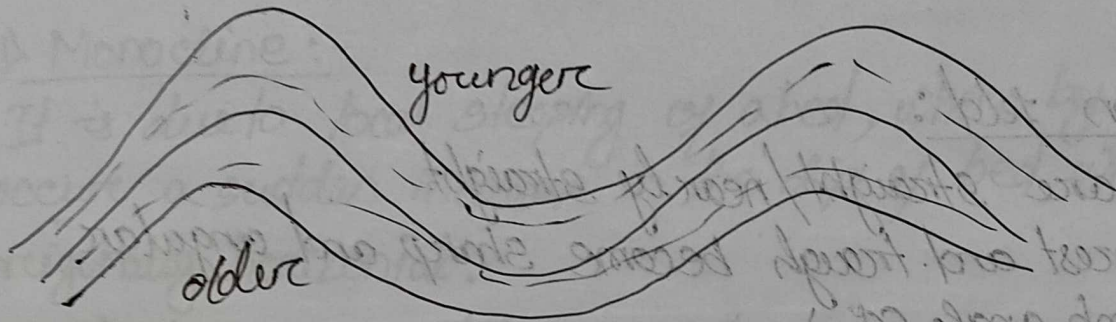
(i) Concentric / Parallel fold:-

- A fold in which beds maintain the same thickness throughout and here the thickness of bed doesn't change during the folding.
- Folded surface is circular.
- Here anticlines become more sharper downward and synclines become more sharper upward.



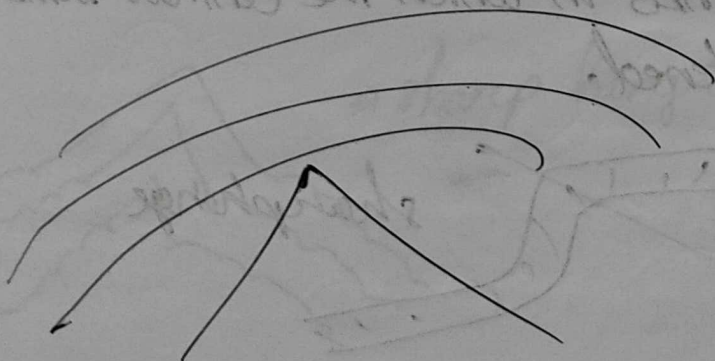
(ii) Bimillare fold:-

- In this thickness of the layers remain constant, when measured $\parallel$ to the axial surface but the thickness along each layer varies.
- Every bed is thicker at the hinge and thinner at limb.



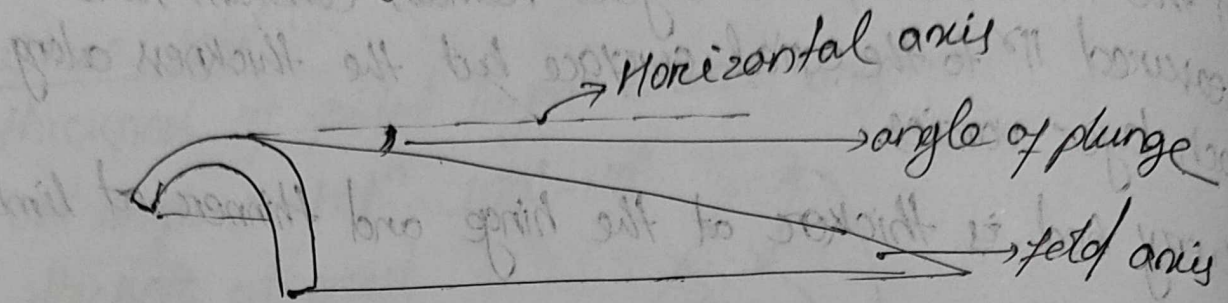
(iii) Supratenuous fold:-

- When folding and sedimentation are contemporaneous i.e. occurring at the same time then supratenuous fold is formed.
- Strata are thinnest at the crest and thickest at the trough.



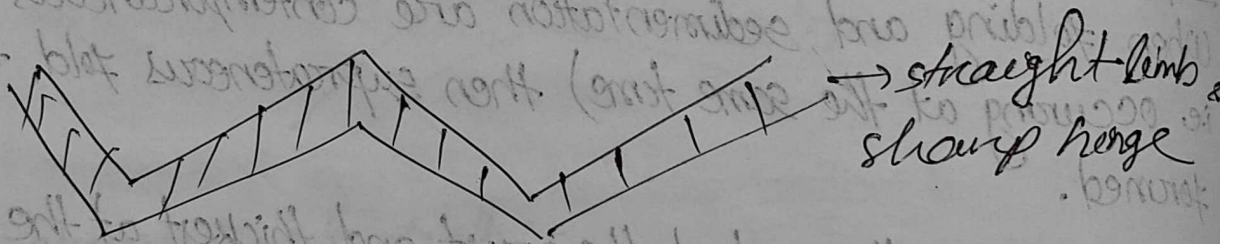
iv) Plunging fold :-

- Folds having inclined axis
- The angle of inclination of a fold axis with the horizontal is called angle of plunge.
- The direction in which the axis is inclined is called direction of plunge.



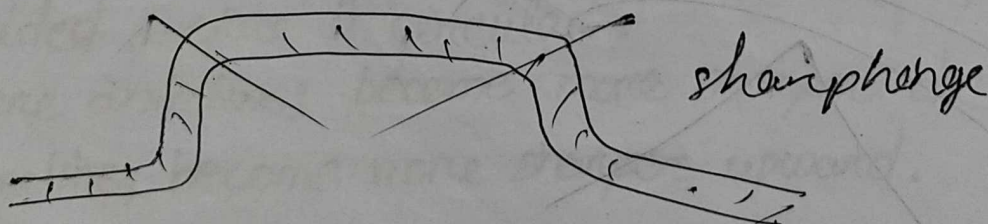
v) Chevron fold :-

- Limbs are straight/nearly straight
- Their crest and trough become sharp and angular (interlimb angle 60°)
- also known as zig-zag, concertina/accordion fold.



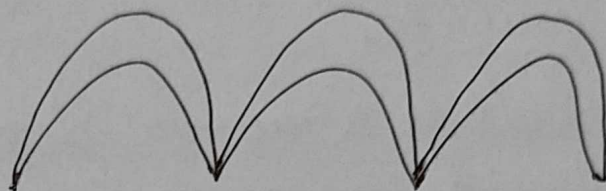
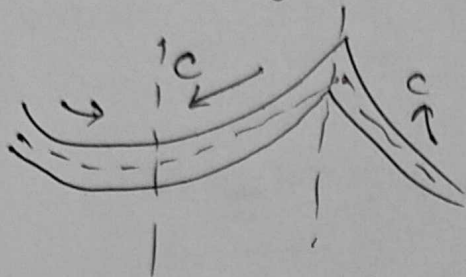
(vi) Conjugate fold :-

- These are composite folds characterised with 2 hinges and 3 planar limbs in which the central limb is exceptionally flattened.



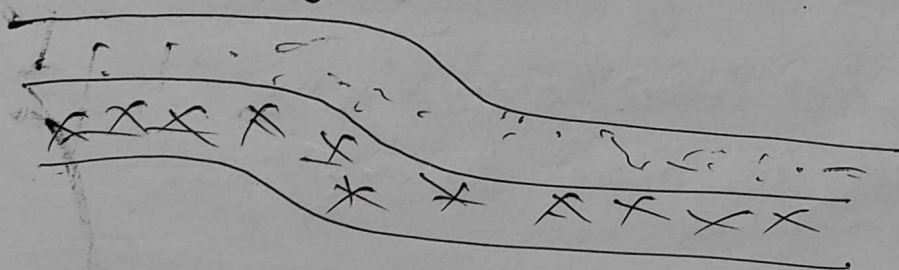
vii) Cusped fold:-

- limbs of the folds are not planar. They are become concave upwards in case of anticline and concave downwards in case of syncline.
- Therefore hinge zones are not very sharp. Rounded and sharp hinge.



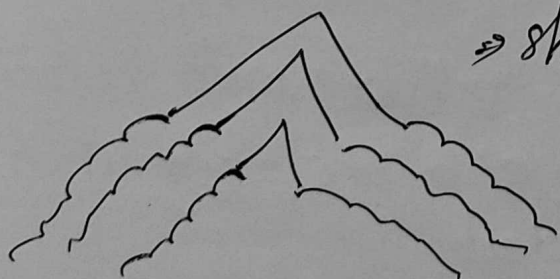
viii) Monocline:-

- It is due to local steeping of a bed, where by there occurs a sudden increase in the dip of bed which is originally horizontal.
- Axial plane may not be present.



- * 2 horizontal plane with 1 inclined plane
- * It is step like

ix) Arrow headed:-



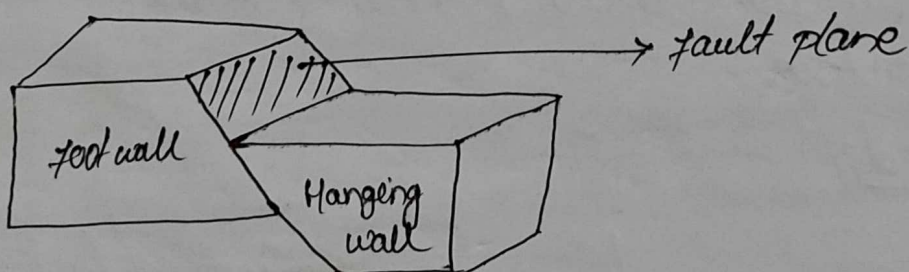
⇒ sharp hinge, curved limb

Fault :-

- Faults are well defined cracks along which the rock masses on either side have relative displacement.
Brittle deformation.
- The entire process of development of fractures and displacement of the block against each other is termed as faulting.
- A fault is a rupture deformation produced either by tensile or compressive force.
- The attitude of faults are defined in terms of their dip and strike.

Parts of fault :-

- ⇒ Fault plane :- It is a planar surface of fracture along which relative displacement of blocks take place during faulting.
- ⇒ Foot wall :- wall lies below the fault plane
- ⇒ Hanging wall :- wall lies above the fault plane

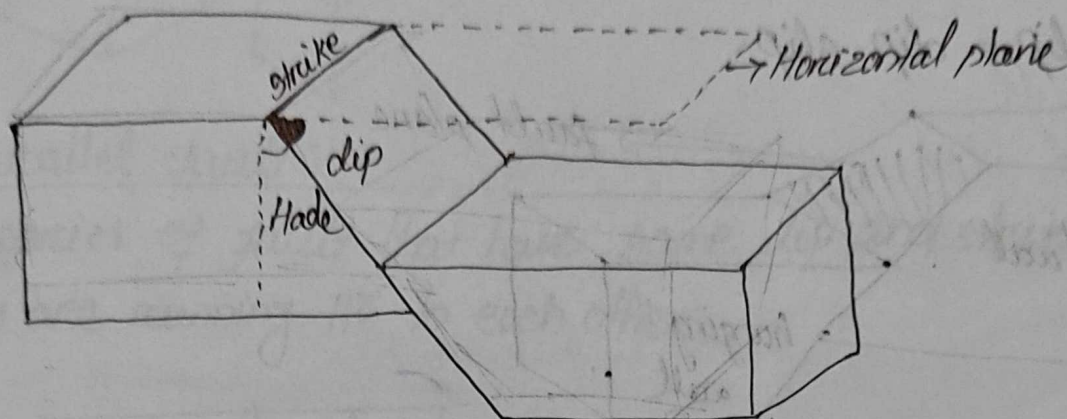


- ⇒ Dip :- angle of inclination of fault plane with the horizontal
- ⇒ Strike :- geographical direction of a line along which the structure is directed
 - common line betⁿ fault plane and imaginary horizontal plane

vii) **Hade** :- angle betⁿ fault plane and the vertical.

→ It is the complement angle of dip. i.e.

$$\boxed{\text{Dip} + \text{Hade} = 90^\circ}$$



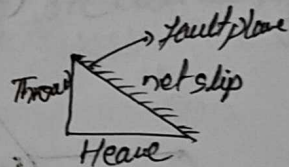
viii) **Throw** :- vertical displacement betⁿ foot wall & hanging wall

ix) **Heave** :- horizontal " " " " " "

x) **Net slip** :- total displacement measured along the fault plane is called "net slip"

→ It is measured betⁿ 2 points which were originally in contact.

$$(\text{Net slip})^2 = (\text{Dip slip})^2 + (\text{Strike slip})^2$$



→ right lateral strike slip fault, hanging wall moves right

→ left lateral strike slip fault, hanging wall moves left

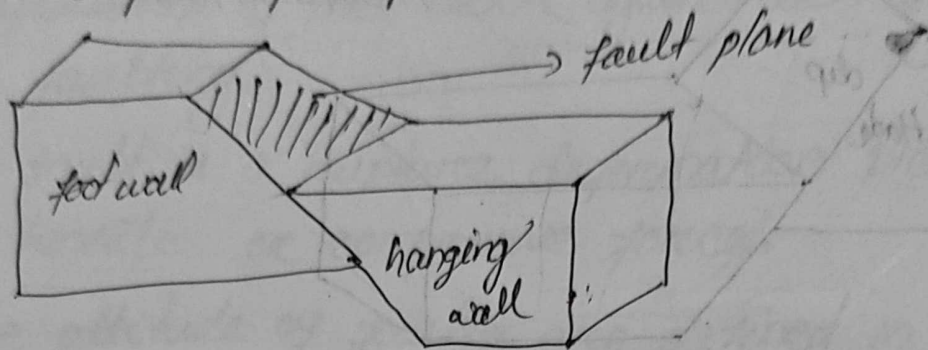
→ normal slip fault: hanging wall moves down

→ thrust or reverse slip fault: hanging wall moves up

(A) Geometrical classification of fault:-

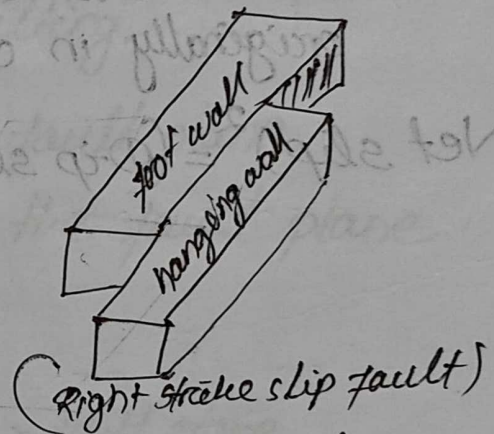
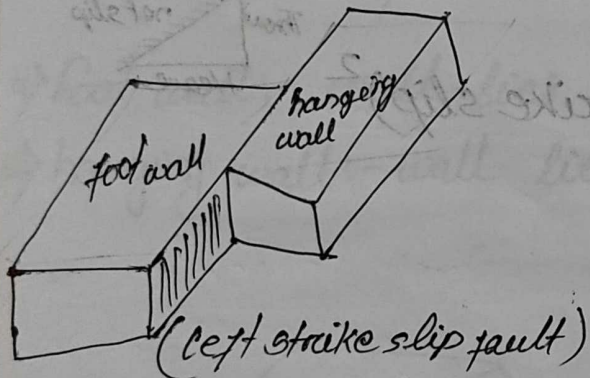
i) Dip slip fault:-

