LEARNING MATERIAL

ON

MINE GEOLOGY-I

SEMESTER : III
BRANCH : MINING ENGINEERING
SUBJECT NAME : MINE GEOLOGY –I
SUBJECT CODE : TH.3

PREPARED BY
SAMAPIKA DASH
SR. LECTURER IN GEOLOGY

DEPARTMENT OF GEOLOGY,
ORISSA SCHOOL OF MINING ENGINEERING, KEONJHAR 758001
Website: www.osme.co.in
Email id: osmegeology@gmail.com

TABLE OF CONTENTS

CHAPTER- 1
Physical Geology

Weathering & erosion

Definition

Weathering process occurs at or near the Earth's surface and produce changes to the landscape that influences surface and subsurface topography and landform development. **Weathering** is the physical disintegration or chemical alteration of rocks at or near the Earth's surface.

Erosion is the physical removal and transportation of weathered material by water, wind, ice, or gravity.

Types of Weathering

I. Mechanical (physical) weathering is the physical disintegration and reduction in the size of the rocks without changing their chemical composition. Examples: exfoliation, frost wedging, salt wedging, temperature changes and abrasion

II.Chemical weathering decomposes, dissolves, alters, or weakens the rock through chemical processes to form residual materials. Examples: carbonation, hydration, hydrolosis, oxidation, and solution

III.Biological weathering is the disintegration or decay of rocks and minerals caused by chemical or physical agents of organisms. Examples: organic activity from lichen and algae, rock disintegration by plantorroot growth, burrowing and tunneling organisms, and acid secretion.

I. MechanicalWeathering

Mechanical weatherig is the physical disintegration and reduction in the size of the rocks without changing their chemical composition.

- Exfoliation
- FrostWedging
- SaltWedging
- TemperatureChanges
- Abrasion

Exfoliation

Exfoliation is a mechanical weathering process whereby pressure in a rock is released along parallel alignments near the surface of the bedrock and layers or slabs of the rock along these alignments break off from the bedrock and move downhill by gravity.

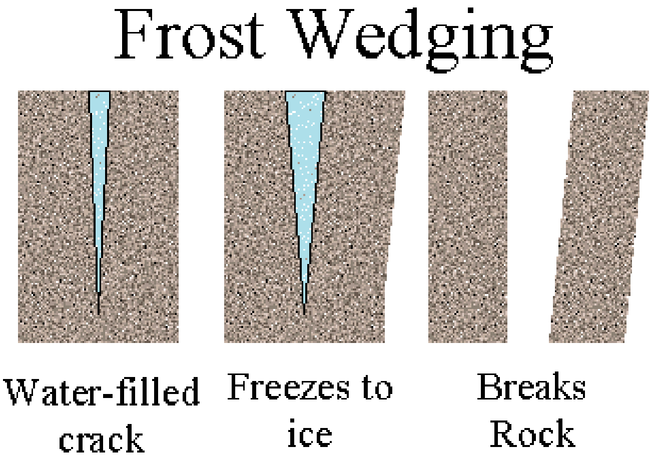
 

FrostWedging

Frost wedging is a mechanical weathering process caused by the freeze-thaw action of water that is trapped between cracks in therock.

When water freezes, it expands and applies pressure to the surrounding rock forcing the rock to accommodate the expansion of theice.

This process gradually weakens, cracks, and breaks the rock through repetitive freeze-thaw weathering cycles.



TemperatureChanges

Daily (diurnal) and seasonal temperature changes affect certain minerals and facilitates the mechanical weathering ofbedrock.

- Warmer temperatures may cause some minerals to expand, and cooler temperatures cause them tocontract.
- This gradual expansion and contraction of mineral grains weakens the rock causing it to break apart into smaller fragments or tofracture.
- This process is more common in desert climates because they experience extreme fluctuations in daily temperature changes.
- Temperature changes are often not the dominant form of weathering, but insteadtemperature
- changes tend to accelerate other forms of weathering alreadyoccurring.

Salt Wedging

- Salt wedging occurs when salts crystallize out of solution as water evaporates. As the salt crystals grow, they apply pressure to the surrounding rock weakening it, until it eventually cracks and breaks down, enabling the salt crystal to continue growing.
- Salt wedging is most common in drier climates, such as deserts.

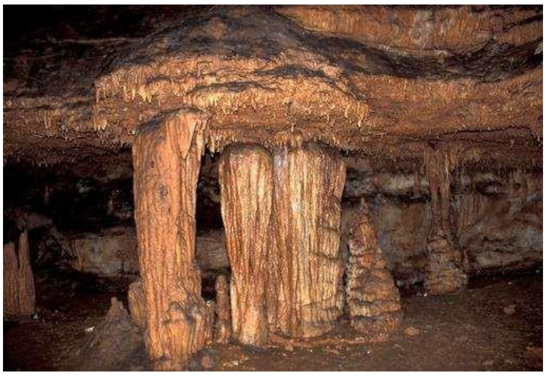
Abrasion

- Abrasion occurs when rocks collide against each other while they are transported by water, glacial ice, wind, or gravitationalforce.
- During abrasion, rocks may also weather the bedrock surface they are coming into contact with as well as breaking into smaller particles and eventually individualgrains.

Types of Chemical Weathering

- Chemical weathering decomposes, dissolves, alters, or weakens the rock through chemical processes to form residual materials.

- Carbonation
- Hydrolysis
- Hydration
- Oxidation
- Solution



Carbonation

- Carbonation is a process by which carbon dioxide and rainwater or moisture in the surrounding environment chemically react to produce carbonic acid, a weak acid, that reacts with carbonate minerals in therock.
- This process simultaneously weakens the rock and removes the chemically weathered materials.

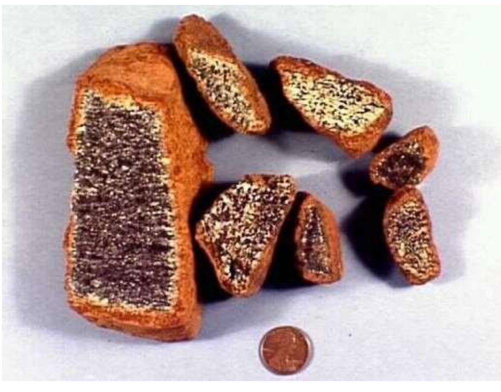
$$\underset{\text{air}}{CO_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

$$\underset{\text{limestone}}{CACO_3} + \underset{\text{carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2}$$

Hydrolysis

Hydrolysis is a chemical reaction between H+ and OH-ions in water and the minerals in the rock. The H+ ions in the water react with the minerals to produce weakacids.

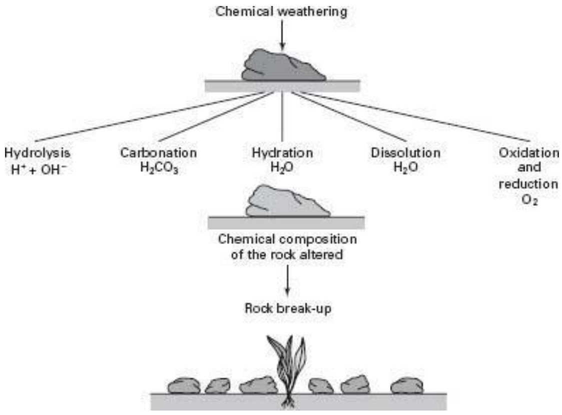
The reaction creates new compounds which tend to be softer and weaker than the original parent rock material.



Hydration

Hydration is a process where mineral structure in the rock forms a weak bond with H20 which causes the mineral grains to expand, creating stress which causes the disintegration of the rock.Hydration often produces a new mineral compound that is larger than theoriginal compound. The increased size expanse the rock and can lead todecay.Hydration can also lead to color changes in the weathered rocksurface.

An example of hydrolosis: Anhydrite ($CaSO_4$) can absorb two water molecules to become gypsum ($CaSO_4 \cdot 2H_2O$).



Oxidation

Oxidation occurs when oxygen and water react with iron-rich minerals and weaken the structure of themineral.

Duringoxidationthemineralsintherockwillchangecolors,takingona‘rusty’,reddish-orangeappearance.

Solution

Solution occurs when minerals in rock dissolve directly into water.

Solution most commonly occurs on rocks containing carbonates such as limestone, but may also affect rocks with large amount of halite, or rocksalt.

Biological weathering is the disintegration or decay of rocks and minerals caused by chemical or physical agents oforganisms.

Organic activity from lichen andalgae

Rock disintegration by plantgrowth

Burrowing and tunnelingorganisms

Secretion of acids

Organism Activity

Some animals may burrow or tunnel into rocks or cracks in rocks and cause the rock to break down and disintegrate. Small animals, worms, and other insects, often contribute to this form of biological weathering.

Some organisms, such as snails, barnacles, or limpets, attach themselves to rocks and secrete acid, acids that chemically dissolve the rock surface.

Plant Roots

The most common form of biological weathering is when plant roots penetrate into cracks and crevices of rocks and cause the rock to split or break into smaller particles through mechanicalweathering.

Lichen, Algae, and Decaying Plants

This bio-chemical weathering process leaches minerals from the rock causing it to weaken and breakdown.

The decaying of plant materials can also produce acidic compounds which dissolve the exposed rock. The presence of organisms growing, expanding, or moving across the surface of the rock also exerts a small amount of abrasion and pressure that gradually cause the mechanical weathering of the rock as the organisms extract various minerals.

EROSIONAL LANDFORMS OF WIND (AEOLIAN LAND FORMS)

Wind action is particularly important in arid regions where lack of vegetation and presence of extensive bare rock and sandy soil surfaces make wind erosion, transportation and deposition possible.

Wind performs erosion in 3 different ways

Attrition,

Deflation

Abrasion or corrasion

Attrition is the mutual wearing down of the rock particles carried along by the wind

Deflation is the lifting and removal of loose materials from the earth's surface by wind action

Abrasion is the cutting of rock surface by moving weathered rock particles or more concretely the sand-blast action of wind-blown sand.

Attrition

In the arid regions on account of the great diurnal
and the action of frost there is rapid mechanical disintegration of rocks.
When these rock particles are carried along by the wind, they not only strike against the rocks standing in their way but also strike against one another.
The rock materials are further reduced in size by mutual friction and forceful contact and ultimately they are converted into sand and dust.

Deflation

In the dry regions the wind can easily lift and transport unconsolidated san and dust particles – this process is called deflation

- Large scale removal of sand and dust from a desert region may result either in the formation of depressions called blowouts or in the exposure of the rocky surface beneath the sandy cover.
- Quattara depression in western Egyptian Sahara is a well known depression which has been excavated to nearly 134m below sea level
- The ground water table is the base level of wind erosion and limits the depth of deflation. Thus the base level of wind erosion can be much lower than the ultimate base level of the sea.
- The concentration of boulders and pebbles and larger sized particles which are left behind after the smaller sized particles have been removed by wind are called 'lag deposits' or gravel lags. Such deflation surfaces are often called 'desert pavement'

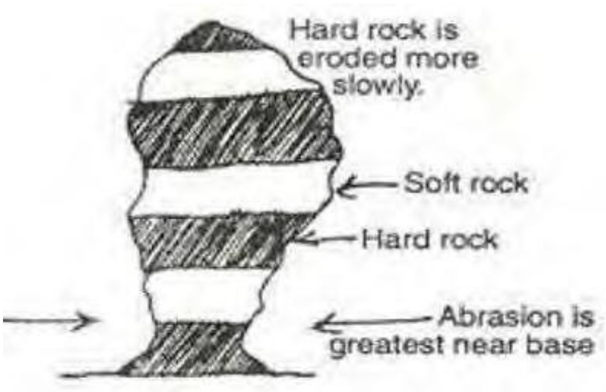
Abrasion or Corrasion

- Strong winds carry with them enormous quantities of sand and small angular rock fragments which act as tools of erosion as they strike against rock surfaces.
- When wind blown sand particles strike against rocks, they act as powerful sandpaper and homogenous rock surfaces are smoothened and polished.
- Where there are both hard and soft rocks, the soft rocks are more easily cut and the surfaces are grooved and fluted.
- In conglomerate rocks the relatively soft cementing materials are more easily abraded while the harder gravels and nodules are much less affected with the result that they look like beehives and present honey-combed surfaces.
- Pebbles or gravels which are worn and polished by wind abrasion and show one or more polished and faceted surfaces and sharp edges are called 'ventifacts' or 'dreikanter'

Landforms of wind erosion

Rock pedestal or mushroom rocks

•Many rock-outcrops in the deserts easily susceptible to wind deflation and abrasion are worn out quickly
• This leads to wearing away of the softer layer leaving some remnants of resistant rocks • Grooves and hollows are cut in the rock surface, carving them into fantastic and grotesque looking pillars called Pedestals
• Such rock pillar is further eroded near bases
• This process of undercutting produces mushroom with a slender stalk and a broad and rounded pear shaped cap above.