- relative displacement take place along the direction of dip
- rake of net slip is 90°
- net slip = dip slip



ii) Strike slip fault:-

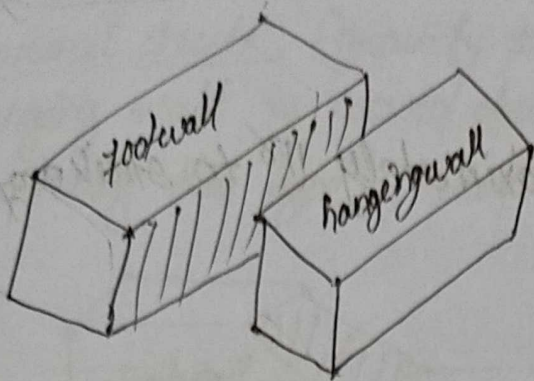
- relative displacement take place along the direction of strike
- rake of strike slip is 0° or 180°
- 2 types (i) right lateral strike slip fault (dextral)
(ii) Left lateral " " " (sinistral)



- right lateral strike slip fault, hanging wall moves right
- left " " " " " " " " left side

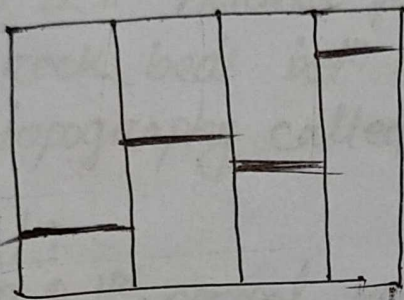
iii) Diagonal slip fault:-

- relative displacement take place in both dip & strike direction
- here, net slip is diagonally up or down
- rake of net slip is $>0^\circ$ but $<90^\circ$.



iv) Parallel fault:-

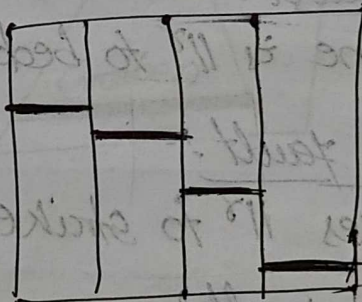
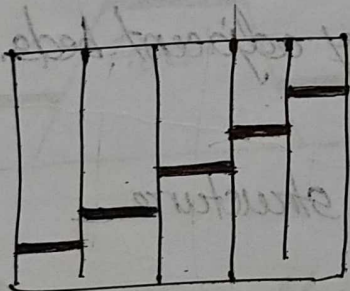
→ A series of fault that have same dip and strike and they are running $\parallel$ to each other.



v) Step fault:-

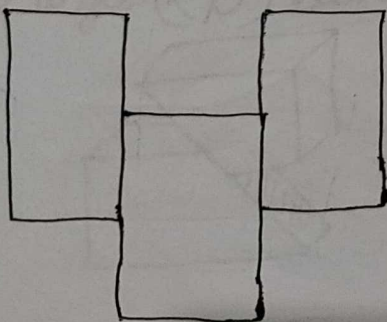
→ $\parallel$ faults are arranged either in increasing or decreasing order

→ form a step like structure



vi) Tear/wrench/trans current fault:- (lateral fault)

→ it occurs when 2 tectonic plates slide past each other.



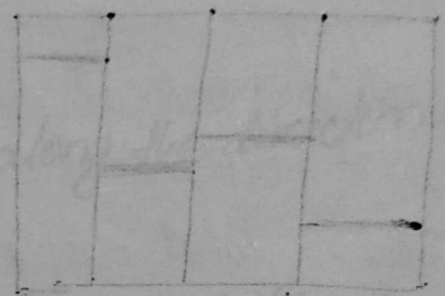
* Based on attitude of fault relative to the attitude of adjacent-beds:-

a) Strike fault:-

→ A fault which strikes approximately 11° to strike of the adjacent rock

b) Dip fault:-

→ A fault which strikes approximately 11° to dip direction of adjacent rock



c) oblique / diagonal fault:-

→ A fault which strikes diagonally to the strike of adjacent bed.

d) Bedding fault:-

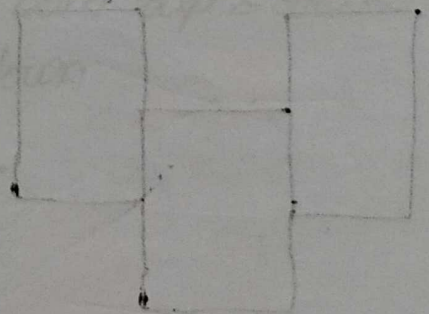
→ fault plane is 11° to bedding planes of adjacent beds.

e) Longitudinal fault:-

→ fault strikes 11° to strike of regional structure.

f) Transverse fault:-

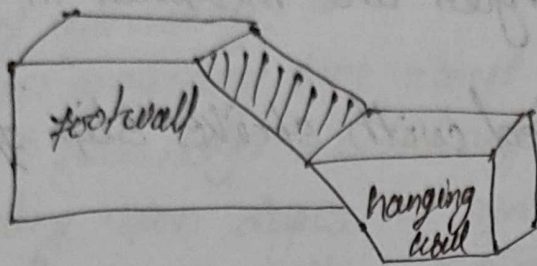
→ fault strikes 1° or diagonally to the strike of the regional structure.



(B) General classification of fault:-

i) Normal fault:- (gravity fault)

- hanging wall is moved downward in comparison to foot wall
- generally this type of fault is seen in nature majorly.

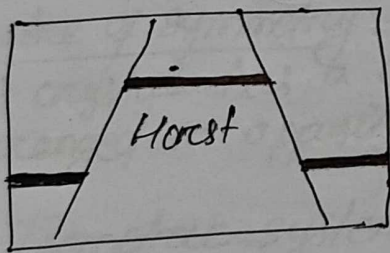


Graben:-

- when 2 11° normal faults have towards each other and the rock beds between them moved downward forming a low topography called graben.

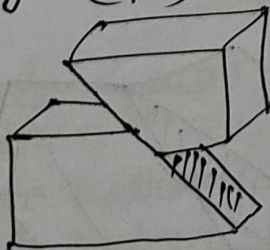
Horst:-

- when 2 11° normal faults have away from each other and the rock block between them is uplifted to form a ridge, the structure is called "horst".



ii) Reverse fault:-

- hanging wall is moved upward in comparison to foot wall
- these are usually high angle fault ($>45^\circ$)
- low angle ($<45^\circ$) reverse fault are called ~~thrust~~ **thrust** fault.



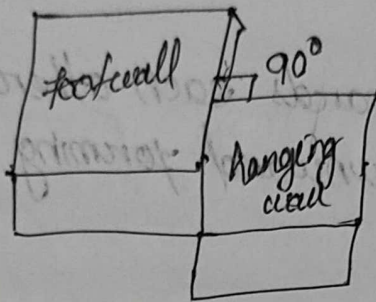
iii) Vertical fault:-

→ Hanging wall moves vertically downward.

→ Here, $\text{dip} = 90^\circ$
 $\text{Hade} = 0^\circ$

→ strike direction and dip angles are measured in horizontal and vertical planes

→ Flower structure associated with strike slip faults (transform boundaries)

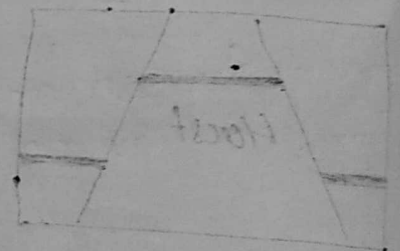
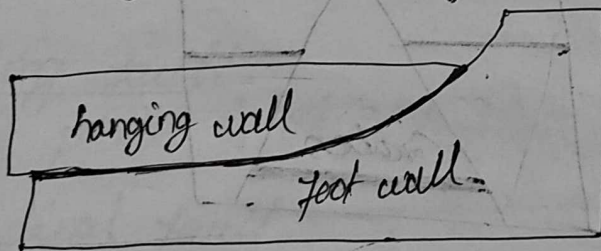


iv) Listric fault:-

→ fault plane is curved

→ dip varies along the fault plane.

→ Steep dipping at top and gentle dipping at bottom

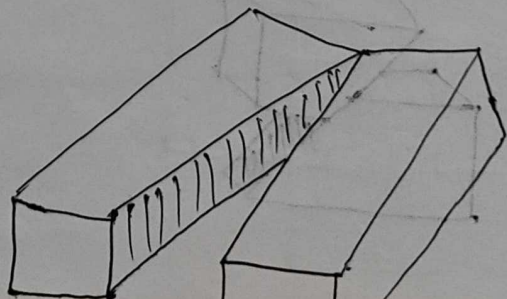


v) Hinge fault:- (Scissor / pivot fault)

→ fault plane is appeared to be rotated from a common point

→ distance betⁿ the fault blocks increasing from the point of contact.

→ It is a rotational fault.



Isometric system:

- In isometric system max^m no. of symmetry element are present.
- It is mainly galena type.
- In this system, form are present and all are in closed form
- Symmetry element of isometric system:-

* Axis of symmetry:-

- It is an imaginary line about which one rotate crystal in 360° the same face, edge & solid angle come to front more than 1.
- Depending upon degree of symmetry, a crystal may come to occupy the same position 2, 3, 4 & 6 times in complete rotation.
- The term applied to the different class of axis
- 2 times = 2 fold (diad) (Diagonal axis) (180° interval)
- 3 times = 3 " (Triad) (Trigonal axis) (120°)
- 4 times = 4 " (tetrad) (90°)
- 6 times = 6 " (Hexad) (60°)

* Plane of symmetry:-

- It is an imaginary plane along which divides a crystal, we get 2 equal halves i.e. for each face, edge or solid angle i.e. another similar face edge or angle which has a like position on the opposite side of the plane.

Centre of symmetry:-

- A crystal has a centre of symmetry when like face, edge are arranged in opposite side of a central point.

* Isometric system (galena)

- * Axis of symmetry:- 13 (3 axis 4 fold 3^{IV}
4 " " 3 " 4^{III}
6 " " 2 " 6^I)

- * Plane of symmetry:- 9 (3 axial
6 diagonal)

- * Centre of symmetry:- 1

1. cube
2. Rhombohedron
3. Octahedron
4. Tetrahedron
5. Trisoctahedron
6. Trapezohedron
7. Rhombicuboctahedron

Cube:-

- 6 similar faces & each face is $\parallel$ to 2 of the crystallographic axes meets the 3rd one
- General symbol (100)
- each face is a square & interfacial angle is 90°
- form → closed

Rhombo-dodecahedron:-

- bounded by 12 similar faces & 2 of axes cut the face & one is $\parallel$
- General symbol (110)
- form → closed

Octahedron:-

- include 8 similar faces & each cut 3 axes at equal distance
- General symbol (111)
- each face is an equilateral triangle with plane angle 60°
- In octahedron the form are closed form

Tetrahedron:-

- 24 like faces, each of which is an isosceles triangle
- general formula (hko)
- each face is $\parallel$ to one of the axes while it meets the other 2 axes at unequal distance, which are definite multiples of each other
- form → closed

Triso-octahedron:-

- bounded by 24 similar faces, each of these is an isosceles triangle
- such of which intersects 2 of the crystallographic axes at distance & 3rd at greater distance
- General formula (hhl)
- form → closed

Tapezo hedron:-

- bounded by 24 like faces each of them are quadrilateral or trapezoid
- each of which intersects 2 of the crystallographic axes at equal distance & 3rd at smaller distance
- general symbol (hll)
- closed form

Hexa-octa hedron:-

- bounded by 48 similar faces each of which is a scalene triangle and each intersects the 3 axes at equal distance
- general symbol:- (hkl)
- closed form

Joints :-

Joint :- cracks along which there is no relative displacement between the adjacent blocks.

- formed as a result of either diastrophism or contraction (tensional force)
- no visible movement to the surface of joints otherwise it would be classified as a fault.
- may be vertical, horizontal and inclined.

Joint set :- series of $\parallel$ joints

Joint system :- ≥ 2 joints sets intersect with each other.

Geometric classification of joints :-

- according to the trend (strikes) of joints trace relative to attitude of rock masses (dip & strike)

i) Strike joint :- joints run $\parallel$ to strike of the country rocks

- may be vertical or inclined.

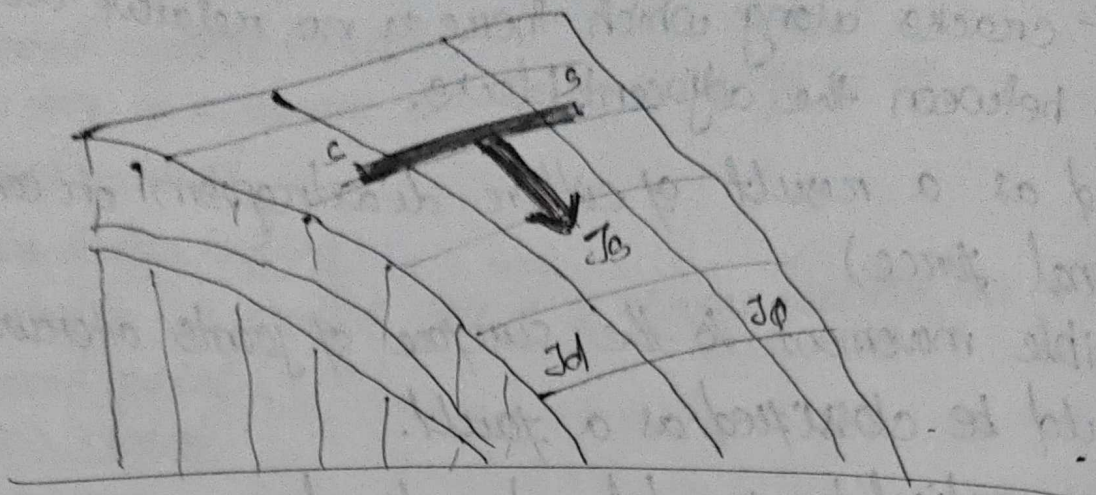
ii) Dip joint :- joints run $\parallel$ to dip direction of the country rocks

- may be vertical / inclined

iii) Oblique / diagonal joint :- joint strikes an angle to direction of dip and strike of bed rock.

- develop at any angle betⁿ dip and strike

iv) Bedding joint :- joints run $\parallel$ to bedding plane of associated country rock.



Genetic classification of joints :-

- a) Tension joint (Igneous rock :-
- mural joint cubic
 - Sheet " sheet
 - Columnar " column
- Sedimentary " :-
- master " rectangle
 - extension " joint
 - Released ")

b) Shear joint (criss cross)

Tension joint :-

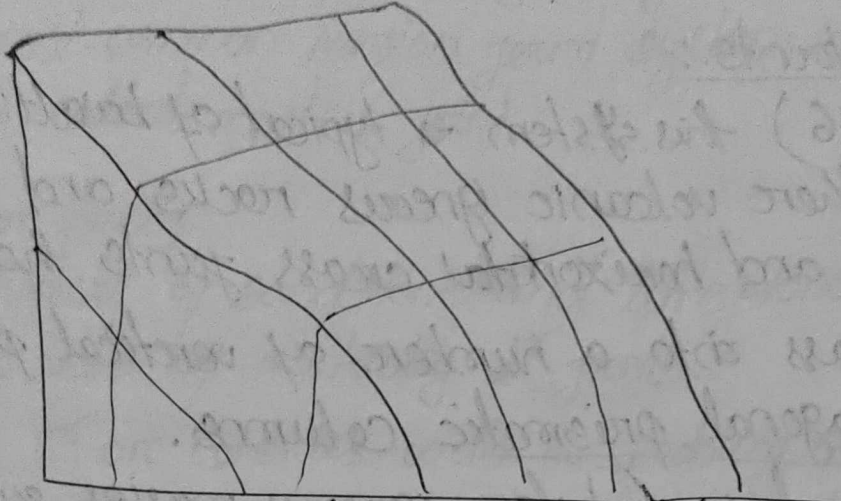
- produced by tensional force developed by increase or decreasing of volume of rocks due to drying shrink
- while cooling or dehydration and stretching of limbs of folded strata
- large and irregular
- These are related to various types of rocks and their modes of formation and are affected by the lithological nature of rocks.

Tension joints in igneous rock:-

→ Mural joint:-

This system is typical of granites and related massive plutonic and certain hypabyssal rocks, granites commonly show 3 sets of joints.

(1 horizontal and 2 vertical) mutually at right angles which divide the rock mass into cubical blocks/mural



(mural joints in granite)

→ Sheet joint:-

This system is typical of granites and other plutonic rocks, consists of one set of prominent joints $\perp$ to the ground surface with varying spacing usually increasing with depth and the other less marked at right angles generally layers of rocks are thinner near the surface and thicker at depth.

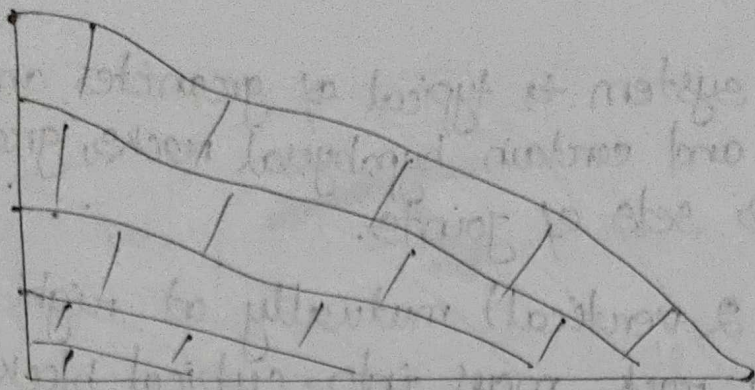
→ These joints are produced by tensional forces due to relief from confining pressure

ex:- chamundi granite

Adichunchana giri granite

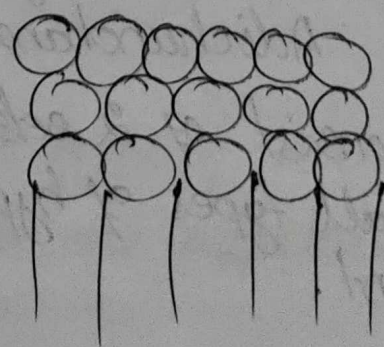
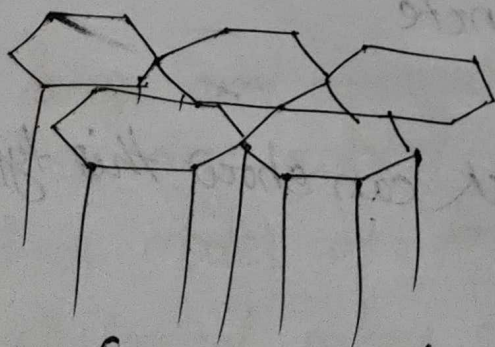
→ It consist of 2 sets of joints

ex:- all types of hypabyssal rock can show this type of joint.



(iii) Columnar joints :-

- (Gosman 1916) this system is typical of basalt and certain other volcanic igneous rocks and consists of vertical and horizontal cross joints that dissect the rock mass into a number of vertical polygonal, usually hexagonal prismatic columns.
- It is formed in tabular igneous masses such as dykes, sills etc.
- Such columns develop at right angles to the chief cooling surface.
- These system is also called prismatic joints (as the cracks bound in between hexagonal prismatic columns of rocks)
- ex: - columnar joints of basalt - Antrim Ireland, Gilbert hills basalt, Andheray, Bombay, basalts of Belgauem, California, USA



(Columnar joints in basalt)

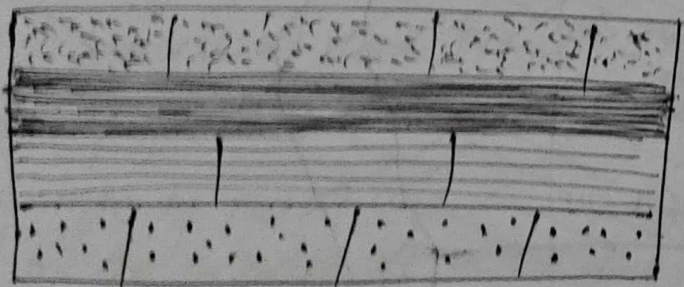
Tension joints in sedimentary rocks

- ↳ Master joint
- ↳ Extension joint
- ↳ Released joint

- Sediments become more and more solidate under pressure and occupy smaller volumes & finally ruptures, thus joint sets develop at right angle to each other.
- The most common tension joint system in sedimentary rock is called master joint.

↳ Master joint:-

- It is typical of sandstone and limestones and consist of three sets of mutually $\perp^{\circ}$ joints.
- 1 set is $\parallel^{\circ}$ or coincides with the bedding plane and the other 2 sets are transverses across the beds are staggered in respect of successive beds.
- These joints persist for long distance with remarkable regularity in spacing and width, thus are called master joints.
- Master joints dissect the rock mass in to rectangular blocks.
- In shale these joints are generally very closely spaced.



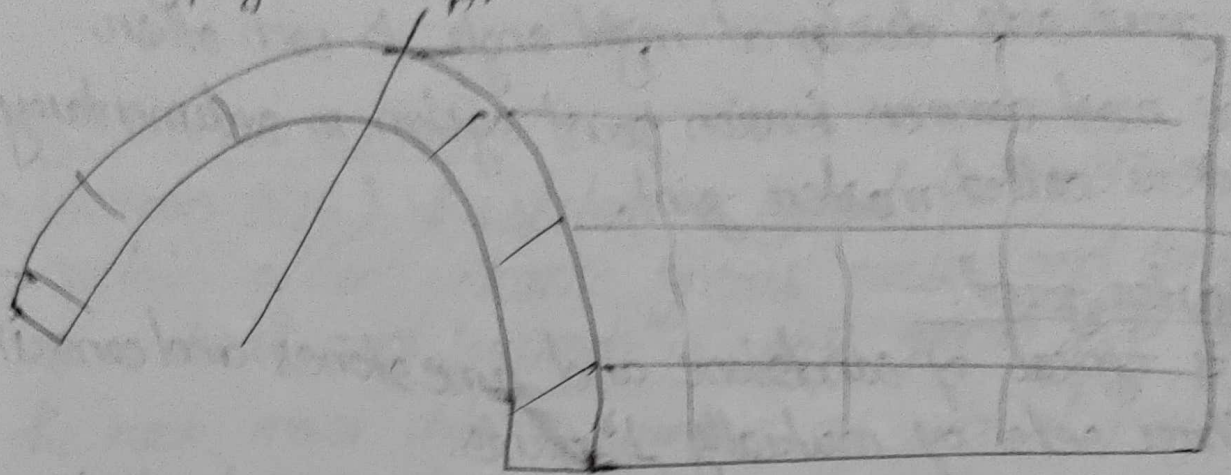
(ii) Extension joint:-

- Joints $\perp^{\circ}$ to the axis of folds are common in the orogenic belt and such joints may be termed as extensive joints.

→ These may be result from slight elongation 10° to the axis of fold.

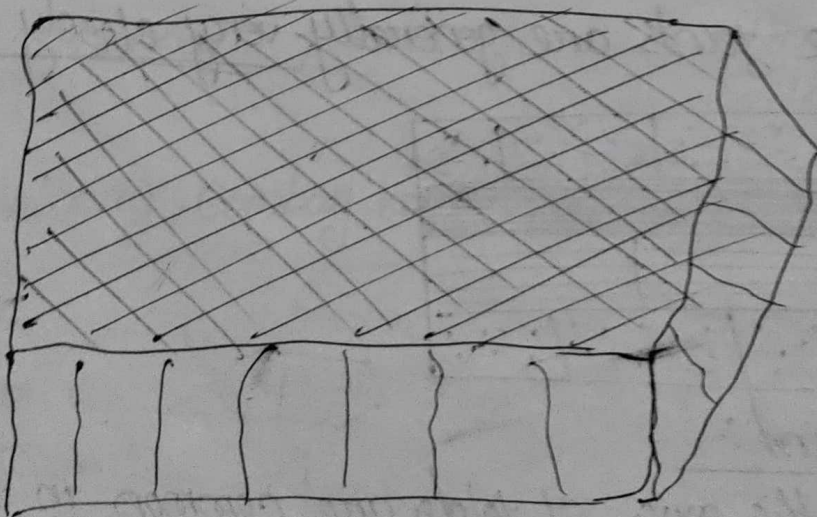
Released Joint:

→ Joints 15° to axial plane of fold may be termed as released joints.



(b) Shear joint:

- formed due to compressional forces involved in the folding and faulting of rocks.
- consist of intersecting or cross-cross sets at a high angle. These are called conjugate joint system.
- formed diagonal and it directs the rock mass into irregular blocks, it is very closely spaced.



ex: Pegmatite, schist, Amphibolite, Diorite

Significance:

- Joints break the continuity of rocks and reduce their strength greatly.
- Joints commonly control the drainage patterns of an area.
- Joints provide passage for percolation of water.
- It often provide passage for groundwater to rise to the surface and forms springs.
- Joints also determines the localisation of some mineral deposits.
- Joints influence quarrying and blasting pattern.
- Joints render rocks weak and unstable.
- In many instances joints and faults have a common origin. Therefore joints become frequent as a fault is approached.

Joints

- i) Joints are well defined cracks along which there has been no visible movement betⁿ the adjacent blocks.
- ii) Space betⁿ joints are less
- iii) Age difference of rock on 2 side of joints is same
- iv) Same type of rocks are found in the 2 sides of a joint.
- v) Relatively closely spaced
- vi) Surface is rough or smooth never slicken sided.

Faults

- i) Faults are well defined cracks along which the rock masses of either side have relative displacement.
- ii) Space betⁿ faults are very high.
- iii) Age difference betⁿ the block is very high.
- iv) Different types of rocks are found in the both side of fault.
- v) Comparatively widely spaced
- vi) Surface is rough slicken sided grooved, scratched.

* Cleat $\rightarrow$ jointing found in coal

* Plumose mantling $\rightarrow$ very small ridges and depression on the surface of joints

$\rightarrow$ Joints may be filled up with mineral matter i.e. quartz, calcite, dolomite or clay

* Cooling joints: - are columnar joints that result from either lava from the exposed surface of a lava lake or flood basalt flow on the side of a tabular igneous typical basaltic intrusion. They exhibit a pattern of joints that join together at triple junction either at or about 120° angles.

$\rightarrow$ The columns are hexagonal

$\rightarrow$ The spacing joints lie out with depth and gradually becomes zero.

* Mural joint $\rightarrow$ cuboidal block

* Master " $\rightarrow$ Rectangular "

* Sheet " $\rightarrow$ Slab like "

* closely spaced " $\rightarrow$ crushed stone

$\rightarrow$ The distance betⁿ any 2 joints may be described as fracture cleavage.

Unconformity:-

- defined as an old erosion surface which separates younger strata from older strata (Billings 1942)
- major breaks in sedimentation → unconformity
- it represents an interval of time of unknown length which is spent in the erosion of the underlying strata before the deposition of the overlying rocks development.

Its development involves several stages

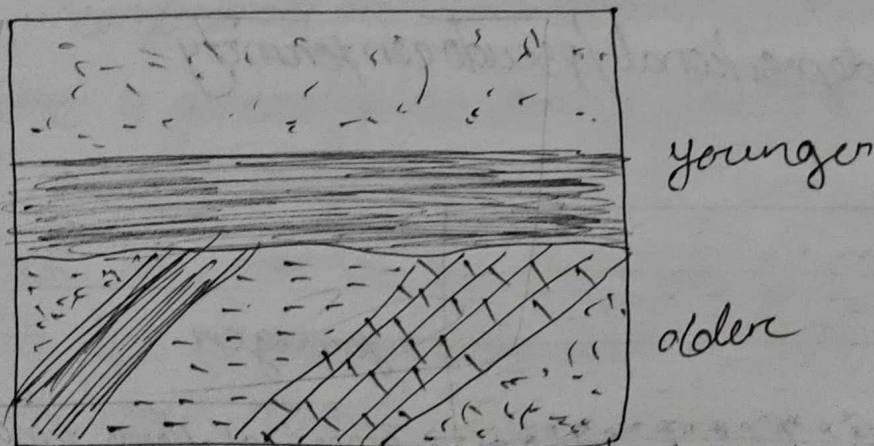
- formation of older rocks
- up-liftment and erosion of these several stages
- formation of younger strata above the surface of erosion
- Unconformities may be local or regional like the great Epanchean unconformity betⁿ the ancient archean and the overlying younger cuddaph series (proterozoic)

Types of unconformity:-

- i) Angular unconformity
- ii) Butler's "
- iii) Local " $\rightarrow$ age
- iv) Para " $\rightarrow$ traces of flora, fauna
- v) Non-conformity $\rightarrow$ heterolytic
- vi) Dis-conformity $\rightarrow$ wave

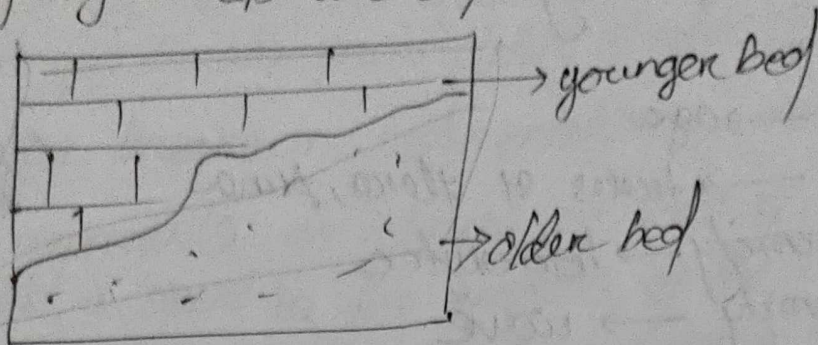
Angular unconformity:-

- $\rightarrow$ younger series of beds is found to be laid upon a cradled surface of a deformed older series the strata on opposite sides will not be $\parallel$ to each other. They meet at an angle this is called an angular unconformity
- $\rightarrow$ plane of unconformity betⁿ 2 series may be horizontal, inclined, undulation
- $\rightarrow$ older series may be steeply inclined, folded and faulted and intruded.
- $\rightarrow$ younger series may be horizontal or tilted
- $\rightarrow$ most common type of unconformity



i) Butlers unconformity :-

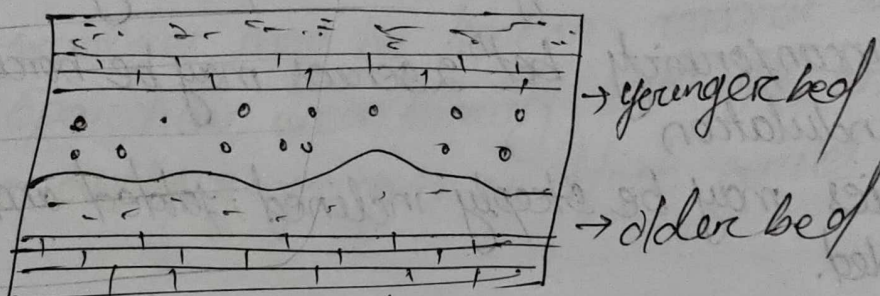
→ younger beds are deposited against older strata.



ii) Local unconformity :-

→ when an unconformity is traceable only in small area it is termed as local unconformity.