Zeugen

• These are tabular masses which have a layer of soft rocks lying beneath a surface layer of more resistant rocks

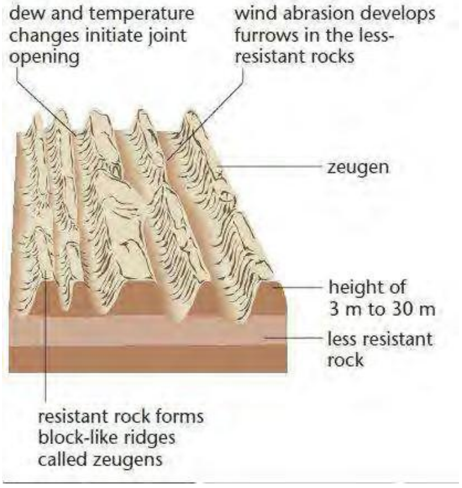
• The sculpting effects of wind abrasion wear them into a weird looking ridge and furrow landscape

• Their formation is initiated by opening up of joints of surface rocks by mechanical weathering • Deep furrows are developed by wind abrasion eating into the underlying softer layers

• The hard rocks then stand above the furrows as ridges or Zeugen

• Such tabular blocks of Zeugen may stand 10 to 100 feet above the sunken furrows.

• Continuous abrasion by wind gradually lowers the Zeugen and widens the furrows



Yardangs

• The word yardang originated in the interior deserts of central Asia where they are best developed • Yardangs are a steep-sided irregular ridge of sand lying in the direction of the prevailing wind • They look quite similar to the ridge and furrow landscape of Zeugen • They are formed by the dual action of wind abrasion by dust and sand, and deflation which is the removal of loose material • Wind abrasion excavates the bands of softer rocks into long, narrow corridors, separating the steep-sided, over-hanging ridges of hard rocks, called yardangs. • They are commonly found in the Atacama desert, Chile

Mesas (Table) and buttes

• Mesa is a Spanish word meaning table .

• It is a flat, table-like land masses with a very resistant horizontal top layer and very steep sides • The hard stratum on the surface resist denudation by both wind & water, and thus protects the underlying layer of rocks from being eroded away

• Continuous denudation through the ages may reduce Mesas in an area so that they become isolated flattopped hills called Buttes.

Inselberg

• Inselberg is a German word meaning Island-mountains.

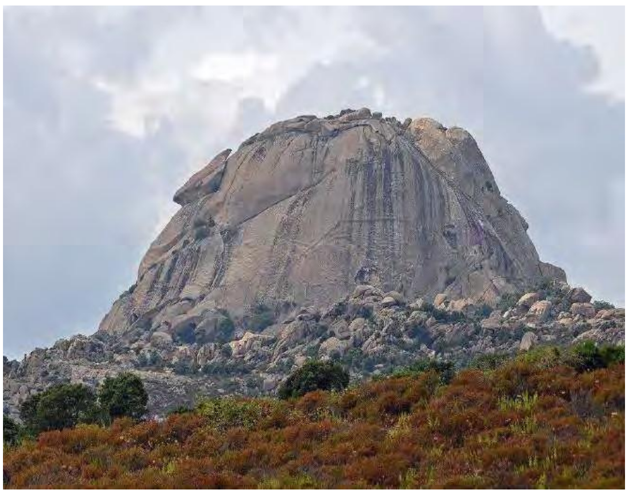
• An inselberg is an isolated residual hill rising abruptly from a gently sloping or virtually level surrounding plain.

• They are characterized by their very steep slopes & rather rounded tops

• They are often composed of granite or gneiss

• They are probably the relics of an original plateau which has been almost entirely eroded away

• Inselbergs are typical features of many deserts and semi-arid landscapes in old age



Ventifacts

• Ventifacts are pebbles faceted by sand blasting
• They are shaped and polished by wind abrasion
• Mechanically weathered rock fragments are moved by wind in open settings to blast against the rock formations carving facets
• If wind direction changes another facet is developed
• Such rocks have characteristic flat facets with sharp edges
• Among the ventifacts, those with the three wind faceted surfaces are known as Dreikanter.

Landforms of wind deposition

When the velocity of wind decreases, its carrying capacity also decreases. As a result, the grains of sands starts to settle down, and it leads to the formation of depositional landforms in a desert.

• Depending upon the size of the particles, velocity and direction of the wind, different depositional landforms can be found in arid and desert areas:

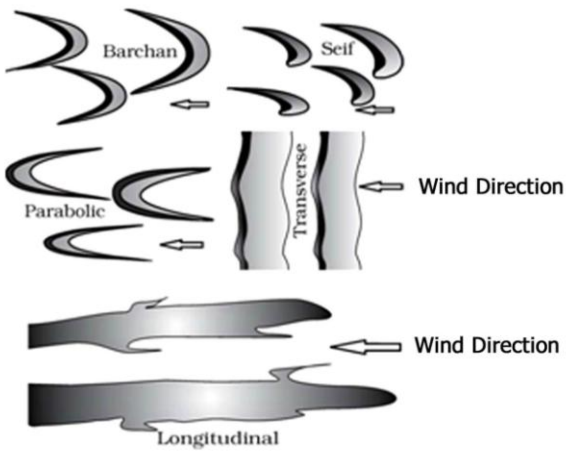
Dunes

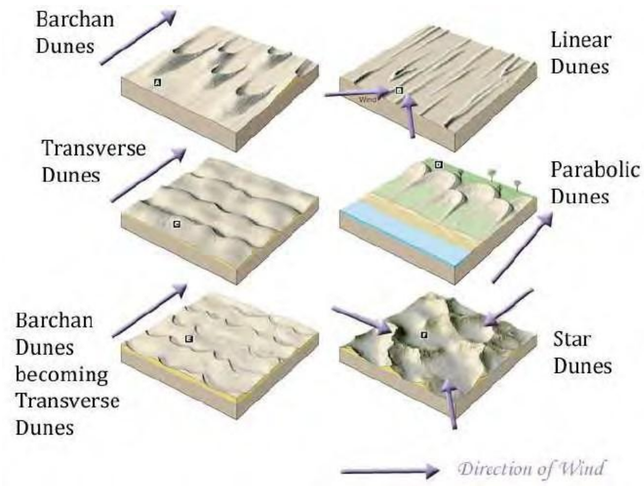
• Dunes are hills of sand formed by the accumulation of sand & shaped by the movement of winds
• Dry hot deserts are good places for sand dune formation
• They may classifies as active and inactive dunes - active or live dunes are constantly on move and inactive or fixed dunes are rooted with vegetation.

Types of dunes

Because of their great contrast in shape, size and alignment, they have been given classified into several types of dunes viz linear dunes, strar dunes, parabolic dune, transverse dune, etc.

• However, there are two most common types of dunes are barchans and seif which are described as below:





1) Barchan
   - They are moon or Crescent shaped live dunes
   - They may occur individually or in groups
   - They have their points or wings directed away from wind direction i.e., downwind
   - They are initiated probably by a chance accumulation of sand at an obstacle, such as patch of grass or a heap of rocks
   - They occur transversely to the wind
   - Thus, their horns thin out & become lower in the direction of the wind.
   - The windward side is convex & gently sloping whiles the leeward side is concave & steep.
   - The crest of sand dunes moves forward as more sand is accumulated by the prevailing wind.
   - The sand is driven up the windward side & on reaching the crest slips down the leeward side so that the dune advances
   - The migration of Barchans may be a threat to desert life as they may encroach on an oasis burying palm trees & houses.
   - They are most prevalent in the deserts of Turkestan and in the Sahara.

2) Seif

• Seif is an Arabic word meaning sword

• They are long, narrow ridges of sand, often over a hundred miles long lying parallel to the direction of the prevailing winds

• Seif is similar to barchan with a small difference; it has only one wing.

• Prevailing winds increases the length of the dunes into tapering linear ridges while occasional crosswinds tend to increase their heights & width

• Extensive seif dunes can be found in Sahara desert, West Australian desert, Thar desert etc.

Loess

• The fine dust blown beyond the desert limits is deposited on neighbouring lands as loess.

• It is a yellow, friable (easily crumbled) material is usually very fertile.

• Loess is in fact, fine loam, rich in lime, very coherent and extremely porous

• Water sinks in readily so that the surface is always dry,

• Streams may cut deep valleys through the thick mantle of soft loess to develop badland topography.

• The most extensive deposits are found in north-west China in the loess plateau of the Hwang-Ho basin.

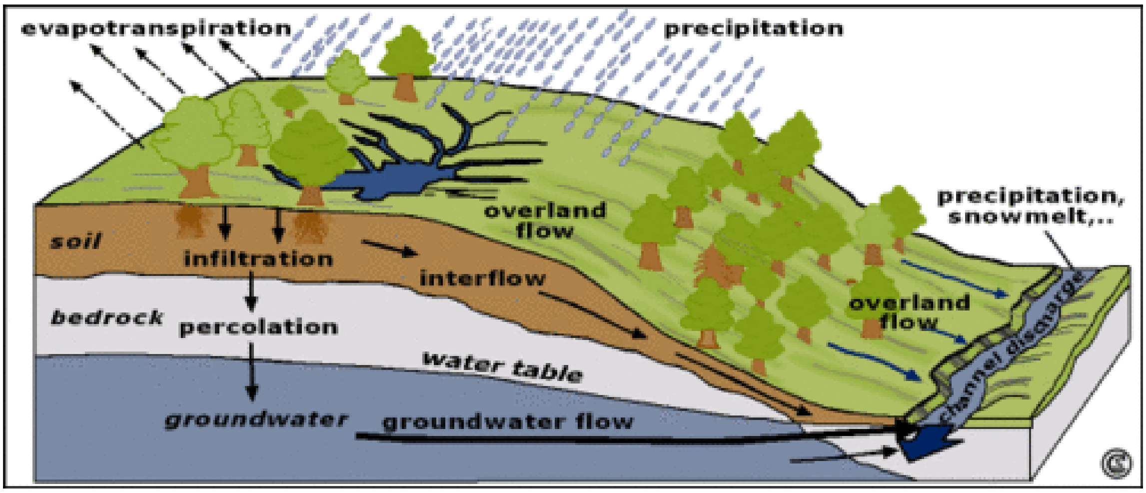
EROSIONAL AND DEPOSITIONAL LAND FORMS PRODUCED BY RIVER.

Fluvial Processes and Landforms

• The term ‘fluvial’ (from Latin fluvius, river) refers to the work of rivers but in the context of landscape development it includes the work of both overland flow and stream flow.

• Thus landforms shaped by running water are called fluvial landforms. It constitutes the largest proportion of the environment of terrestrial life and the major areas of food production, as almost all the land under crop cultivation as well as grazing has been shaped by fluvial processes. Mechanics of Fluvial Erosion

• Rain water falling on the surface is removed by infiltration into the soil or rock, by sheet flow over the surface and/or by flow through a system of rill, gullies and finally stream channels. 1. Overland flow (sheet flow): is the term used for the movement of water over the surface of the land when it is not confined to distinctive channels. It is responsible for much erosion before streams attain identity lower down the slope. Soil particles are loosened by rain drop impact. This is called ‘splash¬ erosion’. It is effective in arid and semi arid regions where the rainfall is sporadic and torrential, the surface is loose and friable and there is no vegetation cover. The loosened particles are entrained in the run-off flow covering a¬ considerable area, resulting in ‘sheet erosion’. As the water flows further down there will be concentration of flow in a¬ number of tiny superficial and ill defined channels called ‘rills’. During high intensity storms rills may be widened by absorption to be called a ‘gully’.



Sheet erosion

Gully erosion

Rill erosion

Valley erosion

2. Streamflow (linear flow):
The rill or gully system develops into a full fledged drainage pattern as it undergoes systematic changes. There is rapid increase in tributaries by bifurcation at the head and by growth of rills down the side slopes of widening gullies.
• The total length of stream channels rapidly increases by elongation at the heads where erosion is carried on by rain itself.
• It enables headward erosion to cut back into the slope above the point at which the headstream starts its career.
• The movement of water in the channel is laminar flow, i.e., stream-lined transference of its mass in a downhill direction. Ideally, it is so if the channel were straight and smooth.
• The flow in stream channel is varied and non-uniform and there is gradual change in velocity and depth to compensate for bends, obstruction, contractions and expansions. • Any obstacle in its bed or projecting from the banks causes eddies and turbulence.
• Roughness and turbulence both reduce the overall speed of flow, but turbulence is a major eroding and transporting agent.
• The energy of a river depends primarily upon its volume and velocity called discharge. • The discharge increases downstream with the addition of water from tributaries
• Discharge is expressed in ‘cusecs’ (cubic feet/sec) or ‘cumecs’ (cubic metre/sec)
• The number of cumecs/cusecs is obtained by multiplying the rate of flow in m/s or ft/sec by the cross section of the river at a particular point in square metres/square feet. • River regime or their

seasonal variation in volume has received much attention in recent years in connection with schemes of flood control and hydro-electric development.
• Rivers have 3 types of regimes: simple, double and complex
• Simple regime: has one period of high and low water, closely following the seasonal rainfall regime.
• Double regime: has two distinct periods of high water
• Complex regime: is the feature of world's largest rivers with extensive basins covering various climatic regions.