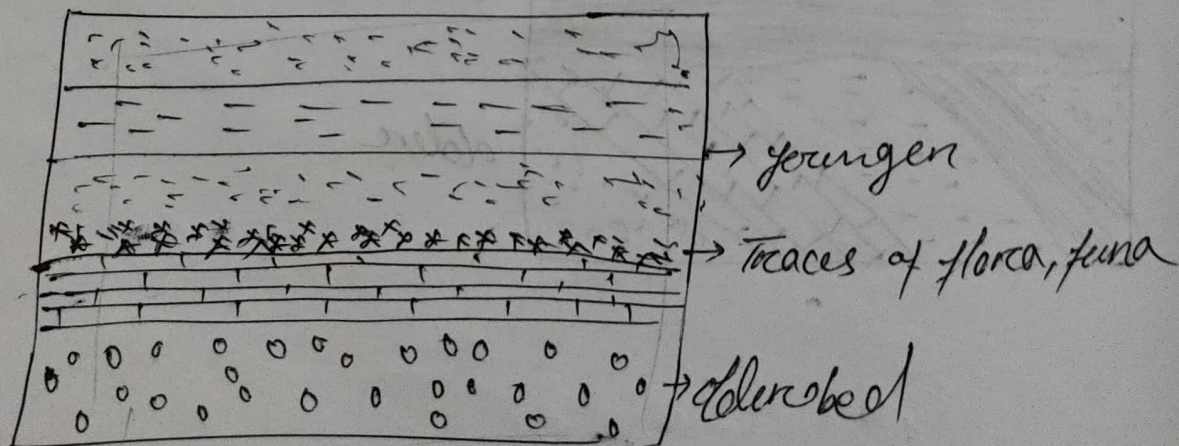
→ similar to disconformity but it is traceable only in small areas.



iii) Pareca unconformity :-

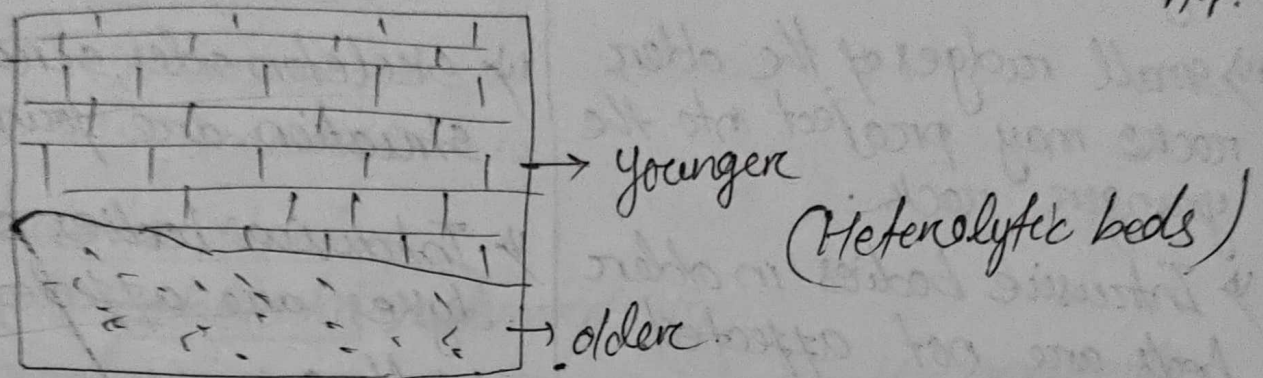
→ Strata are 11° , there is no apparent erosion and the unconformity surface resembles a simple bedding plane.

→ known as non-depositional/pseudoconformity
flooda, fauna



✓ Non-conformity:-
 → unconformity betⁿ 2 series of different origin (heterolytic) in which the underlying older rocks are of igneous/metamorphic origin (unstratified) and overlying rocks are of sedimentary origin (i.e. stratified)

ex:- The Tirupathy non-conformity betⁿ younger sandstone and older archaean formation in the Tirupathy hills A.P.



✓ Dis-conformity:-

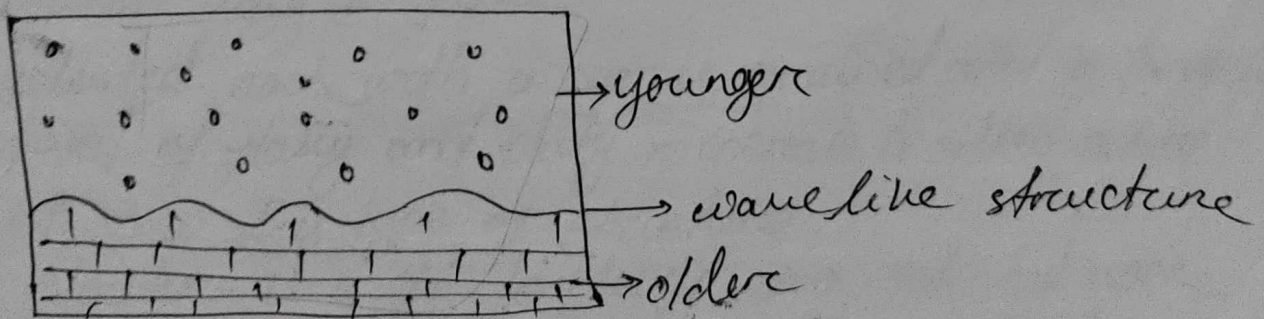
→ when a younger series is deposited on the eroded surface of an undeformed older conformable series in a 1st sequence the 2 series are described as disconformable series and the erosion surface betⁿ 2 series is called a 1st unconformity or disconformity [Grobau 1905]

→ There is generally no folding, faulting or tilting of strata.

→ It covers a large area

→ These are marked by features of subaerial erosion

→ This type of erosion can leave channels and paleosols in the rock record.



Unconformity :-

- i) Surface of erosion that separate younger rock from the older
- ii) an erosional surface
- iii) indicated by a layer of basal conglomerate
- iv) small ridges of the older rocks may project into the younger rock.
- v) Intrusive bodies in older beds are not affected.
- vi) Involves ≥ 2 series of different ages
- vii) Sudden changes in the fossil content.
- viii) Structural & stratigraphic importance
- ix) Valuable mineral and ore deposits and petroleum are associated

Fault :-

- i) cracks along which there is relative displacement on either side of the rock.
- ii) displacement of rocks along the fracture
- iii) indicated by mylonites, fault breccia etc
- iv) skeleton sides, scratches / striation are found
- v) Intrusive bodies sills & dykes are affected by faulting
- vi) One series of a period or
- vii) No change of sequence and included fossils in the footwall and hanging wall formation
- viii) Structural importance
- ix) Valuable minerals are associated

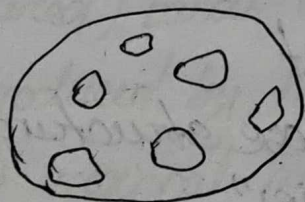


Metamorphic Structure :-

- It is defined as the Juxta position of 2 or more texture within a small rock unit.
- depends upon various agents which are responsible for re-crystallisation and mechanical deformation.
- 5 types (i) Cataclastic structure.
(ii) Schistose "
(iii) Maculose "
(iv) Granulose "
(v) Gneissose "

(i) Cataclastic structure :-

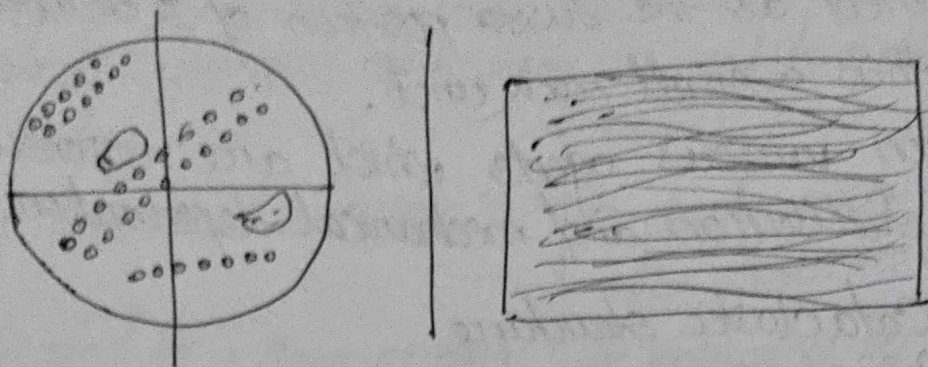
- due to cataclastic metamorphism
- mineral grains are broken up into smaller fragments due to mechanical breaking down of pre-existing rocks.
- no new mineral formation
- found in Crush breccias & mylonite rocks



(ii) Schistose structure :-

- due to dynamothermal metamorphism
- most obvious structural fracture of most metamorphic rocks is the alignment of minerals in 110° layers
- Longer direction are 110° to max^m stress direction
- platy/flaky minerals like mica show a preferred orientation along 110° planes.
- A foliated rock with is coarse grained and is largely composed of flaky and platy minerals is called schist.
- Schist show this type of structure.
- Schistosity :- it is the tendency of a foliated rock whereby it can be readily split along

Foliation plane.



(iii) Maculose structure:-

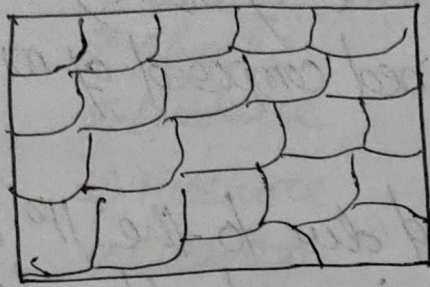
- produced by metamorphism of argillaceous rocks like shales
- larger crystals andalusite, cordierite and biotite are well developed giving a spotted appearance to the rock.
- The spot on the spotted rocks are due to the development of bigger crystals of some minerals such as andalusite, cordierite and biotite within the fine grain groundmass.
- Crystals are called prophyroblast
- This structure is known as "maculose structure"
- It belongs to the "Hornfels facies"



(iv) Granulose structure:-

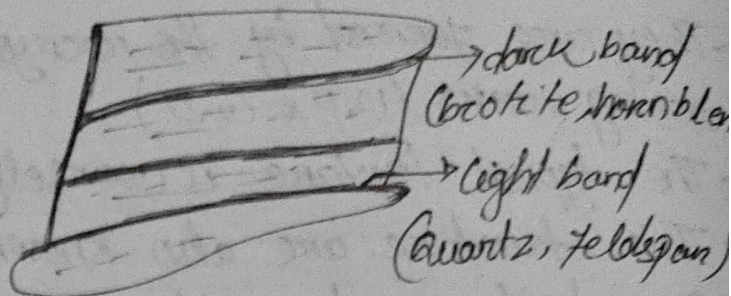
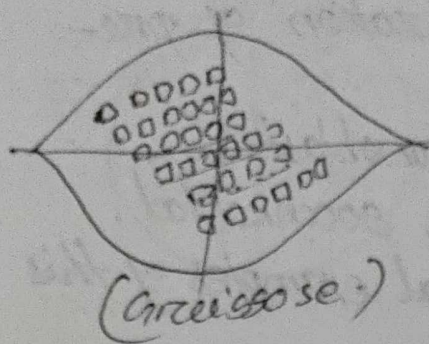
- produce due to predominance of equidimensional minerals such as quartz, feldspar, pyroxene and calcite.
- These structure formed under plutonic metamorphism (uniform pressure and great heat)

- The flaky minerals little absent or present only in small amounts
- They are formed by the recrystallization of pre-existing rocks, (V.P & G.D)
- The typical texture is coarsely granoblastic.
- This structure are also known as gneissoid.
- Quartzites and marbles are typical examples of this structure.



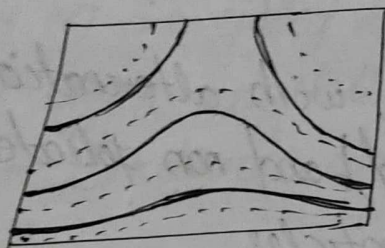
(V) Gneissose structure:-

- It is a composite structure with alternations of foliated (schistose, dark coloured) and non foliated (granulose, light coloured) bands and lenticles.
- It is produced by highest grade of metamorphism, typically by regional metamorphism.
- The band differs from one another in colour, texture, and mineral composition.
- The light colour bands are composed of quartz and feldspar while dark coloured bands are composed of ferromagnesian minerals.
- In gneissose rocks, the plane of schistosity are poorly defined.
- Gneiss typically show this type of structure and hence the name.



* Slaty structure:- (structure of slate)

- These are very fine grained composed of microscopic flakes and mica.
- These structure is formed due to the 11° orientation of flaky minerals like mica and chlorite.



* Hornfelsic structure:-

- It is characteristic of the contact metamorphic rock called the "hornfels".
- A hornfels is a dark, compact, fine grained rock having granoblastic texture.
- Hornfelsic structure is formed due to the predominance of equidimensional minerals such as feldspar, andalusite, cordierite and quartz.

Mineralogy :-

Physical properties of mineral :-

Mineral :- naturally occurring solid homogeneous substance formed by inorganic process having definite atomic structure and chemical composition.

ex:- olivine, quartz, gypsum, garnet, hornblende, diamond etc

→ It includes

i) Colour	vi) Form
ii) Streak	vii) Hardness
iii) Lusture	viii) Specific gravity
iv) Fracture	ix) Odor
v) Cleavage	x) Tenacity
	xi) Diaphaneity

i) Colour :- natural colour of mineral seen through naked eye

ex:- olivine → green

Azurite → sky blue

Galena → black

Talc → white

ii) Streak :- colour of mineral powder (may be same or not as colour of the mineral)

→ Non metallic mineral → lighter streak
metallic " → darker streak

eg	<u>mineral</u>	<u>colour</u>	<u>streak</u>
	Gold	→ yellow	→ yellow
	Galena	→ Black	→ Black
	Hematite	→ steel gray	→ cherry red

iii) Lusture :- appearance of mineral surface in reflected light

a) Metallic lusture :-

ex:- Haematite, chromite, magnetite

b) Non-metallic lusture:-

- ↳ Vitreous :- lusture of glass → quartz, calcite, feldspar
- ↳ Pearly " :- " " pearl → talc, calcite, opal
- ↳ Silky " :- shiny appearance similar to silk → Asbestos, gypsum
- ↳ Adamantine " :- like diamond → Diamond, zircon
- ↳ Earthy/Dull " :- lacks any shine → Magnesite, Bauxite

iv) Fracture :- nature of randomly broken surface of mineral

- | | <u>broken surface</u> | <u>examples</u> |
|------------------|--|---------------------|
| a) Even :- | flat, plane & smooth | → magnesite, chalk |
| b) Uneven :- | rough & ir-regular | → Pyrite, magnetite |
| c) Hackly :- | very ir-regular like end of broken stick | → Copper, kyanite |
| d) Conchoidal :- | smooth & curved | → quartz, opal |

v) Cleavage :- direction or plane along which a mineral tends to break easily

→ represents the plane of weakness

- * 1 set (basal) → Talc, mica
- b) 2 set (prismatic) → Feldspar, pyroxene, Amphibole
- c) 3 set (cubic) → Calcite, galena
- d) 4 set (octahedral) → Fluorite, Diamond
- e) 6 set (dodecahedral) → Sphalerite
- * NO cleavage :- quartz, olivine, garnet

vi) Form / habit :- shape & size of mineral

- a) Acicular :- needle like crystal → Natrolite, sillimanite
- b) Bladed :- crystals are flattened like bed → kyanite
- c) Columnar :- cylindrical column → Tourmaline

iv) Botryoidal :- bunch of grapes → Greothite, psilomelane, chalcedony

v) Foliated :- appear as thin sheet → mica group of minerals

vi) Reniform :- kidney shaped → Hematite

vii) Granular :- composed of many individual grain → chromite, marble

viii) Pisolitic :- pea sized grain → Bauxite

vii) Hardness :- resistance offered by the mineral to abrasion or scratching.