The work of Rivers

The river does 3 kinds of work
• 1. Erosion
• 2. Transportation
• 3. Deposition.
These three kinds of activity are not quite independentϖ of one another but are inter-dependent.
Through the joint action of these activities the riverϖ degrades the surface of the land, carves its own valley, creates flood-plains and deltas and leaves the areas of relatively harder rocks as residual hills and pllateaus.

Erosion

The erosion performed by a river is of two kinds – chemical and¬ mechanical.
Some of the rocks over which the river flows, such as limestone, are¬ soluble and the river dissolves the rocks along the joints and forms cavities in them.
This is chemical erosion or Corrosion.
Apart from solution, the erosive work of a river consists of 3 interacting¬ processes – hydraulic action, corrasion and attrition.
The river not only erodes its sides but also its bed¬
Through the mere force of its flow, the river can cut its bed and its sides.¬ This is hydraulic action.
In this the river erodes without the assistance of pebbles and rock¬ fragments and without chemical action.
The rock fragments present in the river water greatly increase its erosive¬ power.
These rock fragments strike against the rocks along the bed and the sides and abrade and break them as they move down with the flowing water.
It is known as abrasion or corrasion.
The rock fragments also collide against one another and in the process get disintegrated into small, smooth and rounded pieces of rock and ultimately into sand and silt. It is called attrition.
• The erosive action of the river is more evident in the mountainous regions where on account of the steep slope the river flows with great speed.
• The erosive power of a river depends on the volume of water, its speed, the size and number of rock fragments in the river water and the hardness of the surface rocks over which the river flows.
• It is not merely the amount of the load that determines the amount of erosion that a river can perfom but the size and the nature of the load are also important.

• If the load is fine and of very small size, they move either in suspension or in solution with the water.
• If the load is bigger in size and angular in shape, they are dragged along the river bed with the moving water and are able to perform more erosion
• Corrasion increases with increase in load

Transportation

• The river carries long distances the rock fragments, sand and silt with its flow. The river transports these materials principally in two ways.
• 1. the minute particles of sand and silt float in the river water and flow down along with it. The river water is muddy.
• 2. the small and big fragments of rock roll down along the bed of the river with the moving water – traction or bed load.
• The transporting power of a river depends on the volume and velocity of its water, its gradient and the transportability of its load. The more the volume of water in a river, the more the materials it can carry.
• As the velocity increases, the transporting power of a river increases.
• The solid materials which a river carries with itself is called its 'load'
• Sometimes it is also held in solution – solution load.
• Some material of intermediate size too heavy to be held in suspension and lighter than the bed load may bounce or jump along the stream bed – saltation load.
• The largest amount of given size debris that a river can move in traction as bed load is called its 'capacity'
• The largest diameter of particles that it can carry as bed load measures its 'competence'
• Both the capacity and competence of a river increase with increase in volume and velocity.
• The more the velocity of a river the more the load it can carry, and more the load the greater is the corrasive power of the river.

Deposition

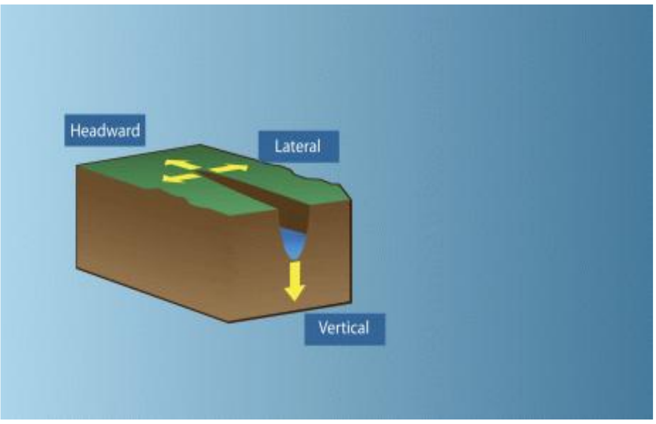
• As the velocity of a river decreases, it begins depositing its load of rock fragments, sand and silt, since its capacity to transport these materialsis dependent upon its velocity.
• When a fast flowing hill stream emerges from the mountains and reaches a relatively level surface, there is deposition of a huge amount of stony debris, sand and silt and alluvial cones and fans are formed here.
• When the river reaches the more level surface of its valley, its flow slackens further, and the river starts depositing sand and silt in its bed resulting in the formation of 'diaras'.
• In times flood when the river water overtops its banks and inundates the neighbouring areas, there is deposition of sand and silt outside the confines of its channel – flood plain
• Maximum deposition takes place where the river enters the sea. Course of a River
• The point of origin of a river is called its 'source' and the point where it ends is called its 'mouth'
• The course of a river from the source to its mouth may be divided into three parts – upper, middle and lower
• For example, the Ganga has its upper course above Hardwar, its middle course from Hardwar to Rajmahal, and its lower course below Rajmahal.
• In the upper course the river cuts and deepens its channel, and sometimes this section is called the valley tract.
• In its middle and lower courses the river transports and deposits its load and in this way forms alluvial plains.
• Both these sections are therefore referred to the plain tract.

Forms of Erosion

1. **Headward erosion** it is a process by which a river increases its upstream length. This is achieved by a river cutting back at its source

2. Lateral erosion it is a process through which river channel is extended in its width due to sideways erosion at the outside banks of the rivers

3. Vertical erosion Vertical erosion takes place at the base of the river. The channel of the river gets deepened through vertical erosion.



The fluvial cycle of erosion

• Three distinct stages of youth, maturity and old age can be identified during the lifetime of a stream. At different stages of the erosional cycle, the valley acquires different profiles. The characteristics related to each stage of landscape development in running water regimes are summarised as below:

Youth (Upper Course)

Streams are few during this stage with poor integration and flow over original slopes

• The valley developed is thus deep, narrow and distinctly V-shaped with no floodplains or with very narrow floodplains.

• Downcutting predominates over lateral corrasion

• Streams divides are broad and flat with marshes, swamp and lakes.

• Some of the outstanding features which are developed in this stage are gorges, canyons waterfalls, rapids and river capture etc.

Mature (Middle Course)

• During this stage, streams are plenty with good integration.

• Lateral corrasion tends to replace vertical corrasion

• The valleys are still V-shaped but wide and deep due to an active erosion of the banks;

• Trunk streams are broad enough to have wider floodplains within which streams may flow in meanders confined within the valley.

• Swamps and marshes of youth stage, as well as flat and broad interstream areas, disappear. The stream divides turn sharp.

• Waterfalls and rapids disappear.

• Meander and slip off slopes are the characteristic features of this stage

Old (Lower Course)

• The river moving downstream across a broad level plain is heavy with sediments.

• Vertical corrasion almost ceases in this stage though lateral corrasion still goes on to erode its banks further

• Smaller tributaries during old age are few with gentle gradients.

• Streams meander freely over vast floodplains. Divides are broad and flat with lakes, swamps and marshes.

• Depositional features predominate in this stage

• Most of the landscape is at or slightly above sea level

• Characteristic features of this stage are floodplains, oxbow lakes, natural levees and Delta etc.

FLUVIAL EROSIONAL LANDFORMS

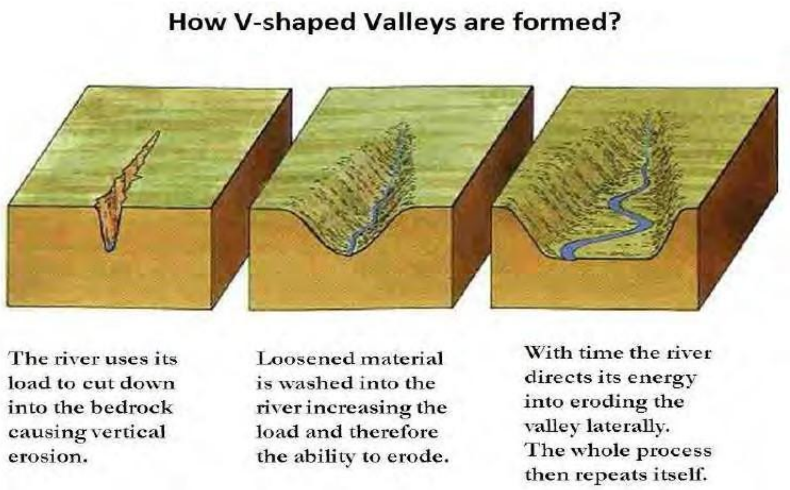
• Most of the erosional landforms associated with running water are made by youthful rivers vigorously flowing over steep gradients. With time, stream channels over steep gradients turn gentler due to continued erosion, and as a consequence, lose their velocity, facilitating active deposition. There are two components of running water. One is the sheet that refers to overland flow on the land surface. Another is streams and rivers that refer to linear flow as in valleys.

River Valleys

• The extended depression on the ground through which a stream flows throughout its course is called a river valley.
• At different stages of the erosional cycle, the valley acquires different profiles
• Valleys start as small and narrow rills
• The rills will gradually develop into long and wide gullies
• The gullies will further deepen, widen and lengthen to give rise to valleys.
• Depending upon dimensions, shape, types and structure of rocks in which they are formed, many types of valleys like the V-shaped valley, gorge, canyon, etc. can be recognised.

V-shaped valley

Gorge



Canyon

V-shaped Valley

- The river is very swift as it descends the steep slope, and the predominant action of the river is vertical corrasion

• The valley developed is thus deep, narrow and distinctly V-shaped

Gorge

A gorge is a deep and narrow valley with very steep to straight sides

• A gorge is almost equal in width at its top as well as its bottom.

• Gorges are formed in hard rocks.

• Example Indus Gorge in Kashmir

Canyon

• A canyon is a variant of the gorge.

• Unlike Gorge, a canyon is wider at its top than at its bottom.

• A canyon is characterised by steep step-like side slopes

• Canyons commonly form in horizontal bedded sedimentary rocks

• Example Grand Canyon carved by Colorado River, USA

Waterfalls and Rapids

• When rivers plunge down in a sudden fall of some height, they are called waterfalls

• Their great force usually wears out a plunge pool beneath

• Waterfalls are formed because of several factors like the relative resistance of rocks lying across the river, the relative difference in topographic reliefs e.g. in Plateau etc.

• A rapid is similarly formed due to an abrupt change in gradient of a river due to variation in resistance of hard and soft rocks traversed by a river

• Waterfalls are also transitory like any other landform and will recede gradually and bring the floor of the valley above waterfalls to the level below.

Rapids

Water rafting in rapids

Potholes

Waterfalls

Plunge pools

Potholes and Plunge Pools

- Potholes are more or less circular depressions formed over the rocky beds of hill-streams, because of stream erosion aided by the abrasion of rock fragments.
- Once a small and shallow depression forms, pebbles and boulders get collected in those depressions and get rotated by flowing water and consequently the depressions grow in dimensions.
- Eventually, such depressions are joined leading to deepening of the stream valley.
- At the foot of waterfalls also, large potholes, quite deep and wide, form because of the sheer impact of water and rotation of boulders. These deep and large holes at the base of waterfalls are referred to as plunge pools.
- These pools also help in the deepening of valleys

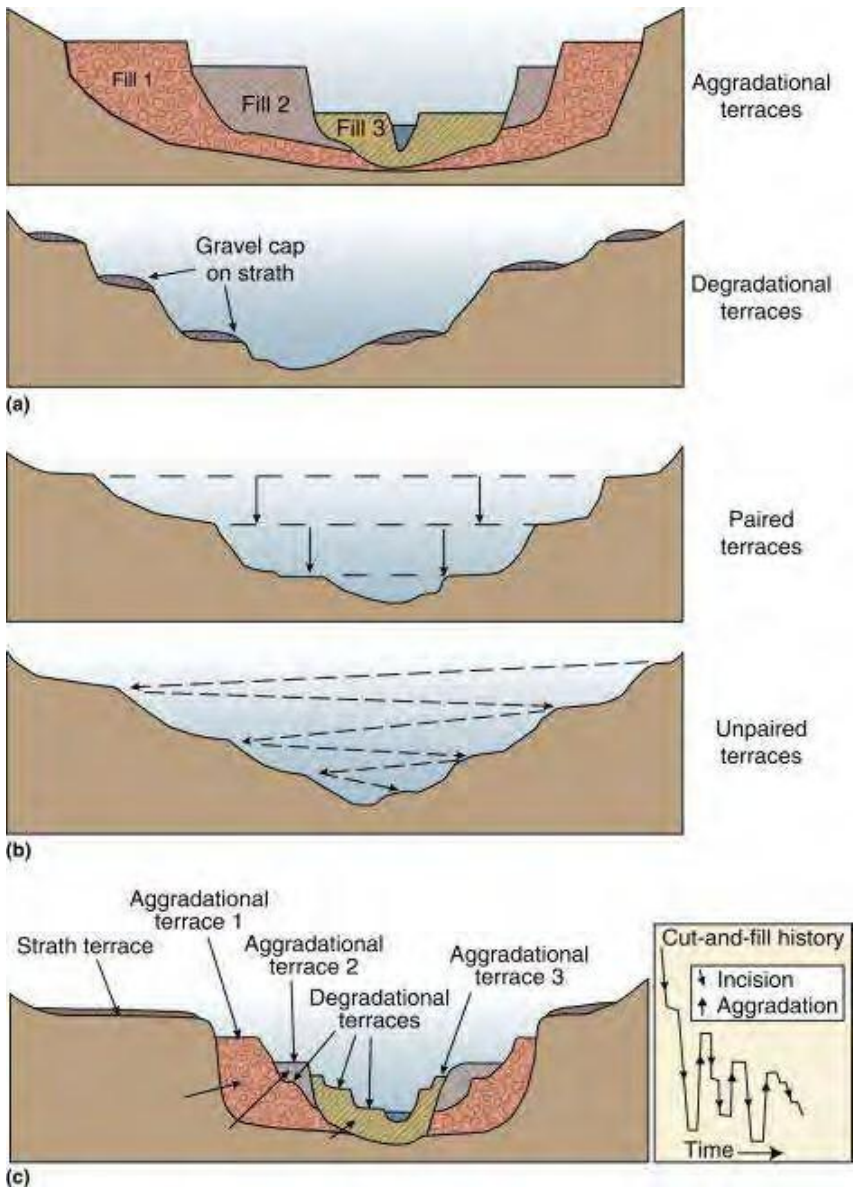
Incised or Entrenched Meanders

- Incised or entrenched meanders are found cut in hard rocks. They are very deep and wide.
- In streams that flow rapidly over steep gradients, normally erosion is concentrated on the bottom of the stream channel.
- Entrenched meander normally occurs where there is a rapid cutting of the river bed such that the river does not get to erode the lateral sides.
- Meander loops are developed over original gentle surfaces in the initial stages of development of streams and the same loops get entrenched into the rocks normally due to erosion or gradual uplift of the land over which they started.
- They are widened and deepened over a long period of time and can be found as deep gorges and canyons in the areas where hard rocks are found.
- They give an indication of the status of original land surfaces over which streams have developed.
- Incised meanders are said to be an impact of river rejuvenation.