Moh's scale of Hardness :-

<u>mineral name</u>	<u>Hardness</u>	<u>common-object</u>
Talc	→ 1	→ scratch with finger nail
Gypsum	→ 2	→ finger nail
Calcite	→ 3	→ scratch with coin
Fluorite	→ 4	→ easily scratch with knife
Apatite	→ 5	→ scratch with knife blade
Orthoclase	→ 6	→ scratch with steel file
Quartz	→ 7	→ scratch with window glass
Topaz	→ 8	→ scratch with quartz
Corundum	→ 9	→ scratch with topaz
Diamond	→ 10	→ scratch with corundum

viii) Specific gravity :- ratio betⁿ density of mineral in air and density of mineral in water.

→ it is unit less

$$\text{specific gravity} = \frac{w_a}{w_a - w_w} \text{ or } \frac{\text{density of mineral in air}}{\text{" " " " water}}$$

i) Odor :- smell of mineral

a) Arsenical :- odor of garlic → arsenic mineral

b) Sulfurous :- " burning sulfur → Pyrite

c) Argillaceous :- " clay → Kaoline

→ Sulfur has a smell of rotten egg.

*) Tenacity :- reaction of mineral to stress, such as crushing, bending, breaking

a) Brittle :- breaks to powder easily → Quartz

b) Ductile :- draw into wire → Gold

c) Sectile :- cut into slices → Gypsum, gold

d) Malleable :- hammered into thin sheet → Silver

*) Diaphaneity :- degree of transparency of mineral

a) Transparent :- allowing light to pass through → muscovite

b) Translucent :- semi-transparent → calcite

c) Opaque :- not transparent → Galena, pyrite

Microscopic identification of mineral:-

- The optical properties of mineral in thin section can be examined in different type of microscopic setups
 - ↳ under plane polarised light
 - ↳ " crossed nicol position

under plane polarised light:-

Properties like colour, pleochroism, refractive index, cleavage, shape and habit, alteration, inclusion & relief & twinning are studied in plane polarised light (PPL)

↳ Colour:-

- distinctive character of a mineral
- colour of mineral under microscope depends upon the manner in which they transmitted light is absorbed by the section.
- Standard thickness of thin section $\Rightarrow$ 0.035 mm
 - Coloured minerals $\Rightarrow$ biotite, hornblende
 - Colourless " $\Rightarrow$ Quartz, feldspar, muscovite
- Isotropic mineral has different colour in diffⁿ vibration direction.

↳ Pleochroism:-

- It is the change in quantity and/or quality of colour of mineral on rotating the microscope stage; containing the thin section.
- It is due to unequal absorption of light in different direction.
- In isotropic mineral absorption is same in all direction, so they are non-pleochroic.
- Basal section of uniaxial mineral is non-pleochroic.
Prismatic section is pleochroic. e.g. tourmaline (uniaxial)
- Bi-axial minerals are trichroic since they have 3 vibration direction. e.g. Hornblende (bi-axial)

iii) Form and shape :-

→ The shape and degree of perfection of crystal outline :-

- a) Euhedral :- smooth face → olivine, Pyroxene
- b) Subhedral :- partly smooth faces → orthoclase
- c) Anhedral :- rough faces (not well formed faces) → Quartz

iv) Refractive Index (R.I.) :-

→ When ray of light passes from light medium to denser medium or vice-versa, it gets refracted and its velocity changes.

→ The ratio betⁿ velocity of light in air and velocity of light in mineral is -----

$$\text{R.I.} = \frac{\text{velocity of light in air}}{\text{" " " " mineral}}$$

→ Uni-axial mineral have 2 R.I. (correspond) to O & E-ray

→ Bi-axial " " 3 R.I. (i.e. α, β, γ) correspond to X, Y, Z vibration direction.

→ R.I. can be determined by immersion method, back line meth

v) Relief :-

→ It means how distinctly the outline and surface of mineral is visible in thin section.

→ It also refers to the relative difference in R.I. betⁿ neighbouring crystal.

a) Low :- outline aren't clearly visible → Quartz, Orthoclase

b) Moderate :- outline is more/less distinct → Amphiboles

c) Strong :- mineral borders are bounded by dark lines and clearly visible → Garnet, Zircon

Relief as a whole depends upon the difference betⁿ the R.I. of mineral and that of immersion medium (Canada Balsam)

So, if R.I. of mineral is high then relief will be high and if R.I. is low then relief will be low.

vii) cleavage :- plane of weakness along which a mineral breaks with smooth surface

1 set $\rightarrow$ mica

2 set $\rightarrow$ Feldspar, amphibole

3 set $\rightarrow$ calcite

4 set $\rightarrow$ fluorite

6 set $\rightarrow$ sphalerite

no set $\rightarrow$ quartz

viii) Alteration :-

$\rightarrow$ It refers to various natural process that alter a mineral chemical composition and crystallography.

$\rightarrow$ It starts at the margin or cleavage of the mineral.

$\rightarrow$ Zircon & quartz are highly resistance to alteration.

e.g. $\rightarrow$ Zircon alters to cryptolite.

ix) Inclusion :-

$\rightarrow$ It is any material that is trapped inside a mineral during its formation.

$\rightarrow$ They are usually other minerals or rock but may also be water, gas or petroleum (fluid inclusion)

e.g. $\rightarrow$ In case of amber, it is possible to find insects and plants as inclusion.

Properties under crossed Nicol :-

i) Isotropism / Anisotropism

ii) Extinction

iii) Interference colour

iv) Birefringence

v) twinning

vi) optical sign

vii) Interference figure

viii) Dispersion

i) Isotropism/Anisotropism:-

- Minerals belonging to the cubic system and the basal section of uniaxial mineral (tetragonal & hexagonal) are isotropic & remain dark under crossed nicol throughout the complete rotation of stage.
- Minerals belonging to other crystal system are anisotropic and four maximum darkness is observed during the complete rotation of the mineral section.

Isotropic mineral → Galena, Garnet, diamond, basal section of uniaxial minerals like zircon, quartz, calcite

Anisotropic mineral → Olivine, pyroxene, amphibole group, mica group, feldspar group.

ii) Extinction:-

- when the vibration direction of mineral are 180° to the plane of polarization of the polarizer and analyser the mineral appears dark.
- All minerals show 4 position of extinction in a single rotation (90° apart).
- The angle betⁿ a crystallographic direction/one of the cross hair and vibration direction of the mineral plate to the position of maximum extinction is known as "extinction angle".

iii) Interference Colour:-

- The colours that anisotropic minerals show under the CPL arrangements are known as interference colour.
- The max^m intensity of these colour are seen in betⁿ 2 extinction position (at 45° position)

iv) Birefringence:-

- It is the difference betⁿ the max^m and min^m R.I value shown by a mineral.
- The interference colour shown by a mineral depend on its birefringence.

v) Twinning:-

- It may be defined as the symmetrical intergrowth of 2 or more crystals in such a way that some crystallographic planes are common to the parts of twinned crystals.
- Often only a single plane is seen but in some minerals (particularly plagioclase, feldspar) multiple / lamellar twinning occurs.

vi) Optic sign:-

- All anisotropic minerals have 2 R.I. i.e. R_{I_o} & R_{I_e} . According to these values the optic sign is determined

$$R_{I_o} > R_{I_e} \text{ (-ve)}$$

$$R_{I_o} < R_{I_e} \text{ (+ve)}$$

vii) Interference Figure:-

- It is an important optical property that are used in the identification of minerals as well as to determine other properties of mineral such as
 - optic sign
 - whether a mineral is uniaxial/biaxial

viii) Dispersion:-

- When white light entering into the mineral section is split into the colours of the spectrum. This breaking up the white light is called "dispersion".
- In many minerals the amount of dispersion is very small

and will not affect the mineral optical properties.

But Na-rich amphiboles,

Na-rich clinopyroxene possess very strong dispersion.

Uniaxial minerals:

It may be defined as the symmetrical arrangement of atoms or crystals in such a way that some crystallographic planes are common to the parts of turned crystals. Often only a single plane is seen but in some minerals (particularly plagioclase feldspar) multiple (homonuclear) twinning occurs.

Optic sign:

→ All anisotropic minerals have 2 R.I. i.e. R_1 & R_2 . According to their values the optic sign is determined

$$R_1 > R_2 \text{ (-ve)}$$

$$R_1 < R_2 \text{ (+ve)}$$

Interference figure:-

It is an important optical property that is used in the identification of minerals as well as to determine other properties of mineral such as

- optic sign
- whether a mineral is uniaxial/biaxial

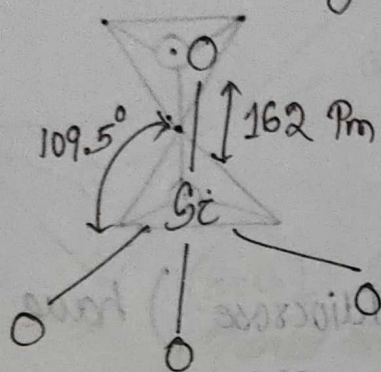
Dispersion:

→ When white light entering into the mineral section is split into the colours of the spectrum. The spreading up the white light is called "dispersion".

→ In many minerals the amount of dispersion is very small

Silicate Structure :

- The silicate mineral group is of great importance because they constitute about 90% of earth's crust.
- They are found in all the common rocks except limestone (CaCO_3)
- basic unit → Silica - Oxygen (Si-O) tetrahedral
- Each oxygen atom is 5 times longer as the silicon atom
- The distance betⁿ any 2 oxygen atom is 2.8 Å or 2.8×10^{-8} cm



(Pm = Picometer)
Si-O → 1.55 - 1.72 Å

Classified into 6 major types :

→ Neo/Ortho silicate :- (island silicate)

- Independent tetrahedral (SiO_4)
- The atomic packing of neo/ortho silicate structure is generally dense which cause the mineral of this group to have relatively high specific gravity and hardness.
- The crystal habit of these minerals generally equidimensional and they have poor cleavage.
- Si : O = 1 : 4 ex:- olivine → $(\text{MgFe})\text{SiO}_4$
Zircon → ZrSiO_4
Garnet → $\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$

→ Don't have any share oxygen. (bridging oxygen)

→ ex:- epidote, piemontite, phenakite group, andalusite, chloritoid, sillimanite, kyanite, staurolite, sphene, topaz

ii) Soro / Pyro silicate :-

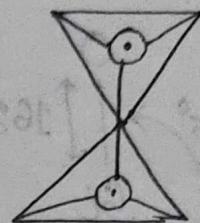
- It is characterised by linked pairs of SiO_4 tetrahedra.
- They are characterised by high S.G. & high R.I. and tabular habit.

→ $\text{Si}:\text{O} = 2:7$ ex:- Melite ($\text{Ca}_2\text{MgSi}_2\text{O}_7$)

Hemimorphite ($\text{Zn}_2(\text{Si}_2\text{O}_7)(\text{OH})_2\text{H}_2\text{O}$)

→ Shared oxygen $\rightarrow 1$

ex:- Lawsonite,
danburite,
pumpellyite



* Epidote, Zoisite and vesuvianite (Idiocrase) have a combination of both SiO_4 & Si_2O_7 groups.

iii) Cyclo/meta silicate :- (Metasilicate)

→ Rings of linked SiO_4 tetrahedral

→ $\text{Si}:\text{O} \rightarrow 1:3$, shared oxygen $\rightarrow 2$ (exhibit either trigonal hexagonal symmetry)

3, 4, 6 linked tetrahedral

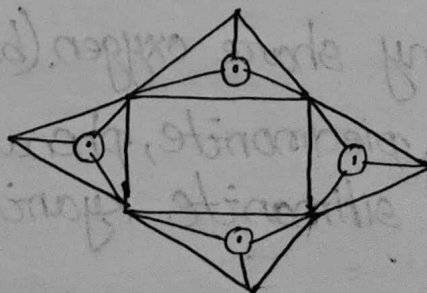
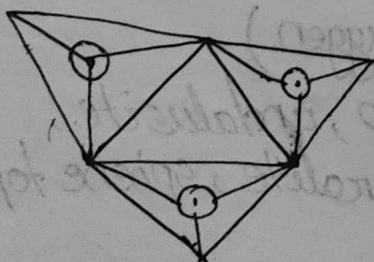
→ These are extremely strong mineral.

ex:- Beryl $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ (6 membered link)

(3-link) [Tourmaline
Benitoite - $\text{BaTi}(\text{Si}_3\text{O}_9)$

cordierite

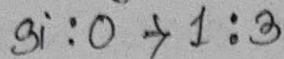
Axinite (4-link) - $(\text{Ca, Fe, Mn})_3\text{Al}_2\text{B}_3\text{Si}_4\text{O}_{12}\text{OH}$



iv) Inosilicate

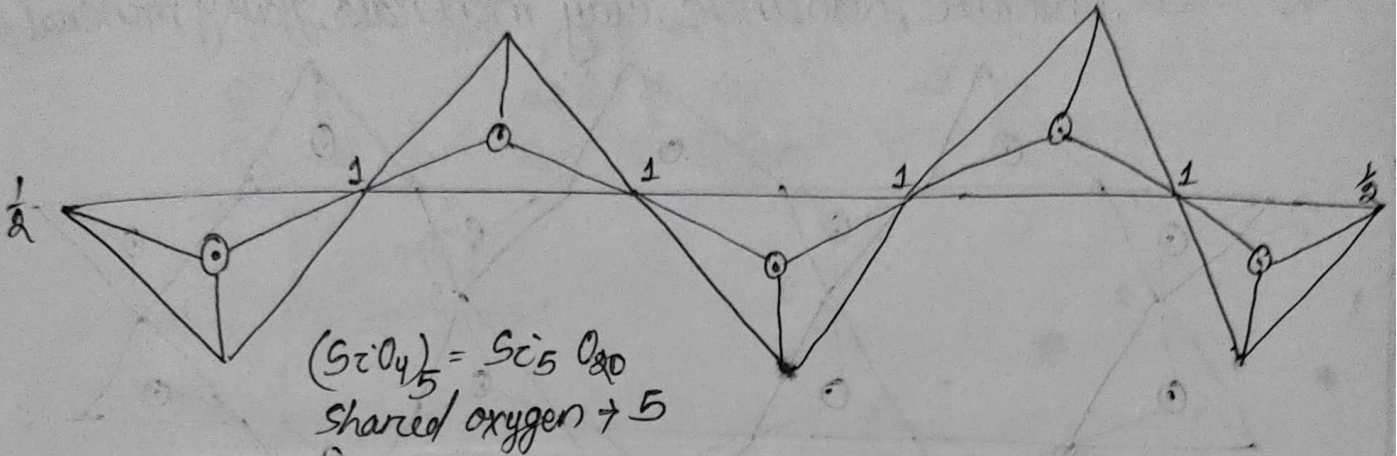
→ characterised by prismatic habit of all kind.