River Terraces

- River terraces refer to surfaces relating to old valley floor or floodplain levels.

- They may be bedrock surfaces without any alluvial cover or alluvial terraces consisting of stream deposits.
- River terraces are basically products of erosion as they result due to vertical erosion by the stream into its own depositional floodplain.
- There can be a number of such terraces. They are found at different heights indicating former river bed levels.
- The river terraces may occur at the same elevation on either side of the rivers in which case they are called paired terraces.



Entrenched or incised meander

Fluvial Depositional Landforms

- Rocks and cliffs are continually weathered and eroded in the youth stage or upper course of the river.
- The river moving downstream on a level plain brings down a heavy load of sediments from the upper course.
- The decrease in stream velocity in the lower course of the river reduces the transporting power of the streams which leads to deposition of this sediment load.
- Coarser materials are dropped first and finer silt is carried down towards the mouth of the river
- This depositional process leads to the formation of various depositional landforms through fluvial action such as Delta, Levees and Flood Plain etc.

Alluvial Fans

An alluvial fan is a cone-shaped depositional landform built up by streams, heavy with sediment load.

• Alluvial fans are formed when streams flowing from mountains break into foot slope plains of low gradient.

• Normally very coarse load is carried by streams flowing over mountain slopes. This load gets dumped as it becomes too heavy to be carried over gentler gradients by the streams

• Furthermore, this load spreads as a broad low to a high cone-shaped deposit called an alluvial fan that appears as a series of continuousfans.

• Alluvial fans in humid areas show normally low cones with a gentle slope from head to toe and they appear as high cones with a steep slope in arid and semi-arid climates.

Floodplains

• Floodplain is a major landform of river deposition.

• Deposition develops a floodplain just as erosion makes valleys.

• Rivers in the lower course carry large quantities of sediments

• Large sized materials are deposited first when stream channel breaks into a gentle slope.

• Sand, silt and clay and other fine sized sediments are carried over gentler channels by relatively slowmoving waters

• During annual or sporadic floods, these materials are spread over the low lying adjacent areas. A layer of sediments is thus deposited during each flood, gradually building up a floodplain

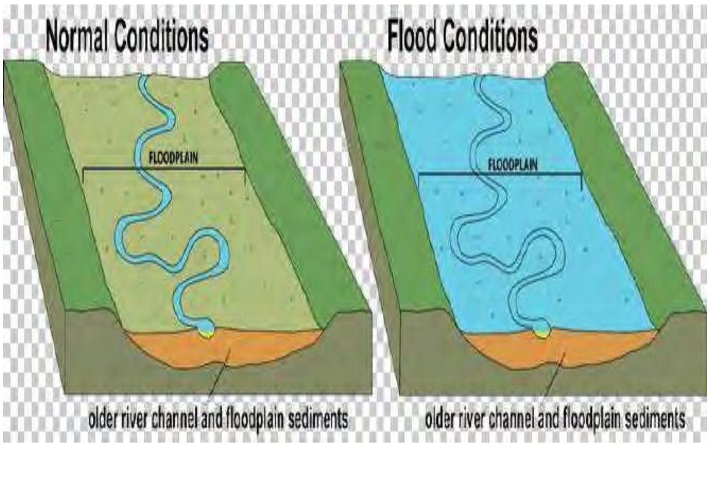
• In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually by relatively coarse deposits.

• The flood deposits of spilt waters carry relatively finer materials like silt and clay.

• Active Floodplain - A riverbed made of river deposits is the active floodplain.

• Inactive Floodplain - The floodplain above the bank is an inactive floodplain. Inactive floodplain above the banks basically contains two types of deposits flood deposits and channel deposits.

• Delta plains - The floodplains in a delta are called delta plains.



Natural Levees

• This is an important landform associated with floodplains.

• They are found along the banks of large rivers.

• They are low, linear and parallel ridges of coarse deposits along the banks of rivers on both sides due to deposition action of the stream, appearing as natural embankments.

• At the time of flooding, the water is spilt over the bank. As the speed of flow of the water comes down, large sized sediments with high specific gravity are dumped along the bank asridges.

• They are high nearer the banks and slope gently away from the river.

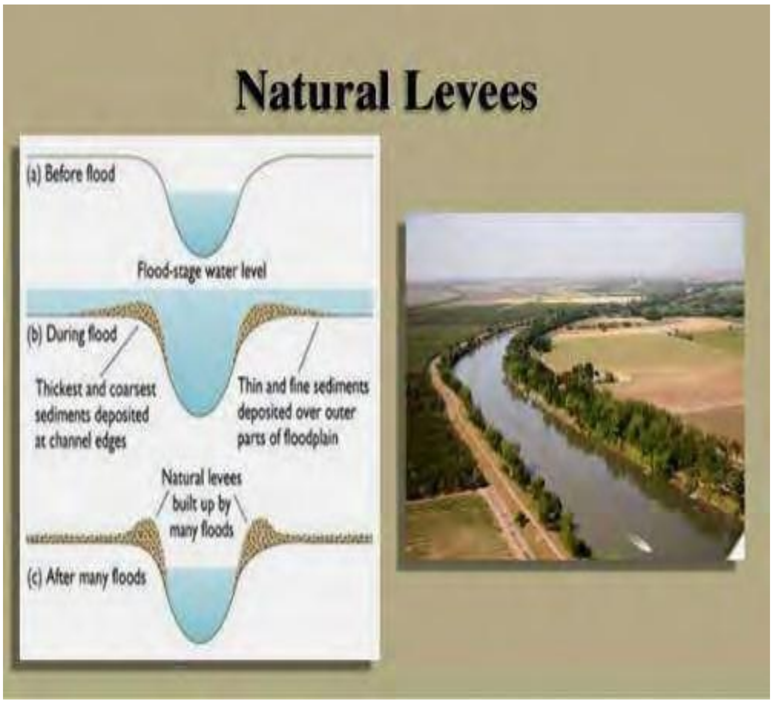
• Generally, the levee deposits are coarser

• When rivers shift laterally, a series of natural levees can form.

• Artificial embankments are formed on the levees to minimize the risk of the floods.

• But sudden bursts in the banks due to the pressure of water can cause disastrous floods.

• An example of such flood can be seen in Hwang Ho river which is also called China s sorrow .



Point Bars

• Point Bar is also associated with floodplain

• Point bars are also known as meander bars.

• A point bar is a depositional feature

• It is formed by alluvium that accumulates in a linear fashion on the inside bends of streams and rivers below the slip-off slope.

• They are found on the convex side of meanders of large rivers.

• They are almost uniform in profile and in width and contain mixed sizes of sediments.

• Long and narrow depressions can be found in between the point bars where there is more than one ridge

• Rivers build a series of them depending upon the water flow and supply of sediment. • As the point bars are built by the rivers on the convex side, erosion takes place on the concave side of the bank.

Meanders

• In large flood and delta plains, rivers rarely flow in straight courses. Loop-like channel patterns called meanders develop over flood and delta plains

• Normally, in meanders of large rivers, there is active deposition along the convex bank and undercutting along the concave bank.

• If there is no deposition and no erosion or undercutting, the tendency to meander is reduced.

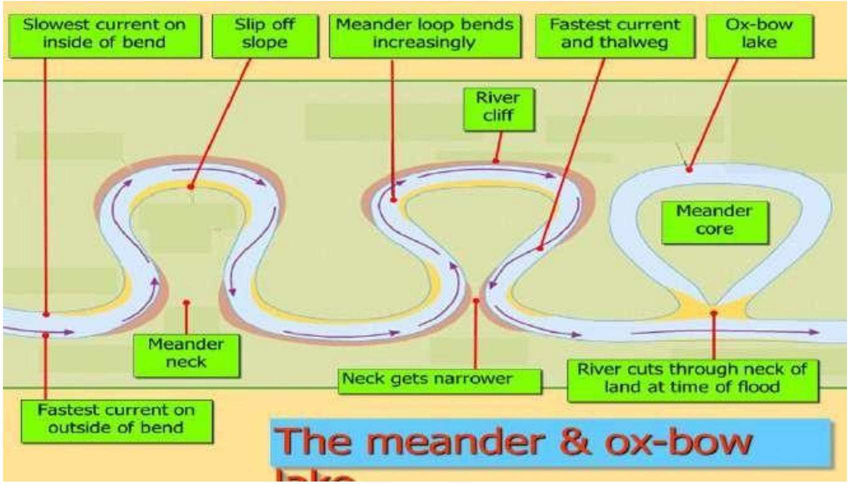
• The concave bank is known as a cut-off bank which shows up as a steep scarp and the convex bank presents a long, gentle profile and is known as the slip-off bank

• Factors responsible for meandering of the rivers

• The propensity of water flowing over very gentle gradients to work laterally on the banks

• Unconsolidated nature of alluvial deposits making up the banks with many irregularities which can be used by water exerting pressure laterally

• Coriolis force acting on the fluid water deflecting it like it deflects the wind.



Oxbow Lakes

• In the lower course of a river, meanders become very much more pronounced

• As meanders grow into deep loops, the same may get cut-off due to erosion at the inflexion points and are left as independent water bodies, known as ox-bow lakes.

• Through subsequent floods that may silt up the lake, oxbow lakes are converted into swamps in due course of time. It becomes marshy and eventually dries up.

Braided Channels

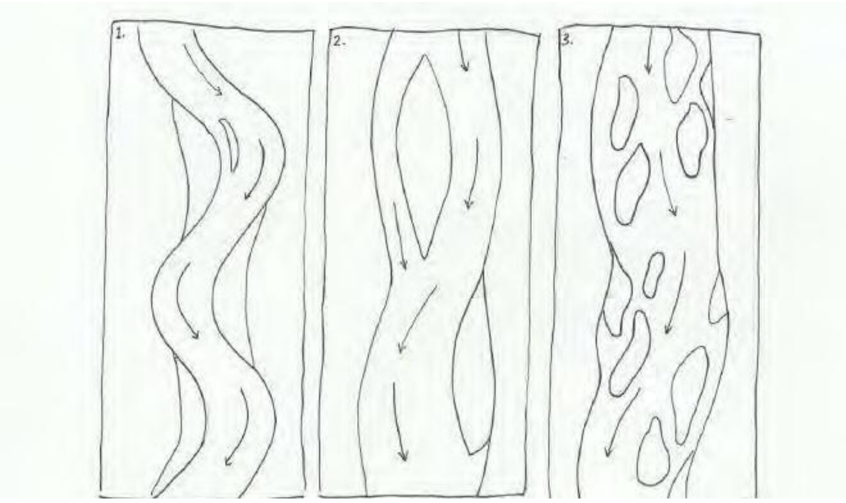
• A braided channel consists of a network of river channels divided into multiple threads and separated by small and often temporary islands called eyots .

• Braided channels are commonly found where water velocity is low and the river is heavy with sediment load

• Deposition and lateral erosion of banks are essential for the formation of the braided pattern.

• There is the formation of central bars due to selective deposition of coarser material which diverts the flow towards the banks causing extensive lateral erosion

• As the valley widens due to continuous lateral erosion, the water column is reduced and more and more materials get deposited as islands and lateral bars developing a number of separate channels of water flow.