→ 2 types (i) single chain inosilicate



shared oxygen $\rightarrow 1$ or 2

ex:- pyroxene group, pyroxenoid



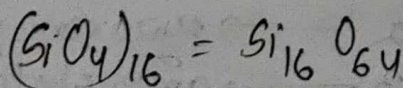
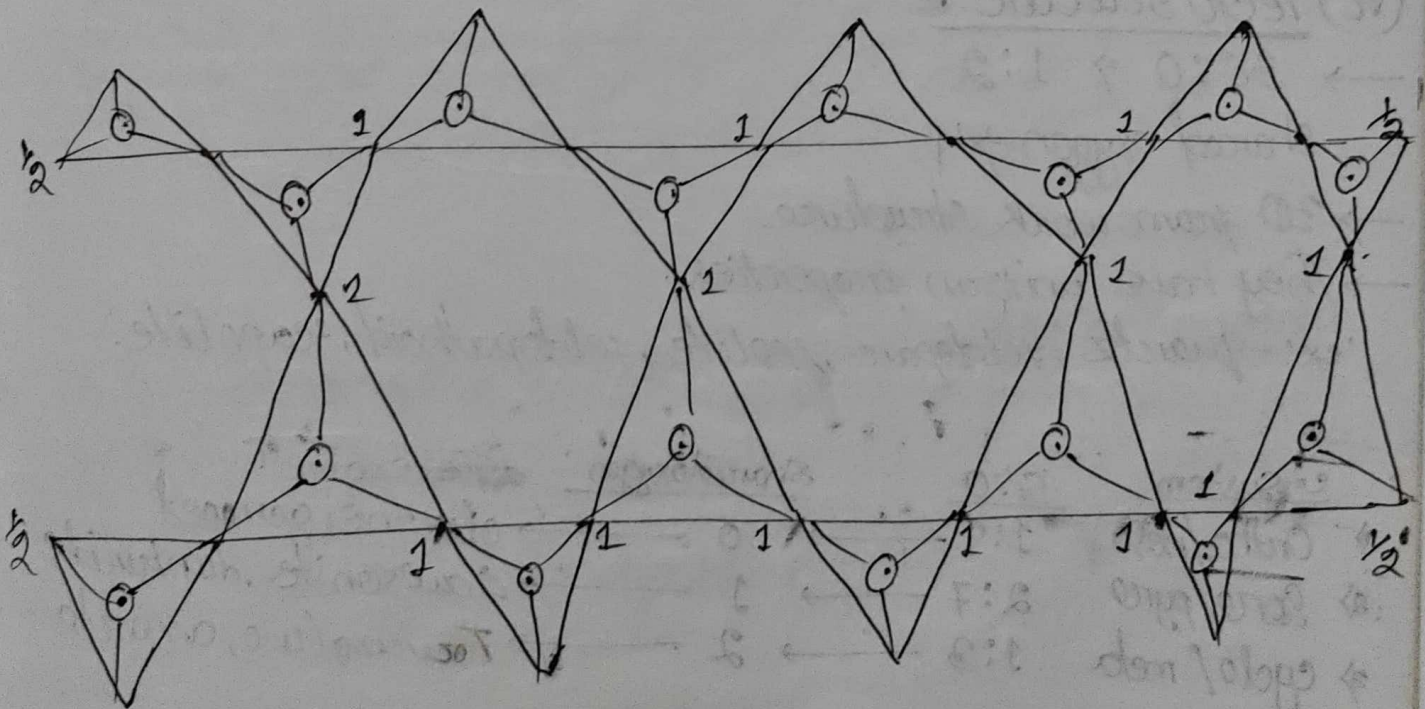
(ii) Double chain Inosilicate



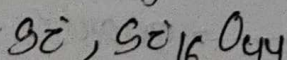
shared oxygen $\rightarrow 2$ or 3

→ commonly form needle like crystals

ex:- amphibole



shared oxygen = 20



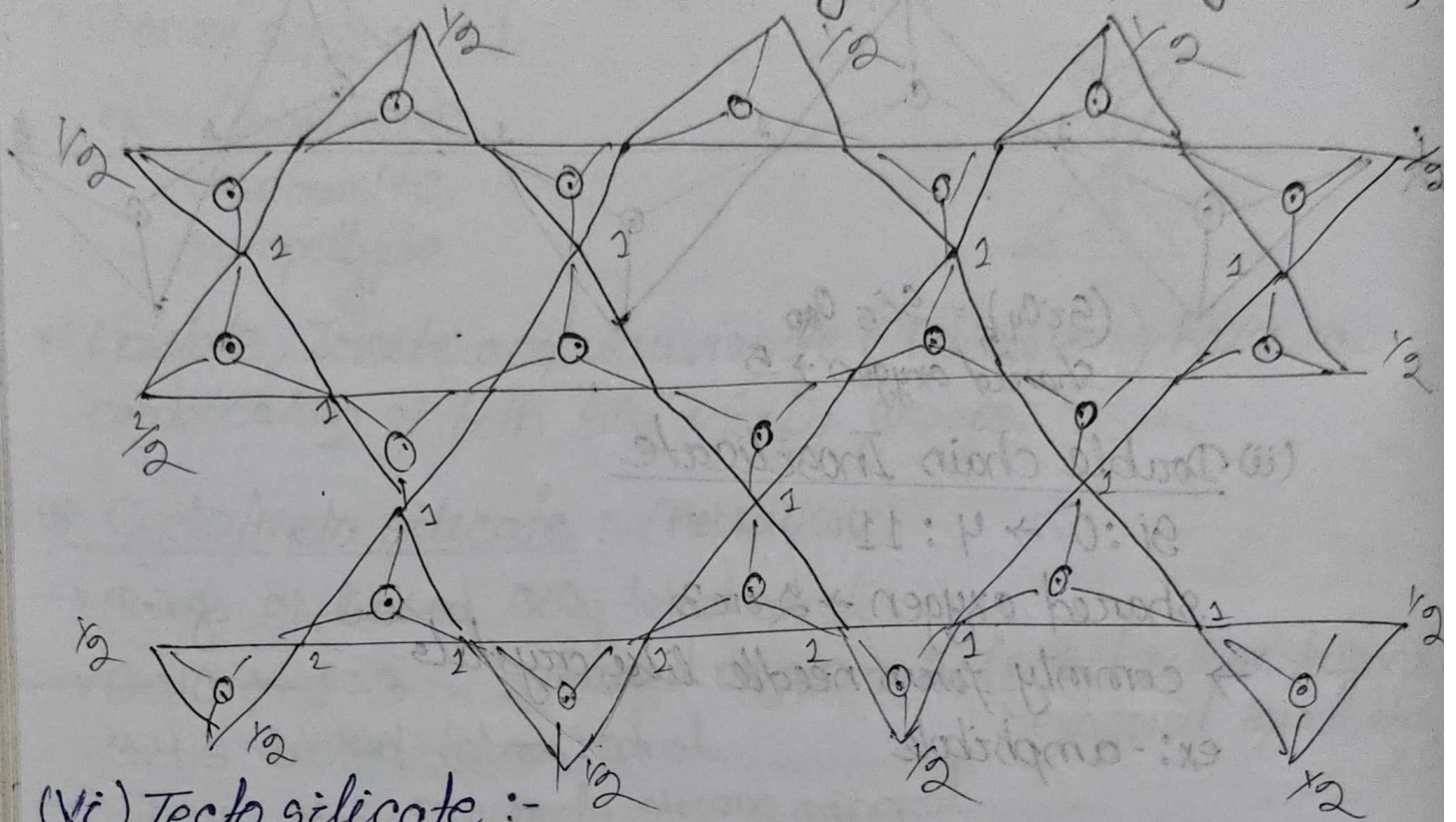
(v) Phyllo / sheet silicate :-

→ They form sheet structure in which there is the continuous linking of hexagonal group of silica tetrahedral.

→ $Si : O \rightarrow 2 : 5$

shared oxygen $\rightarrow 3$

ex:- mica, chlorite, Kaolinite, clay minerals, flaky mineral.



(vi) Tecto silicate :-

→ $Si : O \rightarrow 1 : 2$

shared oxygen $\rightarrow 4$

→ 3D framework structure

→ They have uniform properties.

ex:- quartz, feldspar, zeolite, feldspathoid, scapolite.

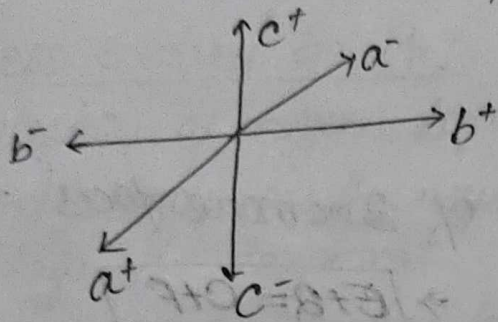
<u>System</u>	<u>Si:O</u>	<u>Shared oxygen</u>	<u>Example</u>
1) Ortho/neso	1:4	0	olivine, garnet
2) Soro/pyro	2:7	1	Lawsonite, danburite
3) cyclo/meta	1:3	2	Tourmaline, anorthite
4) Ino (single)	1:3	1-2	Pyroxene group
(double)	4:11	2-3	amphibole
5) Phyllo / sheet	2:5	3	clay, talc, mica
6) Tecto	1:2	4	quartz, feldspar

Crystallography

→ Crystals are solid polyhedral bodies bounded by well developed smooth surface in which atoms are arranged in a definite pattern and whose surface regularity reflects its internal symmetry.

→ A crystal can be defined by 3 or 4 imaginary crystallographic axis as

a-axis from front to back
b- " " right to left
c- " " top to bottom



→ When the 3 crystallographic axis are of equal length, they are denoted as a_1, a_2, a_3 .

→ The angle betⁿ crystallographic axis are denoted as α, β, γ .

$$\alpha = \angle b_1 + c$$

$$\beta = \angle a_1 + c$$

$$\gamma = \angle a_1 + b$$

→ The 4 crystallographic axes are only use in case of hexagonal system.

→ They are

a_1 → runs from left front to right back

a_2 → " " right to left

a_3 → " " left back to right front

c → " " top to bottom

Interfacial angle :-

- angle betⁿ the adjacent faces of a crystal
- Calcite and siderite are iso-structural but their mutual solubility is limited and they form limited (or partial) solid solutions.

Face:- a natural flat surface on a crystal, that develops as result of internal structure.

Edge:- intersection of 2 faces belonging to 1 or more form

$$E = \frac{1}{2} (F_1 \cdot S_1 + F_2 \cdot S_2 + \dots)$$

F = Faces, S = sides

Solid angles (corners):- intersection of 3 or more faces

$$C = E - F + 2$$

$$\Rightarrow E + 2 = C + F$$

E = edge, F = No. of faces

Crystal intercept :-

- distance along a crystallographic axis to its intersection with a crystal face.
- the crystallographic axis may pass through the crystal or we can imaginarily extend the face to obtain the intercept
- If a face is $\parallel$ to an axis, then the intercept is considered as infinity.

Weiss Parameter :-

- It is the relative notation system obtain by dividing crystal intercept with unit length of crystal face.

$$w.p. = \frac{\text{crystal intercept}}{\text{unit length}}$$

Miller indices :-

- It is a mathematical notation to represent crystal plane and its direction in crystal structure.
- It is the reciprocal of weiss parameter that means

we obtained it by dividing unit length of crystal face.

$$M.I = \frac{1}{w.p} = \frac{\text{unit length}}{\text{crystal intercept}}$$

→ It is denoted by h, k, l .

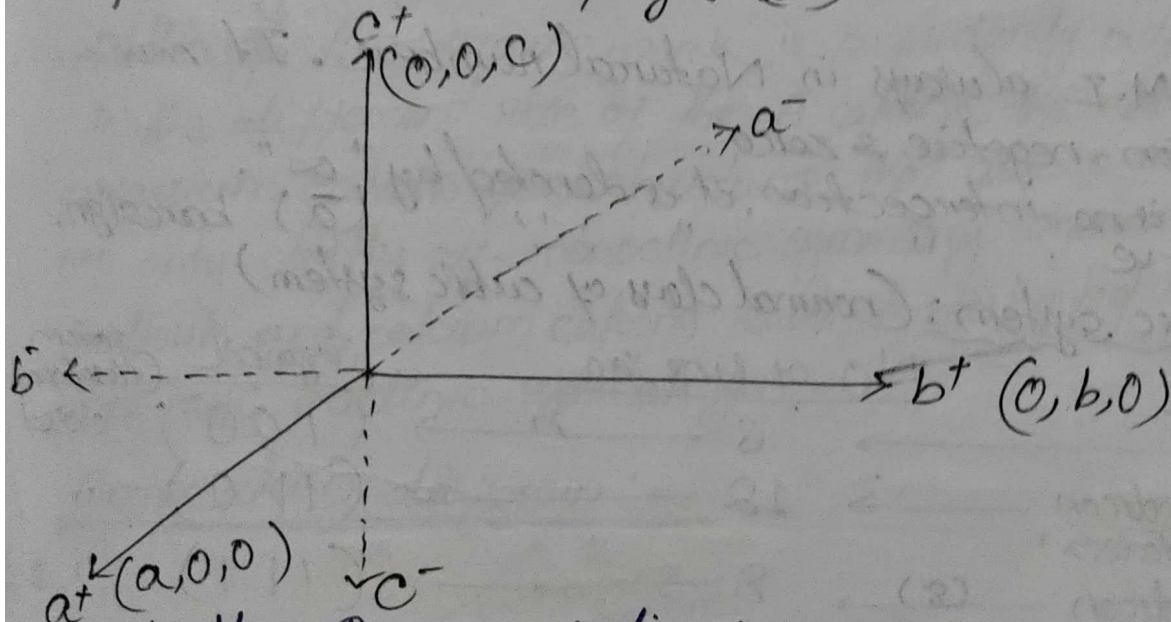
→ It is first developed by 1825 by W. Whewell a professor of mineralogy at Cambridge university.

→ They are named after William Hallaver Miller a student of Whewell's who promoted and popularized their use in 1829.

Steps involved in M.I.

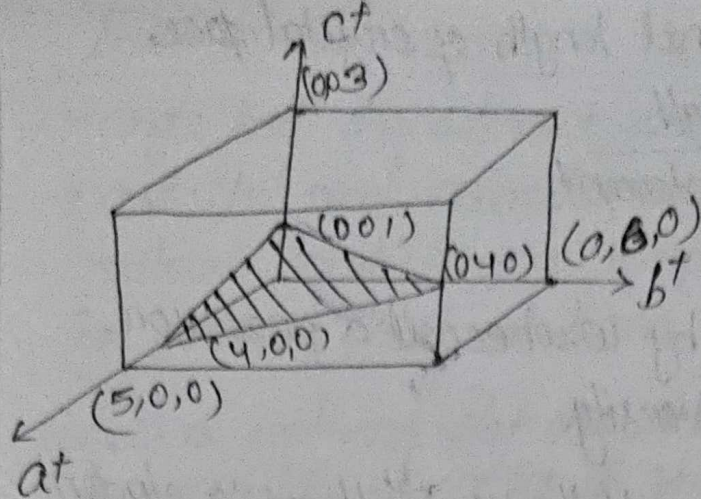
- i) selection of origin - left, down, back
 - ii) Find intercept on the respective axis
 - iii) Obtain the reciprocal
 - iv) Elimination of fraction to make them integer
- It can be integer (ive, -ve or zero) but never be ∞ or fractions.

If -ve, then denoted by $\bar{i}$ (bar).



Miller Bravais indices :-

- This type of indices system is used in case of hexagonal system
 - It consists of 4 indices named as h, k, i and l .
- where $\boxed{h + k + i = 0}$



intercept $(4 \ 4 \ 1)$
 crystal length $(5 \ 6 \ 3)$

$$W.P. = \frac{\text{intercept}}{\text{crystal length}} = \frac{(4 \ 4 \ 1)}{(5 \ 6 \ 3)}$$

$$= \left(\frac{4}{5} \times 30 \quad \frac{4}{6} \times 30 \quad \frac{1}{3} \times 30 \right)$$

$$= (24 \ 20 \ 10)$$

$$= (12 \ 10 \ 5)$$

$$M.I. = \frac{1}{W.P.} = \left(\frac{1}{12} \ \frac{1}{10} \ \frac{1}{5} \right)$$

$$= \left(\frac{1 \times 60}{12} \quad \frac{1 \times 60}{10} \quad \frac{1 \times 60}{5} \right)$$

$$= (5 \ 6 \ 12)$$

(Ans)

* W.P. and M.I. always in Natural number. It never be fraction, negative & zero.

→ If there is no intersection, it is denoted by " ∞ ".
 → ∞ -ve " " " " " " " " " " " "

Isometric system :- (normal class of cubic system)

Sr.	Form	No. of axes	Symbol	form (close/op)
1	Cube	6	(100)	close
2	Rhombohedral (dodeca)	12	(110)	"
3	Octahedron (8)	8	(111)	"
4	Tetrahedron (4-6)	24	(hkl)	"
5	Triso octahedron (3-8)	24	(hhl)	"
6	Trapezohedron	24	(hll)	"
7	Hexa octahedron (6-8)	48	(hkl)	"

Feldspar Group:-

- Major constituent of earth's crust
- Volcanic feldspar are generally of high temperature variety
- General formula AT_2O_8
Tectosilicate $\rightarrow Si:O = 1:2$
- Crystal system $\rightarrow$ monoclinic, $\frac{2}{m}$ to triclinic $\bar{1}$
- General formula for common feldspar is $XAl_{(1-2)}Si_{(3-2)}O_8$
 $X = Na, K, Ca$

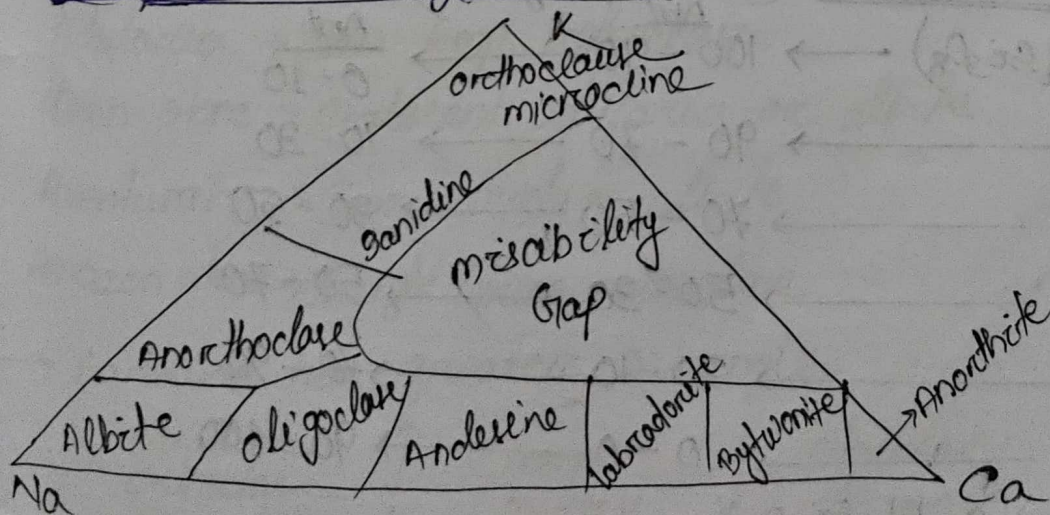
when, there is 1 Al and 3 Si, then at X position contain +1 charge member i.e. Na, K

when, there are 2 Al and 2 Si, then at X position contain +2 charge member i.e. Ca, Ba

Structure:-

- Positively charged cations (Na, K & Ca) that occupy relatively large interstices within the framework.
- Although the framework is sufficiently adjust itself to the different size of the A cations, the relatively large potassium cations give structure that have a monoclinic or only slightly off-monoclinic symmetry where as the smaller sodium and calcium cations leads to distorted structure that have triclinic symmetry.

Composition diagram:-



Alkali Feldspar :-

Microcline :- potassium - aluminium silicate (K-feldspar)
(Biaxial -ve) $\rightarrow$ Triclinic
 $\rightarrow$ Cross-hatched lath-like pattern of twinning

Orthoclase and sanidine :-

- $\rightarrow$ monoclinic K-feldspar
- $\rightarrow$ found in volcanic and sub-volcanic rock
- $\rightarrow$ high temp. variety (sanidine)
- $\rightarrow$ Orthoclase occurs in plutonic rock
- $\rightarrow$ These are Bi-axial -ve.

Anorthoclase :-

- $\rightarrow$ Alkali feldspar K-Na feldspar, not K-feldspar
- $\rightarrow$ It is sodic in composition
- $\rightarrow$ Triclinic
- $\rightarrow$ Twinning similar to monocline
- $\rightarrow$ Hyalophane series $\rightarrow$ K and Ba feldspar

Barium Feldspar :-

- $\rightarrow$ It is considered alkali feldspar ~~from~~ as the result of the substitution of barium for potassium in the mineral structure.
- $\rightarrow$ Monoclinic
Celadon $\rightarrow \text{BaAl}_2\text{Si}_2\text{O}_8$
hyalophane $\rightarrow (\text{K}, \text{Ba})(\text{Al}, \text{Si})_4\text{O}_8$

Plagio-clase series :- (Triclinic system)

	Abt.	Ant.
Albite ($\text{NaAlSi}_3\text{O}_8$)	100 - 90	0 - 10
(Biaxial +ve) Oligoclase	90 - 70	10 - 30
Andesine	70 - 50	30 - 50
Labradorite	50 - 30	50 - 70
Bytownite	30 - 10	70 - 90
Anorthite	10 - 0	90 - 100
(Bi-axial -ve) ($\text{CaAl}_2\text{Si}_2\text{O}_8$)		

Physical Properties :-

→ Colour → Generally light coloured white-grey
(Orthoclase - flesh red / buff red)

→ Lustre → vitreous

→ cleavage → 2 set perfect 90° 001 010

→ Hardness → 6

→ Specific gravity → 2.5 to 3

Optical properties :-

→ form → subhedral to anhedral

→ Refractive index → Low R.I.

→ Birefringence → weak

→ Extinction angle → $15-30^\circ$

Twinning :-

<u>Twinning</u>	<u>Plane</u>	<u>Mineral</u>
Carlsbad	→ 010	→ orthoclase
Baveno	→ 021	→ "
Mona Bach	→ 001	→ "
Albite law	→ 001	→ microcline
Pericline law	→ 010	→ " & plagioclase

Varieties :-

Sandstone → High temp K-feldspar

Adularia → Low temp. orthoclase

Moon-stone → Opalescent adularia or albite

Aventurine → Gem variety of albite

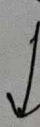
Amazon stone → Bright Green microcline

→ Sandstone has greater 2V angle

Sandstone
Orthoclase
microcline



Temp.
increase



stability
decrease

→ Zebra stripe found in albite

Occurrence:-

- Perthite → orthoclase / microcline + albite / oligoclase
- Anti-perthite → microcline + albite
- Graphic inter growth → Quartz + orthoclase
- Myrmekitic inter growth → Quartz + Plagioclase

→ Plagioclase minerals after to clay minerals or sericite.

→ An-orthoclase composed of labradorite feldspar.

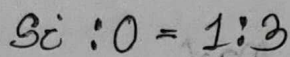
Mineral	Plane	Twining
Orthoclase	010	inverted
"	021	normal
"	001	one lock
Microcline	001	little lock
"	010	vertical lock
Plagioclase		

Characteristics:-
Solid solution → high temp K-feldspar
labradorite + low temp. orthoclase
con. str. → exsolved labradorite or albite
venturine → (can variety of albite)
no con. str. → bright green microcline
solid solution has greater 2V angle

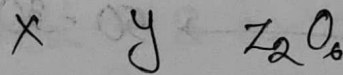
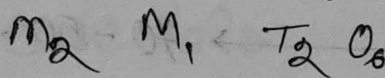
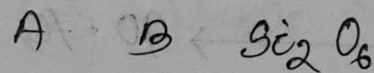
solid solution
↑ temperature
↓ stability
↓ decrease

Pyroxene Group:-

- from greek word, Pyro = fire
Xenos = stranger → Pyroxene = fire stranger
- It was given by Rene Haüy in 1796 to the greenish crystal found in many lava.
- Pyroxene was named because of its presence in a glassy/vitreous lava. Pyroxene was believed to be an impurity in the glass and therefore a stranger to fire and not formed by the action of heat.
- Crystal system → monoclinic, orthorhombic
Silicate structure → Inosilicate (Single chain)

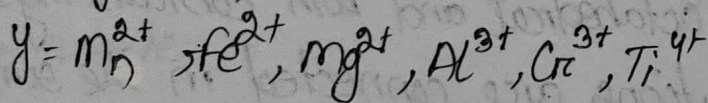


General formula → $X_{1-n} Y_{1+n} Z_2 O_6$



where, $X = \text{Na}^+, \text{Ca}^{2+}, \text{Mn}^{2+}, \text{Fe}^{2+}, \text{Mg}^{2+}$

Filling octahedral site called m_2



Filling smaller octahedral site called m_2

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

$T = (\text{tetrahedral})$

M_1 (small octahedron) (structural site)

m_2 (larger cation site) (" ")

→ apical oxygens - m_1

Base - m_2

→ If $m_2 \rightarrow 6$ fold co-ordination → orthorhombic
" " " " → monoclinic

→ Pyroxene classification is based on the occupancy of m_2 sites and symmetry

Ortho pyroxene → orthorhombic system

Clino pyroxene → monoclinic system

(Pyroxenoid → Triclinic system)

Pyroxene → ortho pyroxene (Opx)

low Ca clinopyroxene (pigeonite)

Ca → clinopyroxene Cpx

Ortho pyroxene :-

Solid solⁿ series

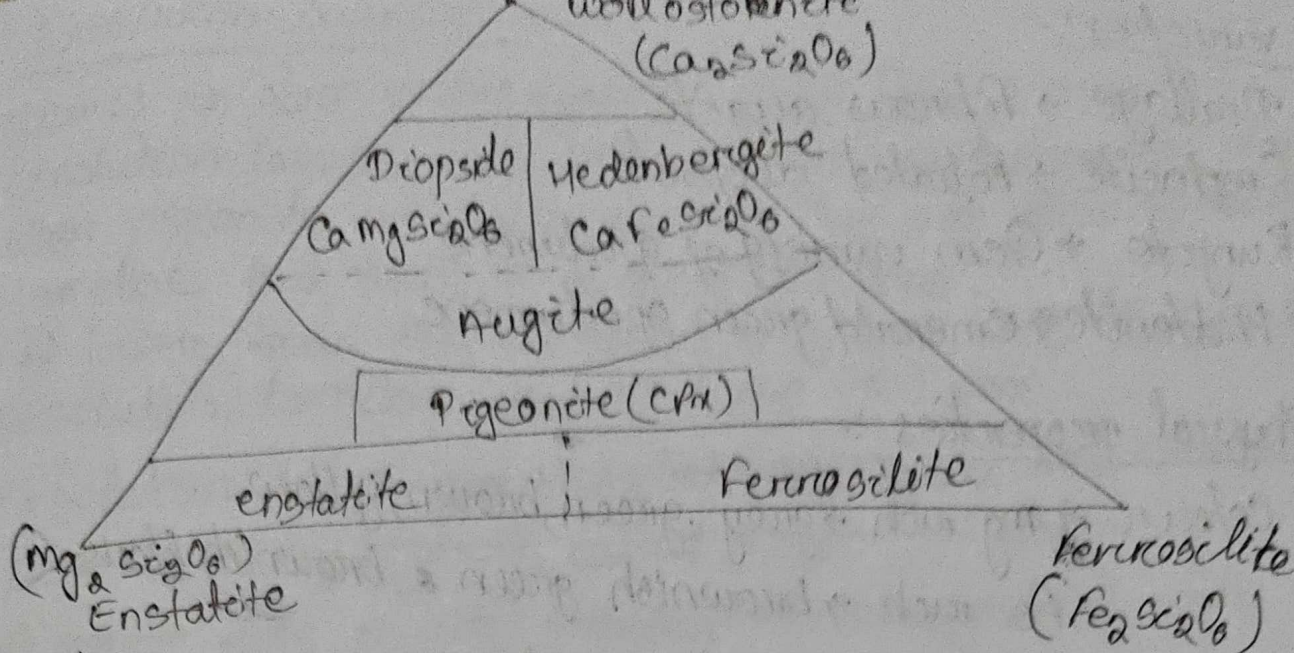
	<u>Mg %</u>	<u>Fe %</u>
Enstatite ($Mg_2Si_2O_6$)	100 - 90	0 - 10
Bronzite	90 - 70	10 - 30
Hypersthene	70 - 50	30 - 50
Ferro hypersthene	50 - 30	50 - 70
Eulite	30 - 10	70 - 90
Ferrosilite	10 - 0	90 - 100

→ Both m_1 & m_2 sites are octahedral and both contain Mg & Fe but the larger Fe cations are connected in the somewhat larger m_2 sites.

→ At high temp., orthopyroxene may accommodate more Ca in the m_2 sites than at low temp. with slow cooling, the excess Ca is expelled to form exsolution lamellae of augite parallel to (100)

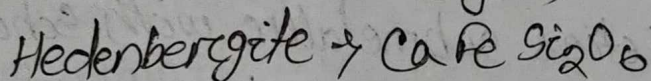
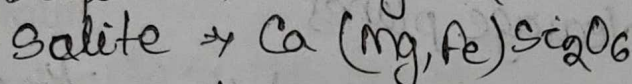
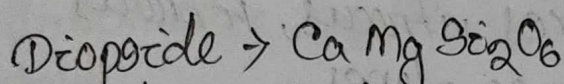
→ Donpeacorite - Mn, Mg silicate

→ Nishwaningite - Hydrated Mn silicate



Clinopyroxene :-

→ It includes solid solution that extend from Diopside to heden bergite.



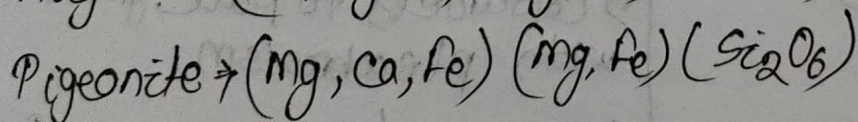
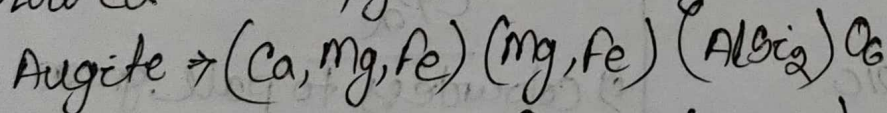
The M_2 site contain $\rightarrow \text{Ca} \rightarrow 8$ co-ordination

M_1 " " $\rightarrow \text{Mg, Fe}$

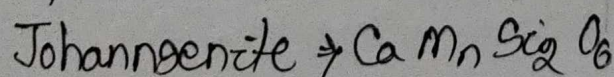
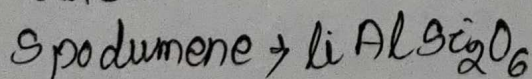
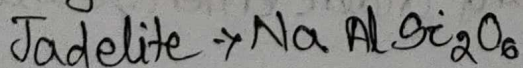
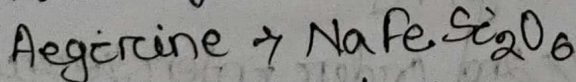
→ most abundant clinopyroxene $\rightarrow$ Augite

→ Ca - montmorillonite is formed by the chemical weathering of Augite.

→ low Ca - clinopyroxene $\rightarrow$ Pigeonite



Alkali Pyroxene :-



→ also called aegirite due to acicular shape.