Braided Channels

GLACIER

A glacier is a large mass of ice that is persistently moving under its own weight over the land or as linear flows down the slopes of mountainsin broad trough-like valleys

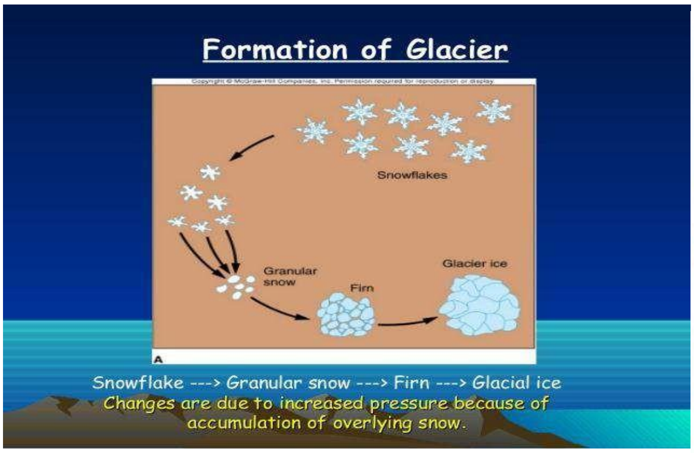
• Glaciers are formed in the areas where the accumulation of snow exceeds its ablation (melting and sublimation) over many years, often centuries.

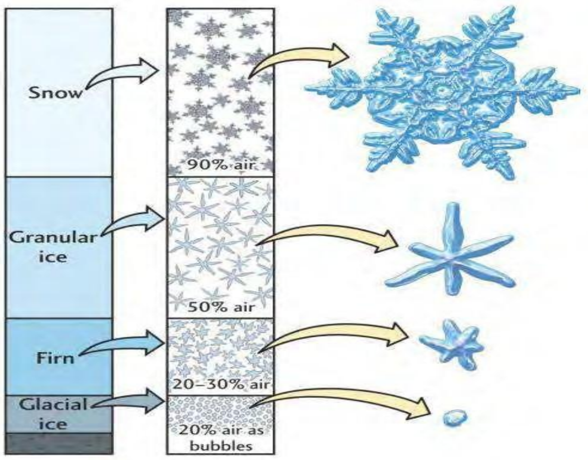
• Glaciers move under the influence of the force of gravity.

• The movement of glaciers is slow, unlike water flow. Glaciers flow like very slow rivers.

• Their movement could be a few centimetres to a few metres a day or even less or more

• Like rivers the glacier does three kinds of work – erosion, transportation, and deposition.





Erosion:

Glacial erosion results from the movement of ice over the rock floor and the main tools of erosion are the rock fragments embedded in the ice at the ice-rock interface.

• The basal ice is armed with sharp angular rock fragments of various sizes and as the glacier moves under pressure these fragments polish, scratch and cut grooves in the rock surfaces. This process is known as abrasion.

• If the debris is rock-flour or sand, the rock surface will become polished. If the debris is of gravel or boulder size, the rock surface will be striated (scratched) or grooved.

• The other major mechanism of glacial erosion is 'plucking' or quarrying or joint-block removal. Abrasion involves erosion at the ice-rock interface without movement of the parent rock and with the removal small parts of the parent rock. Plucking involves larger fragments of the parent rock

Transportation:

The materials can be transported by glacier ice either on its surface or along its bed or somewhere in between the two, i.e.,

• supraglacially, • subglacially • englacially.

• An erratic (or erratic block) is a rock that has been transported more or less far by a glacier and has remained in ice-free terrain after the melting of the glacier.

• It differs from the size and type of rock native to the area in which it rests

• Sometimes the erratics are perched on narrow basement made of other rocks – called 'perched blocks'

Deposition:

The glacial debris transported by the glacier ice and its associated meltwater is deposited either in the bed or along the sides or in the terminal zone of the glacier.

• Moraine is the term used to describe the rock debris transported and deposited by glacier.

• Glacial Till : Unassorted materials

• Outwash plain: assorted materials

Types of Glaciers

Glaciers are categorized by their morphology, thermal characteristics, and behaviour.

Glaciers are mainly of four types - continental glaciers, ice caps, piedmont glaciers and valley glaciers.

• Continental Glaciers - Continental glaciers are continuous masses of ice that are much larger than alpine glaciers. By definition, they have areas larger than 50,000 km2, some examples of Continental Glaciers are Antartica, Iceland, Greenland etc.

• Ice caps - Ice caps are the covers of snow and ice on the mountain ranges from which the valley or mountain glaciers originate. Though they can also be found at the lower altitudes. Ice caps have an area of less than 50,000 km2.

• Piedmont Glaciers - The piedmont glaciers form a continuous ice sheet at the base of mountains. The Malaspina Glacier in Alaska is one of the most famous examples of this type of glacier

• Valley Glaciers - A glacier that fills a valley is called a valley glacier. The valley glaciers are commonly known as Alpine Glacier and are found in the valleys created by lofty mountains such as Himalaya in India.

Mechanism of erosion and deposition :

• Erosion by glaciers is tremendous because of friction caused by sheer weight of the ice.

• The rate of erosion is determined by several factors such as the velocity of flow, gradient of the slope, the weight of the glacier, the temperature of the ice and the geological structure of the valley

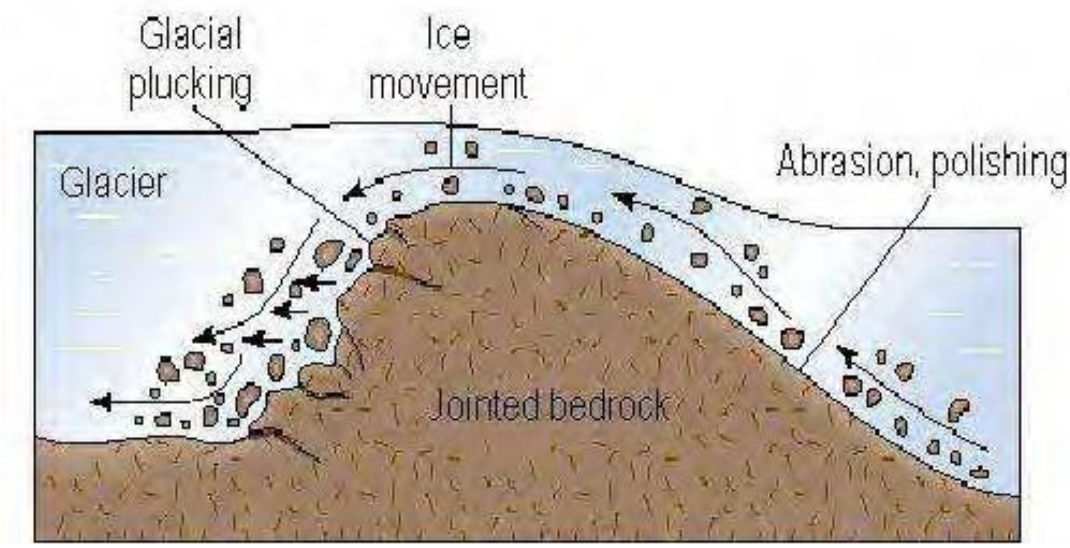
• A glacier erodes its valley through two processes plucking and abrasion.

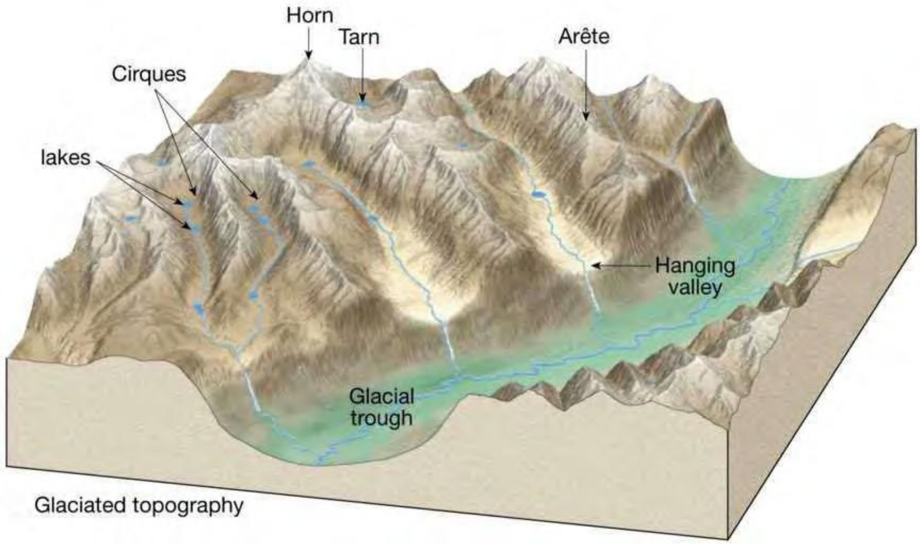
• Plucking - By Plucking , the glacier freezes the joints and beds of the underlying rocks tears out individual blocks and drags them away

• Abrasion - By abrasion , the glacier scratches, scraps, polishes and scours the valley floor with the debris frozen into it. These fragments are powerful agents of denudation

• As glaciers move over bedrock, large blocks and fragments of rocks are plucked from the land by glaciers. This mass of rocks and debris creates huge erosion potential and erodes the bed and sides of the valley through which glaciers flow.

• The movement of glaciers continuously erodes the bedrock and levels of the plain. Eventually, the slope is so much reduced that no further movement is possible and so glacier stops and deposits the debris in the vast outwash plain.





GLACIAL LANDFORMS

Glaciation generally gives rise to erosional features in the highlands and depositional features on the lowlands, though these processes are not mutually exclusive because a glacier plays a combined role of erosion, transportation and deposition throughout its course.

Erosional Landforms

Cirque

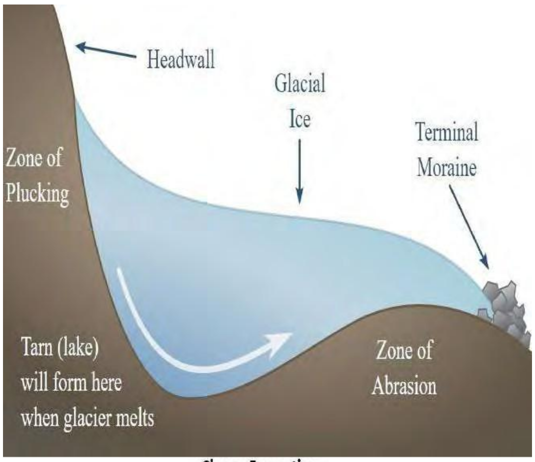
• French term, used by Jean de Charpentiar.

• Cirques are semi-circular steep-sided depressions. Cirques are often found at the head of Glacial Valley

• The accumulated ice cuts these cirques while moving down the mountain tops.

• After the glacier melts, water fills these cirques, and they are known as cirque lake.

• Different names of Cirque: corrie in Scotland, cwm in Wales, kar in Austria and Germany, kjedel in Scandinavia, botn in Norway and nisch in Sweden

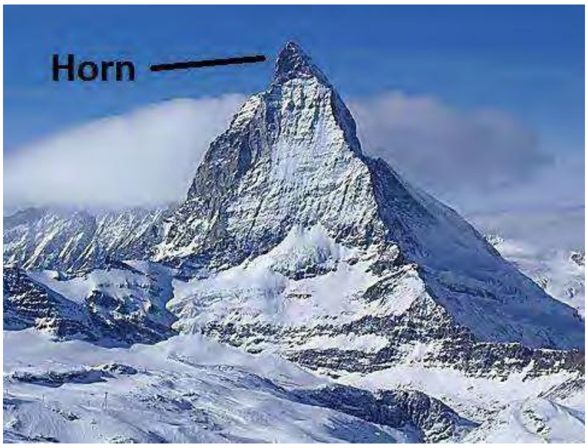


Cirque Formation

Horns

• Horns form through headward erosion of the cirque walls.

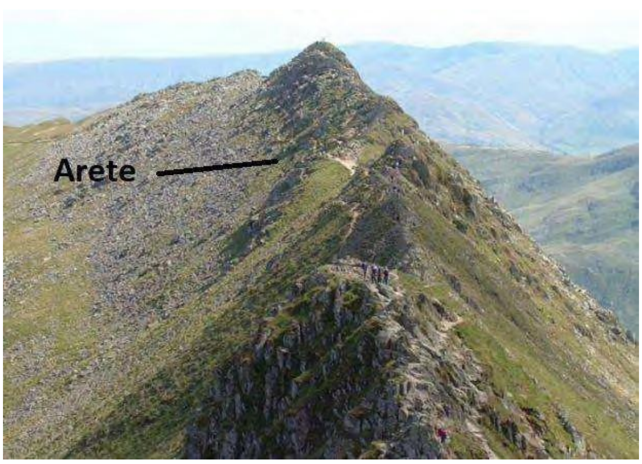
• If three or more radiating glaciers cut headward until their cirques meet, high, sharp pointed and steep-sided peaks called horns form



Aretes

• Arete is a narrow ridge of rock which separates two valleys.

• Aretes are typically formed when two glacial cirques erode headwards towards one another • The divides between Cirque side walls or head walls get narrow because of progressive erosion and turn into serrated or sawtoothed ridges referred to as aretes with very sharp crest and a zig-zag outline.



Glacial Valleys

• Glaciated valleys are troughlike and U-shaped with wide, flat floors and relatively smooth, and steep sides.

• When the glacier disappears, and water fills the deep narrow sections of the valley, a ribbon lake is formed.

Fjords/Fiords

• A fjord or fiord is a long, narrow and steep-sided inlet created by a glacier

• They are formed where the lower end of a very deep glacial trough is filled with sea water

• Fjords are common in Norway, Chile, and New Zealand etc.

Hanging Valleys

• A hanging valley is a tributary valley that is higher than the main valley. Hanging valleys are common along glaciated fjords and Ushaped valleys.

• The main valley is eroded much more rapidly than the tributary valleys as it contains a much larger glacier

• After the ice has melted tributary valley, therefore, hangs above the main valley

• The faces of divides or spurs of such hanging valleys opening into main glacial valleys are quite often truncated to give them an appearance like triangular facets.

• Often, waterfalls form at or near the outlet of the upper valley

• Thus, the hanging valley may form a natural head of water for generating hydroelectric power.

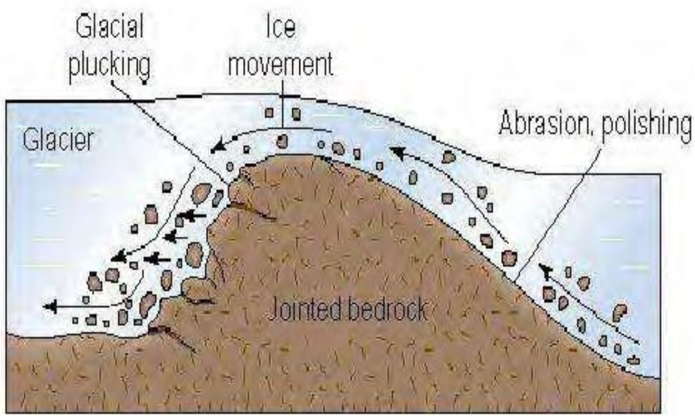
Roches Moutonnees

• Plucking gives a characteristically shattered and broken appearance to a landscape particularly when viewed against the direction of ice flow.

• The smoothed up-glacier slope represents glacial abrasion and polishing while the shattered downglacier side represents joint-block removal by freeze-thaw action.

• The term was introduced by H.B. De Saussure in 1787 • Also known as 'stoss and lee' topograhy

• Largely found along the Norwegian coast.



Depositional Landforms

Outwash plains

• An outwash plain is a plain at the foot of the glacial mountain

• They are made up of fluvioglacial sediments, washed out from the terminal moraines by the streams and channels of the stagnant ice mass.

• As it flows, the glacier grinds the underlying rock surface and carries the debris along.

• When the glacier reaches its lowest point and melts, it leaves behind a stratified deposition material, consisting of rock debris, clay, sand, gravel etc. with larger boulders being deposited near the terminal moraine, and smaller particles travelling further before being deposited.

• The stratified surface thus formed is called as an outwash plain and a downward extension of the deposited finer particles and clay material is called valley train.

MORAINES

The unassorted coarse and fine debris dropped by the melting glaciers is called glacial till.

• The long ridges of deposits of these glacial till is called as Moraines

• Depending on its position, moraines are classified into be ground, lateral, medial and terminal moraine.

• **Terminal Moraines** - Terminal moraines are long ridges of debris deposited at the end (toe) of the glaciers.

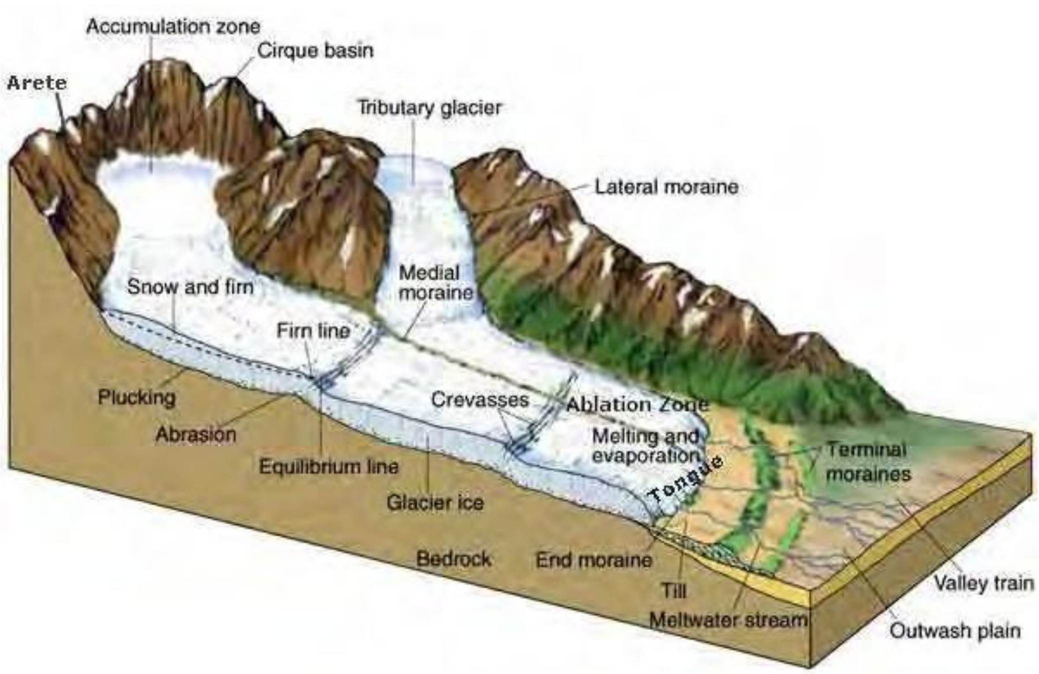
• **Lateral Moraines** - Lateral moraines form along the sides parallel to the glacial valleys. These moraines partly or fully owe their origin to glaciofluvial waters pushing up materials to the sides of glaciers.

• There can be many lateral moraines on either side in a glacial valley. The lateral moraines may join a terminal moraine forming a horse-shoe shaped ridge

• **Ground Moraines** - Many valley glaciers retreating rapidly leave an irregular sheet of till over their valley floors. Such deposits varying greatly in thickness and in surface topography are called ground moraines.

• **Medial Moraines** - The moraine in the centre of the glacial valley flanked by lateral moraines is called medial moraine. They are imperfectly formed as compared to lateral moraines.

• Sometimes medial moraines are indistinguishable from ground moraines.



Eskers •

An esker is a long, winding sinuous ridge of stratified sand and gravel

• Eskers are frequently several kilometres long and, because of their peculiar uniform shape, are somewhat like railway embankments

• When glaciers melt in summer, the water flows on the surface of the ice or seeps down along the margins or even moves through holes in the ice.

• These waters accumulate beneath the glacier and flow like streams in a channel beneath the ice.

• Such streams flow over the ground with ice forming its banks.

• The stream underneath carries coarse materials such as boulders, blocks which gets deposited in the bed and when the glacier melts the deposits forms a sinuous ridge called eskers.

Eskers

Drumlins

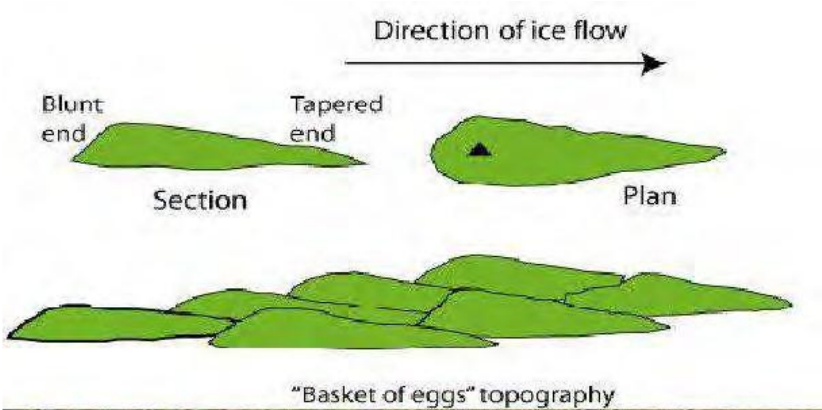
• Drumlins are smooth oval shaped ridgelike features composed mainly of glacial till with some masses of gravel and sand.

• The drumlins form due to the dumping of rock debris beneath heavily loaded ice through fissures in the glacier.

• The long axes of drumlins are parallel to the direction of ice movement.

• They may measure up to 1000m in length and 30-35 m or so in height.

• One end of the drumlins facing the glacier called the stoss end is blunter and steeper than the other end called the tail.



CHAPTER -2

ROCKS AND THEIR CLASSIFICATION

Why study rocks?

- Geologists study rocks because they contain clues about what the Earth was like in the past

➢ Can assemble a historical record of a planet

➢ Trace events that occurred long before humans

Helps us answer questions such as:

❖ Was there a lake or volcano present where the rock was found?

❖ Was there a mountain range or sea?

❖ Was it hot or cold?

❖ Was the atmosphere thick or thin?

Basic point is to better understand our world. This helps us to better coexist with nature and reap the benefits that it has to offer

Every rock has a story to tell....

- We pass by rocks every day....

➢ Never thinking of their place of origin, age, or reason for even being here

So maybe it's just that some people collect rocks, like stamps, solely for habit and maybe the occasional insight?

➢ NO WAY!!!!

➢ Rocks are good story tellers....problem is, in order to know the story, you have to be trained a bit ;)

What defines a mineral?

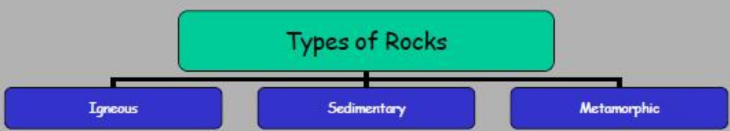
- Naturally Occurring
- Inorganic
- Solid
- Specific composition (e.g., Gold - Au, Salt - NaCl, quartz - SiO_2)
- Definite crystalline structure – atoms are arranged in a specific pattern

What are Rocks?

<u>Rocks</u> are a combination of minerals that are bonded together in some way.

- *<u>All rocks are made of minerals</u>*
  - **Monomineralic-** contain one mineral
    Polymineralic- contain more than one mineral

Rocks are classified into three groups by how they are formed



Rocks

• About 98% of the total Earth's crust is composed of eight elements which are:

Sl. No.	Elements	By Weight(%)
1.	Oxygen	46.60
2.	Silicon	27.72
3.	Aluminium	8.13
4.	Iron	5.00
5.	Calcium	3.63
6.	Sodium	2.83
7.	Potassium	2.59
8.	Magnesium	2.09
9.	Others	1.41

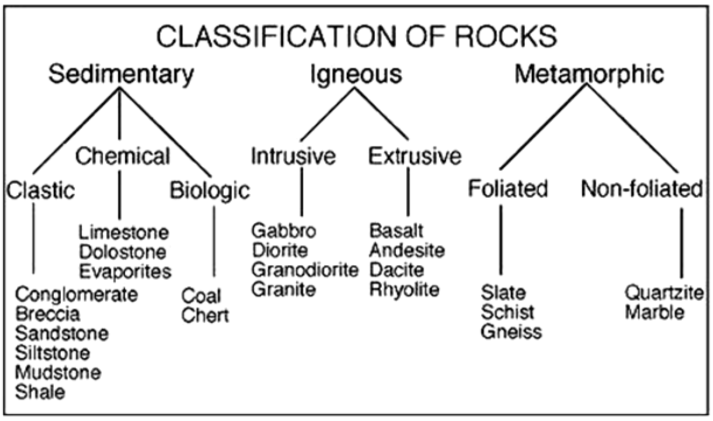
There are major mineral groups that are known as rock-forming minerals.

• Rock is defined as one or more minerals aggregate.

• The hot magma inside the earth is the basic source of all minerals.

• The most common minerals found in rocks are feldspar and quartz.

• Petrology is the science of rocks. The characteristics of rocks directly influence the type of landforms generated. Rocks are mostly classified into 3 forms. They are



Igneous rocks

1. They are formed by cooling and solidification of magma from beneath the earth's crust. These rocks are hard and resistant.
2. They are crystalline in nature
3. They neither occur in strata nor they contain fossils

4. Sub-division on the basis of Mineral composition

1. Acid igneous rocks: High proportion of Silica. They are less dense and lighter in colour. Example: Granite
2. Basic igneous rocks: they contain a greater proportion of basic oxides such as Ferrous or Magnesium while lower Silica content. They are denser and are darker in colour.