→ High pressure monoclinic

Varieties:-

- Diallage → fibrous augite
- Omphacite → foliated diopside
- Kunzite → Gem variety of spodumene
- Hiddenite → emerald green spodumene

Physical properties :-

- Colour → Mg rich → grey, green, brown, yellow
Fe rich → brownish green & brownish black
- Form → prismatic, massive, lamella
- Cleavage → 2 direction at 87° and 93°
- Streak → white, greenish white or grey
- Lustre → Mg rich varieties vitreous, fibrous looking on cleavage planes
Fe rich varieties submetallic with schillerization due to presence of flakes of iron oxide
- Fracture → uneven
- Hardness → 5-6
- Specific gravity → 3.2 - 3.96 increases with iron content

Optical properties:-

OP_x
i) green & pleochroic

ii) High R.I.

iii) Optically +ve

iv) parallel extinction

v) 1st order interference

CP_x
i) Colourless to pale green with pleochroism

ii) Inclined extinction 45°

iii) High RI

iv) 2nd order interference

Exsolution lamellae

- occurs in slow cooling pyroxene like Opx & augite
- Exsolution lamellae are $\parallel$ to certain crystallographic plane.
- when pigeonite or augite exsolve they may form exsolution lamellae that form $\parallel$ to the (001) plane.
- At lower temp. the exsolution of Opx or augite result in exsolution lamellae that $\parallel$ to the (100) plane.
- Exsolution intergrowths betⁿ Opx & Cpx are common & produce $\parallel$ intergrowth called schillare structure.
- Pigeonite twin on (100) inverted to orthopyroxene with augite exsolution lamellae on (001).

Pyroxenoids (not true pyroxene) :-

wollastonite $\rightarrow \text{Ca}_2\text{Si}_2\text{O}_6$

Pectolite

Rhodonite $\rightarrow \text{Mn}_2\text{Si}_2\text{O}_6$

Bustamite $\rightarrow \text{Mn CaSi}_2\text{O}_6$

→ Tectosilicate is a variety of sphere

→ Wollastonite is a product of reaction betⁿ siliceous magma fluid and limestone.

- The name olivine was given by A.O. Werner in 1790, alluding to common olivine green colour. The name is now used as a group.
- The name forsterite was given to honour, J.R. Forster 1739-1804, an English mineral collector and dealer by A. Levy, in 1824. Fayalite was named by J.F. Gemelin in 1840 after the island of Faial (Paya) named after a volcano. It was then thought the source was a local volcanic rock but the mineral is now considered to have been derived from dumped slag from a ship's ballast.
- The name Tephroite ($Mn_{22} + SiO_4$) given by Breithaupt in 1823 was coined from the Greek for ash coloured, alluding to its greyish-green colour.

old name → chrysolite

Silicate structure - Nesosilicate

Crystal system - orthorhombic crystal system

General formula - X_2SiO_4

$X \rightarrow Fe, Mg$

Coordinated with divalent (+2) atoms in 6 fold co-ordination.

Structure :-

- * Mg, Fe occur in octahedral site with 6 nearest oxygen
- All oxygen occur as sheet $11\frac{1}{2}$ to plane arranged in a hexagonal array.
- SiO_4 tetrahedral are arranged alternatively upward and downward.
- Half of the octahedral voids are filled up by M atoms.
- Half of the tetrahedral voids are filled up by Si atoms.
- M_1 atoms are located at the center of symmetry.
- M_2 atoms located at the mirror planes.
- Lacks cleavage due to individual isolated tetrahedral.
- The mineral is held together by the attraction between the tetrahedra and the ions.

Olivine Group

→ the name olivine was given by A.G. Werner in 1790, alluding to the common olivine-green colour. The name is now used as a group name.

→ the name karskerite was given to honour J.R. Forster (1739-1800), an English mineral collector and dealer, by A. Levy in 1824. Fayalite was named by J.F. Gemlin in 1840, after the island of Fayal (Fayal) in the Azores. It was then thought the source was a local volcanic rock, but the mineral is now considered to have been derived from dumped slag from a ship's ballast.

→ the name Tephroite ($Mn_{22} + SiO_4$) given by Brice Thuyt in 1823, was coined from the Greek *tephros* ash coloured, alluding to its greyish-green colour.

* Old Name → Crisolite

→ Silicate structure → Nesosilicate

→ Crystal system → Orthorhombic Crystal system.

→ General formula → $X_2 SiO_4$

X → Fe, Mg

→ linked with divalent (+2) atoms in 6-fold coordination.

structure

* Mg, Fe, occur in octahedral site with six nearest oxygen.

* All oxygens occur as sheets parallel to plane arranged in a hexagonal array.

* Si-O Tetrahedra are arranged alternatively upward and downward.

* Half of the octahedral voids are filled up by M atoms, e. octahedral atoms.

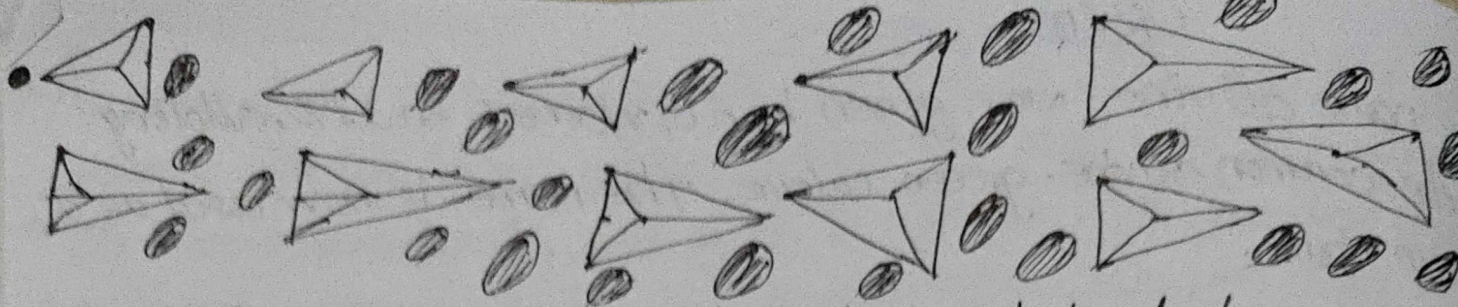
* 1/8th of the tetrahedral voids are filled up by Si atoms.

* M atoms are located at the centre of symmetry.

* M atoms located at the mirror planes.

* Rock's cleavage due to individual isolated tetrahedral.

* The mineral is held together by the attraction between the tetrahedral and positive ions.



- The tetrahedra are independent and do not share any atoms.
- The mineral is held together by the attraction between the tetrahedral and positive ions (Metal cations, such as iron or magn).

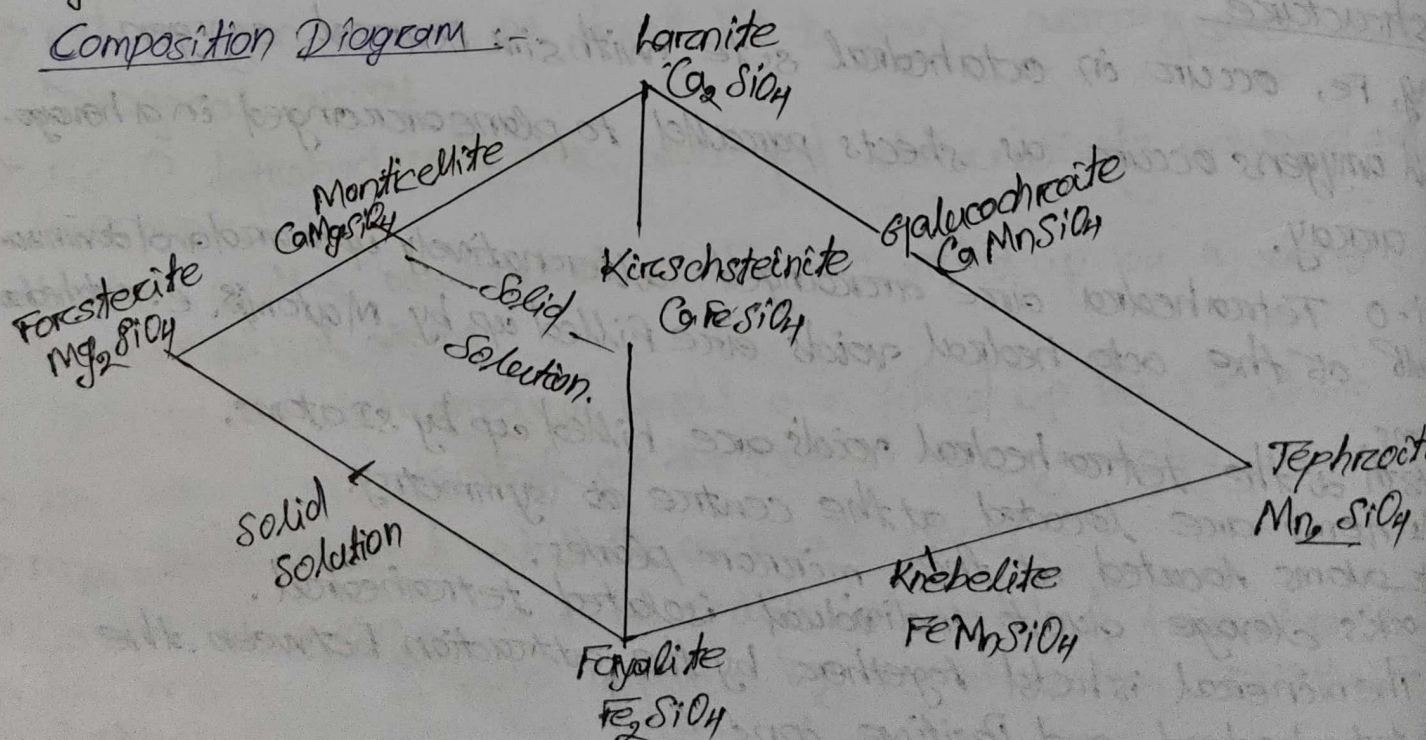
Chemistry

- * Mn, Ca replacement occurs in more iron rich olivine.
- * Ni, Cr. replacement occurs in mg-rich olivine.
- * Olivine Group carries two solid solution series, Fo-Fa and Monticellite - Kirschsteinite.

11.	Roeppertite (Obsidian) → $(Fe_2^{2+}, Mn, Zn)SiO_4$ →
12.	Tephroite → $Mn_2^{2+}SiO_4$ → Manganese Silicate

	<u>FOY.</u>	<u>FAY.</u>
Forsterite (Mg_2SiO_4)	→ 100 - 90	→ 0 - 10
Chrysolite	→ 90 - 70	→ 10 - 30
Hyalosiderite	→ 70 - 50	→ 30 - 50
Herttonolite	→ 50 - 30	→ 50 - 70
Ferroherttonolite	→ 30 - 10	→ 70 - 90
Fayalite (Fe_2SiO_4)	→ 10 - 0	→ 90 - 100

Composition Diagram :-



Olivine Group Members

1) Forsterite	$\rightarrow$ Mg_2SiO_4	$\rightarrow$ Magnesium silicate
2) Fayalite	$\rightarrow$ $Fe_2^{2+}SiO_4$	$\rightarrow$ Iron silicate
3) Kernite	$\rightarrow$ Ca_2SiO_4	$\rightarrow$ Calcium silicate
4) Kirschsteinite	$\rightarrow$ $CaFe^{2+}SiO_4$	$\rightarrow$ Calcium iron silicate
5) Monticellite	$\rightarrow$ $CaMgSiO_4$	$\rightarrow$ Calcium magnesium silicate
6) Wadsleyite	$\rightarrow$ $(Mg, Fe^{2+})_2(SiO_4)$	$\rightarrow$
7) Ishiharaite	$\rightarrow$ $Fe^{2+}Fe^{3+}_2(SiO_4)_2$	$\rightarrow$ Iron silicate
8) Alsimonite	$\rightarrow$ Fe_2SiO_4	$\rightarrow$
9) Liebenbergite	$\rightarrow$ $(Ni, Mg)_2SiO_4$	$\rightarrow$ Nickel magnesium silicate
10) Glaucophane	$\rightarrow$ $CaMn^{2+}SiO_4$	$\rightarrow$ Calcium manganese silicate

Physical Properties

* Forsterite :-

- $\rightarrow$ Hardness $\rightarrow$ 6.5
- $\rightarrow$ Specific gravity $\rightarrow$ 3.2
- $\rightarrow$ Cleavage $\rightarrow$ poor (010) and (100)
- $\rightarrow$ Fracture $\rightarrow$ conchoidal
- $\rightarrow$ Lustre $\rightarrow$ Vitreous
- $\rightarrow$ Transparency $\rightarrow$ Transparent to translucent
- $\rightarrow$ Colour $\rightarrow$ Colourless or green
- $\rightarrow$ Streak $\rightarrow$ White

Fayalite

- $\rightarrow$ Hardness $\rightarrow$ 6.5
- $\rightarrow$ Specific gravity $\rightarrow$ 4.4
- $\rightarrow$ Cleavage $\rightarrow$ Poor (010) and (100)
- $\rightarrow$ Fracture $\rightarrow$ conchoidal
- $\rightarrow$ Lustre $\rightarrow$ Vitreous
- $\rightarrow$ Transparency $\rightarrow$ transparent to translucent
- $\rightarrow$ Colour $\rightarrow$ Green to yellow
- $\rightarrow$ Streak $\rightarrow$ white yellow.

Optical Properties

PPL:-

* Colour $\rightarrow$ Colourless (Fe) to Pale green (Fe)

(Mg-rich olivines are colourless in thin section, Fe-rich olivines are pale yellow or green in thin section and may be weakly pleochroic)

* Form $\rightarrow$ Anhedral (Plutonic rock) Euhedral (volcanic rock)

* Pleochroism $\rightarrow$ Present

* cleavage $\rightarrow$ Poor on {010}

* Relief $\rightarrow$ High

* Crack $\rightarrow$ Present

BXN

$\rightarrow$ Anisotropic

$\rightarrow$ optic sign $\rightarrow$ Biaxial +ve (Fe)
Biaxial -ve (Fe)

$\rightarrow$ 2V - fringes $\rightarrow$ High (with good contrast interference colors)

$\rightarrow 2V - 82^\circ - 134^\circ$

$\rightarrow$ Alteration $\rightarrow$ serpentine

$\rightarrow$ Extinction $\rightarrow$ Parallel/straight

Alteration

$\rightarrow$ Olivine is highly susceptible to hydrothermal alteration, weathering and low grade metamorphism.

$\rightarrow$ chemical weathering forms iddingsite, Bowlingite, chlorophacite

$\rightarrow$ Due to diffusion of H^+ ion in structure and temporary attachment of O^- atoms releases, Mg, Fe, Si replacing Fe^{2+} , Al, Ca.

<u>S.L.No</u>	<u>Alteration product</u>	<u>Description</u>
1	$\rightarrow$ Iddingsite	$\rightarrow$ Brown coloured, consists of smectite, chlorite, Goethite, Hematite
2	$\rightarrow$ Bowlingite	$\rightarrow$ Green colored, consists of smectite, chlorite, serpentine, Talc, mica etc.
3	$\rightarrow$ chlorophacite	$\rightarrow$ Variable colour, less Fe^{2+} , More Fe^{3+} consists of chlorite, smectite.

Serpentinization

olivine readily alters to serpentine and mg-rich olivine even more prone to serpentinization.

* It creates lizardite, chrysotile, Antigorite, Brucite, Talc, and carbonates.

Distinguishing Features :-

- * Poor cleavage
- * longer 2v
- * High Birefringence
- * Highly Fractured
- * Gem variety - Peridot
- * Grystbite - yell or green peridot

	Index	Angle	Form	Ref
(001)	2		cube	1
(011)	24	45°	rhomboid	2
(111)	8		cube	3
(010)	18	22°	octahedron	4
(101)	18	22°	octahedron	5
(110)	18		trapezoid	6
(100)	24	22°	octahedron	7