5. Sub-division on the basis of Origin

1. Plutonic rocks: they cool slowly at greater depths and have large mineral grains. They are intrusive rocks exposed at the surface by the denudation process. Ex: Granite, diorite and Gabbro
2. Volcanic rocks: they are poured out of volcanoes as Lavas, solidify rapidly on the earth's surface and have smaller grains. Ex: Basalt

Sedimentary rocks

1. They are formed as the result of deposition of fragments of rocks by exogenous processes. Various rocks

exposed to the denudation process are transported and deposited following which they undergo the process of Lithification and turn into sedimentary rocks.
2. They are called Stratified rocks due to their characteristic layer formation
3. They are non-crystalline and contain fossil deposits
4. Sub-division on the basis of origin and compaction
1. Mechanically formed: they are formed due to the accumulation of materials derived from other rocks which have been cemented together. Ex: Sandstone, Grit
2. Organically formed:
1. Calcareous: Formed from the remains of living organisms like Corals or Shellfish. Ex: Limestones
2. Carbonaceous: Formed due to heavily compressed vegetative matter – swamps and forests Ex: Peat, Lignite etc
2. Chemically formed: These rocks are precipitated chemically from the solutions of one kind or the other. Ex: Rock salts derived from Seabed, Gypsum, Potash and Nitrates.

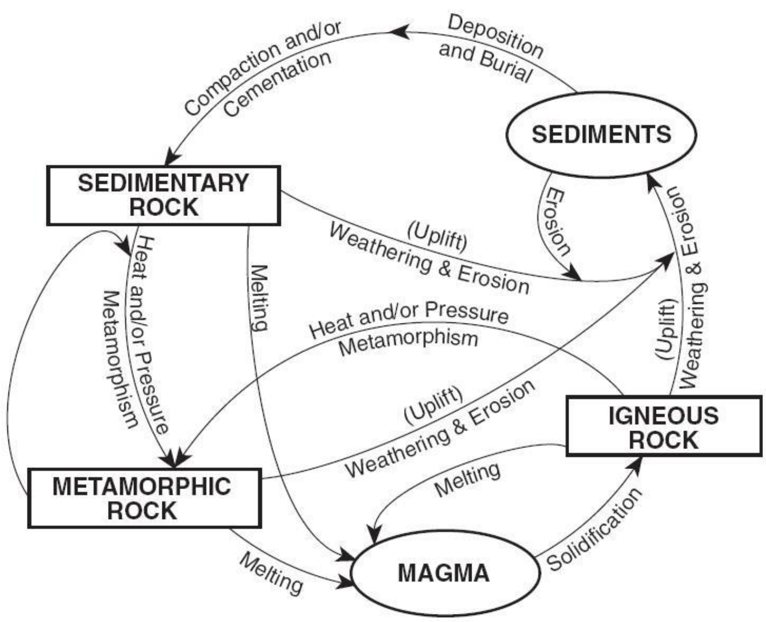
Metamorphic rocks

These rocks are formed when existing Sedimentary and Igneous rocks undergo recrystallization under the action of Pressure, Volume and Temperature (PVT) changes.

Types of Metamorphism
1. **Dynamic Metamorphism**
2. **Thermal Metamorphism**, which may be further sub-divided into
1. Contact Metamorphism 2. Regional Metamorphism
3. **Foliation:** Arrangement of minerals in layers or lines in a metamorphic rock.
4. **Banding**: Arrangement of materials into alternating thick or thin layers appearing in light and dark shades in a metamorphic rock.

Examples: Clay to Slate, Limestone into Marble, Sandstone into Quartz, Granite into Gneisses, Shale into Schist, Coal into Graphite.

Rock Cycle in Earth's Crust



TEXTURES OF IGNEOUS ROCKS

- Texture is defined on the basis of glass vs. mineral grains proportions, their sizes, shapes and mutual arrangements. Perhaps you may have questions asking about importance of textural and structural studies!
- These textures and structures provide an idea about the geological processes during its crystallisation.
- They also provide us valuable information about physical chemistry and cooling history of the igneous rocks. Let us consider an example - if you observe granite and basalt and compare their physical properties, you will find distinct differences as mentioned below:

Colour- granite is light coloured or leucocratic whereas basalt is dark coloured or melanocratic in appearance.
Grain size- granite is coarse grained, whereas, basalt is fine grained or sometimes glassy.
Mutual relationship- in case of granite the crystal is large enough to be seen with unaided eyes but it is not possible in case of a basalt.
However, many more unravelled differences can be discerned when granite and basalt are studied under the petrological microscope. We hope that the concept of granite and basalt that display different textures is clear to you now.
Thus, the textures help us to identify different rock types. The term texture is applied to megascopic (as observed in hand specimens with unaided.

We have already discussed that the texture of an igneous rocks represents intimate relationship between the mineral grains and the glass.
Let us discuss following textural elements with reference to igneous rocks.

- Crystallinity/ degree of crystallisation
- Granularity/ grain size
- Shape of the mineral grains
- Mutual relationship amongst crystals and glass as well

We have learnt that the igneous rock comprises of crystallised as well as non- crystallised components. Study of shape of crystals and mutual relationship between mineral grains and glassy matter is described as fabric. Thus, fabric is defined as the arrangement, orientation and mutual relationship of mineral grains or crystals and/or glass. Fabric is a non-compositional property of rock, comprises of textures and structures both.

Crystallinity

Crystallinity or degree of crystallisation refers to degree or amount of crystalsformed during the process of solidification of magma. The igneous rocks may be composed of the crystals, partly crystals and partly glassy matter or totally glassy matter.

Degree of crystallisation is measured by the ratio between thecrystallised matter and the glass in an igneous rock. It is the modal percentageof mineral grains relative to glass and varies between 0 – 100 %.

Let us learn few more terms related to crystallinity.

Crystallites are embryo of crystals, organised to full crystalline status. They have more varied shapes. Longulites are cylindrical rods with rounded ends. Globulites are minute spherical drops or pellets, often quite opaque and consistof iron oxide. When globulites are aligned like string of beads, the resulting formis called margarites.
Scopulites are rods or needle with divergent plumes.
Trichites are filamentous or hair-like.

Microlites are somewhat larger bodies and can be recognised as minute crystals. They are usually rod or needle shaped and exhibit crystal outlinesappropriate to their mineralogical nature.

Glass: Highly viscous liquid, disordered atomic structure, formed by rapid cooling of silicate melts during crystallisation. This term is specifically used for arock or portion of a rock which is devoid of crystalline structure. It is formed when a highly viscous magma is rapidly supercooled, wherein the atomicgroups and the molecules present in them are not properly and regularlyarranged in a definite order to form crystalline substance.On the basis of crystallinity or degree of crystallisation, textures of igneous rocks are grouped as:

1. **Holocrystalline**: The prefix 'holo' implies entirely or wholly composed of well-defined crystal faces of constituent minerals in the rock, e.g. orthoclasein granite, augite in gabbro. Holocrystalline texture is seen in plutonic rocks (Fig. 2.1a).
2. **Hemicrystalline/ Microcrystalline**: When the rock comprises partly of crystalline and partly of glassy material, e.g. dolerite, basalt, the rock is known to exhibit hemicrystalline texture. This is mainly observed in the rockswhich are crystallised near the surface or at an intermediate depth from the surface (Fig. 2.1b). The other synonym terms in use are merocrystalline or hypocrystalline.
3. **Holohyaline**: The rocks exhibiting this texture are entirely made up of glassy matter or non-crystalline matter (like crystallites and microlites). This results when the rate of cooling is very rapid. This texture is mostly seen in volcanic rocks, e.g. obsidian, pitchstone, nephelinite

Rocks: show a) holocrystalline granite specimen; b) hemicrystalline Dolerite; and c) holohyaline volcanic outcrops.

Crystallinity is largely controlled and governed by following factors:

- **Rate of cooling**- Faster the cooling finer will be the crystals. Volcanic glass is formed by rapid cooling of the lava. Slower rate of cooling favours crystalgrowth of the bigger crystals.
- **Depth of cooling and volume of magma**- Higher the depth, slower will be the cooling rate as heat deccipiation is slow. Similarly, volume of the magmahave significant bearing on crystal growth. Larger the volume slower will be the rate of cooling, hence larger crystals will be formed.
- **Composition and viscosity of magma**- Highly viscous lavas such as rhyolite or siliceous magma favours formation of non-crystalline and/or glassy rocks. Contrarily, less viscous basaltic or mafic lavas/magmas giverise to crystalline rocks e.g. phyric and aphyric basalts. Magma with high viscosity have high volatile content as compared to less viscous magmas.

Granularity

We have already discussed about crystallinity, now let us introduce you to few important technical terms related to granularity. Grain size or granularity in igneous rocks shows wide variation. It varies from a meter size (e.g. pegmatite)to few centimeters to even > 0.01 mm size of a microlite or sometimes even glassy as found in volcanic rocks. Generally, **phaneritic** and **aphanitic** terms are used to describe coarse- and fine-grained rocks, respectively. Coarse- grained crystals can be seen with unaided eyes and mineral grains in rocks areidentified easily. Whereas, study of fine-grained minerals in rocks requires petrological microscope for their identification. Synonym terms for aphanitic texture are hyaline or glassy texture (Fig. 2.2). The alternative terms used for phaneritic and aphanitic rocks are phyric and aphyric respectively.

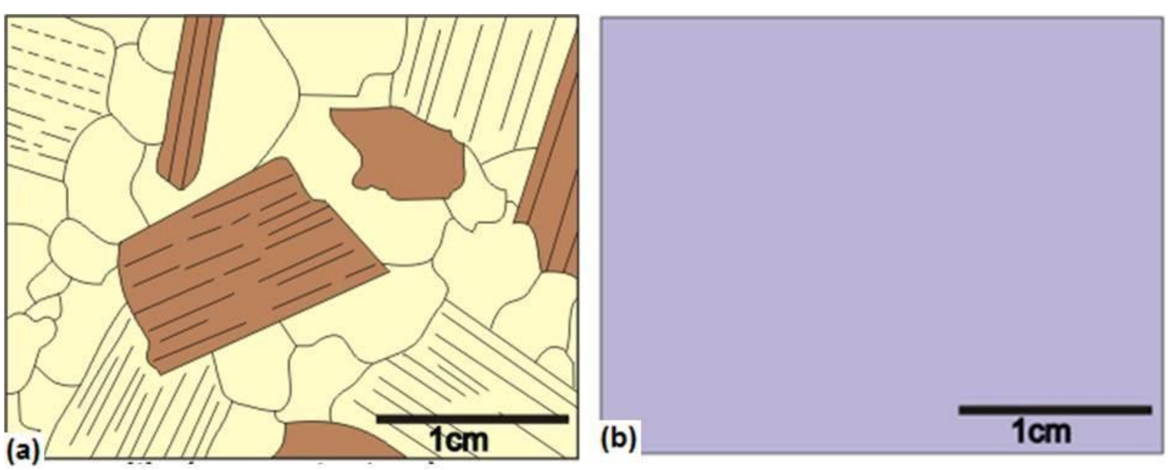
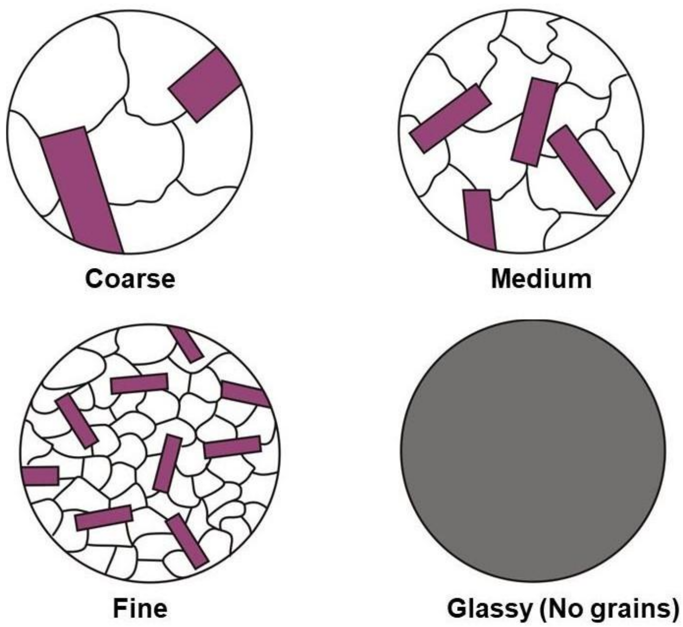


Fig. 2.2: a) Phaneritic; and b) Aphaneritic texture.

Phaneritic rocks: In these rocks minerals grains are large enough to be visible with unaided eyes. Such types of textures are commonly associated with the magmatic intrusions and they reflect crystallisation at low degree of undercooling. Phaneritic texture also indicates low rate of nucleation, formedunder plutonic conditions, and emplaced on the surface due to upliftment. Phaneritic texture is classified into following sub-types. They are referred to as:

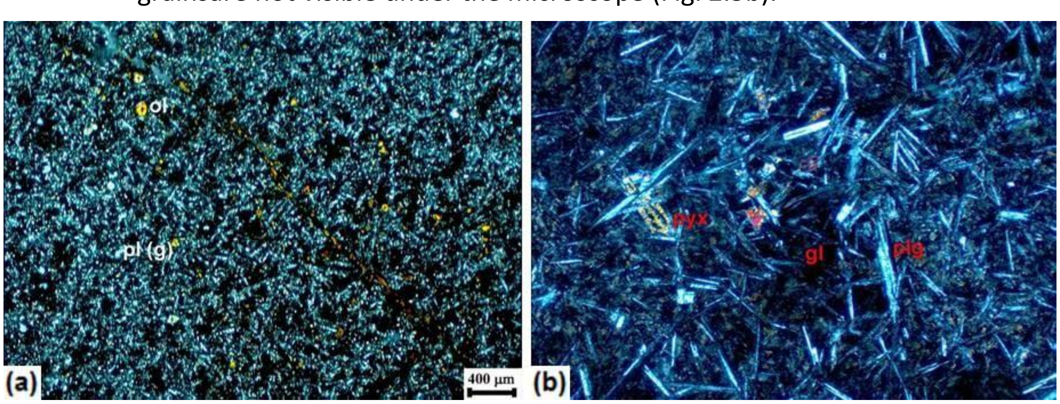
- fine-grain (< 1mm)
- medium-grain (1-5 mm)
- Coarse-grain (3 mm-5cm)
- very coarse-grain (>3 cm)

Rapid cooling of lava flow (being in contact of air or water) results in a fine- grained or glassy rock (< 1mm). The cooling in hypabyssal rocks such as dykesand sills is relatively slow as it takes place under shallower depth that result in medium-grained rock (1-5mm). Large igneous intrusions at much deeper levelsundergo very slow cooling that result in the formation of coarse and very coarse-grained igneous rocks (e.g. pegmatite).



2) **Aphanitic rocks**: They are fine-grained and have too small crystals to be identified with the unaided eyes or even with the help of a hand lens. They are further classified into two sub-types such as:

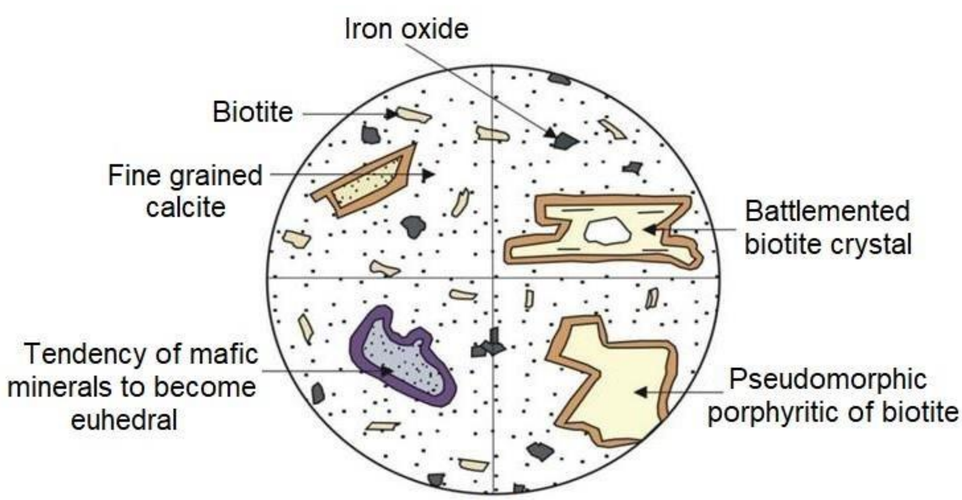
- **Microcrystalline**: In this the grains are visible only under the microscope(Fig. 2.5a).
- **Cryptocrystalline**: In this case only felty mass is seen and mineral grainsare not visible under the microscope (Fig. 2.5b).



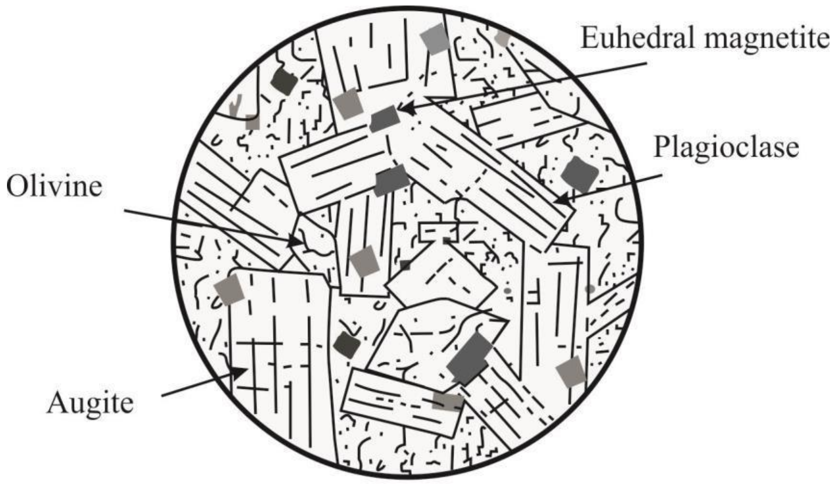
Shape of the Crystals

Let us discuss the three important terms euhedral, subhedral and anhedral and their resulting textures that are universally used to describe relative proportion of the grain shape.

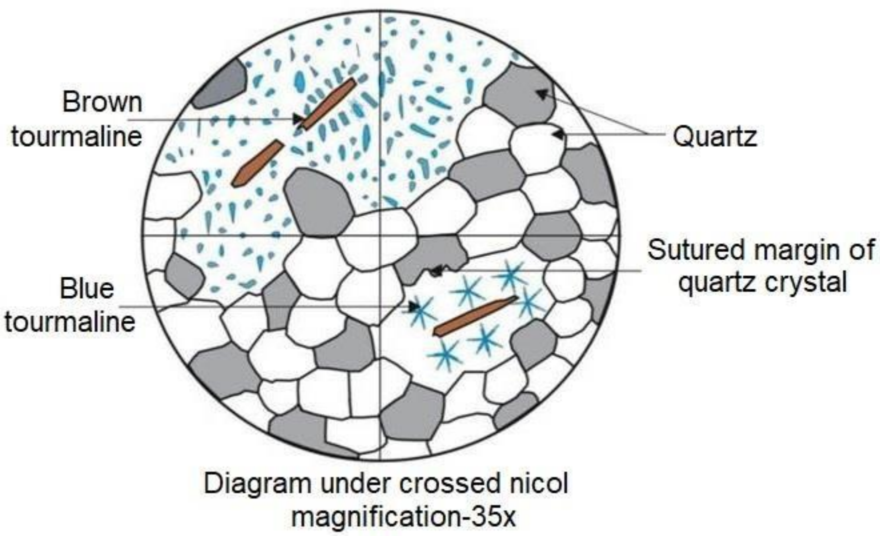
1. **Euhedral** term is used for the mineral grains which possess fully developedgrain/crystal outlines. All the faces are perfectly or near perfectly developed.**Idiomorphic** and **automorphic** are equivalent terms, used for euhedral grains. **Panidiomorphic granular texture** (pan-all; idio-one's own; morph- shape) comprises majority of grains with euhedral shape (e.g. pegmatite).
2. **Subhedral** refers to crystal forms with less or partly developed crystal faces or grain boundaries. **Hypidiomorphic granular texture** (hypo-less or below)consists of dominantly of mineral grains with partly developed or subhedral shape, e.g. gabbro, granite. Thus, hypidiomorphic granular texture is the commonest of the granular texture, also called granitic because this is mostly found in granite rock.
3. **Anhedral** term is used for mineral grains lacking crystal outlines. When majority of the grains are anhedral resulting, texture is known as **allotriomorphic granular texture** (*allotrio*-alien), also called as **xenomorphic granular texture**, e.g. aplite. This texture is also called apliticbecause this is best developed in aplites (hypabyssal equivalent of granite).



(a)



(b)



(c)

2.6: Shapes of crystals and resulting textures: a) Panidiomorphic granulartexture; b) Hypidiomorphic granular texture; and c) Allotriomorphic granular texture.

We know that the crystals tend to develop crystal grains in length, breath and height, thus, exhibits three-dimensional geometry during the process of crystallisation. On the basis of mineral grain dimensions, the mineral grains in the igneous rocks can be grouped as:

1. **Equidimensional**: The mineral grains are equally developed in all thedimensions, e.g. garnet, olivine, leucite.
2. **Prismatic**: The mineral grains show more distinct growth in one direction (along C axis) than the other two directions/axes, e.g. augite, hornblende. Ifthe width and breadth is insignificant as compared to the length, then it is called **acicular** or needle shaped, e.g. sanidine.
3. **Tabular**: The mineral grains have greater development in length ascompared to width, e.g. plagioclase, orthoclase.
4. **Platy or sheet**: The mineral grains are developed in length and breadth inrelation to height e.g.

mica.

5. **Irregular**: The mineral grains are irregularly developed in all the dimensions,

e.g. quartz in granite.

Mutual Relationship between Crystal and Non-Crystalline Material

We have read that apart from describing the shape, fabric also includes mutual relationships of crystals and non-crystalline matrix/glass. It is has been discussed under two sub-groups:

- Equigranular texture
- Inequigranular texture

Equigranular textures: When the majority of the grains are of equal size, itis said to have equigranular texture, e.g. granite and gabbro. It can be grouped into three sub-types:

- **Microgranitic**- It occurs in fine grained rocks, where shape of the grainsis mostly anhedral or subhedral.
- **Orthophyric**- If in a fine-grained rocks grains are mostly euhedral.
- **Felsitic**- If grains are very fine or microcrystalline or cryptocrystalline

Inequigranular textures: In an igneous rock if the grain size difference becomes so pronounced that one set of grains is distinctively larger and associated with another set which is much finer in size, then it is termed asinequigranular. They are of following types:

- Porhyritic texture
- Poikilitic texture
- Intersertal/intergranular texture

Porphyritic texture: In this, the larger grains are surrounded by the groundmass consisting of smaller grains (microcrystals) or glassy part. The larger grains are termed as **phenocryst**. Please note that this textureis visible both megascopically (Fig. 2.7a) and microscopically (Fig. 2.7b and 2.9a). Porphyritic texture resulted due to change in physicochemical conditions, molecular concentration and insolubility

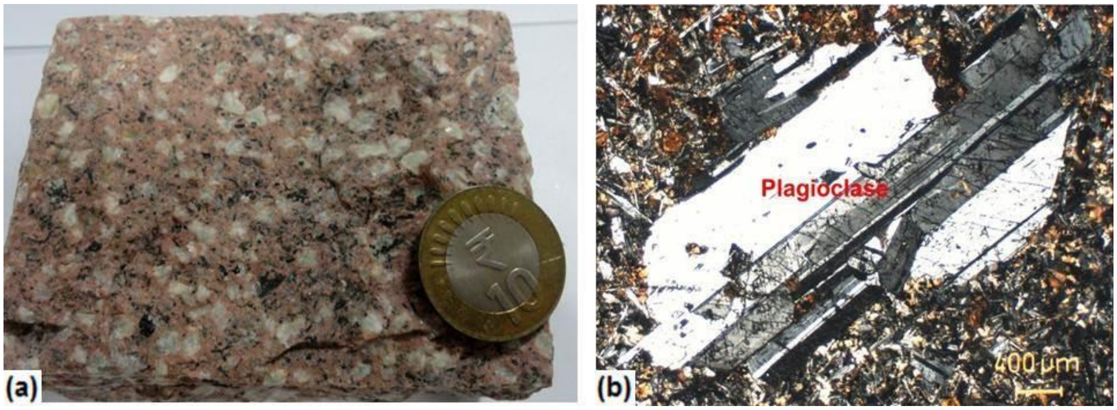


Fig. 2.7: Porphyritic texture: a) Handspecimen showing phenocrysts (white) inmottled pinkish groundmass; and b) Photomicrograph showing plagioclase phenocryst in groundmass consisting of fine-grained plagioclase, augite, glass and iron oxide.

- The term microphenocryst is subjectively used to distinguish finer phenocrysts from coarser ones for which the term megaphenocryst is used.

Porphyritic texture is of three types:

- **Vitrophyric**: phenocryts are enclosed by glassy groundmass (Fig. 2.8a)
- **Felsophyric**: phenocryts are enclosed by cryptocrystalline groundmass
- **Glomeroporphyritic**: phenocryts are the early formed crystals of minerals such as olivine, pyroxenes and plagioclase (Fig. 2.8b and 2.9b)clubbed together and form distinct clusters of crystals or crystal aggregates

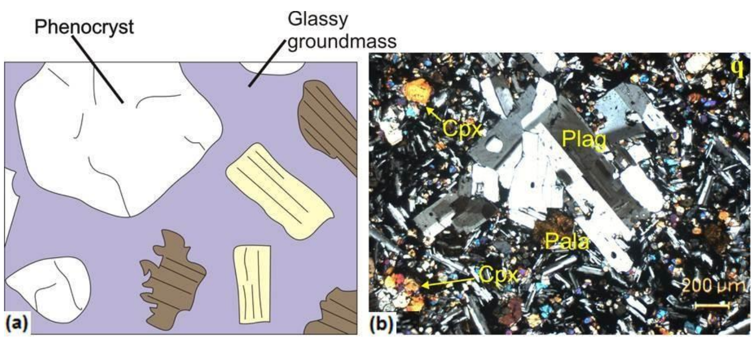
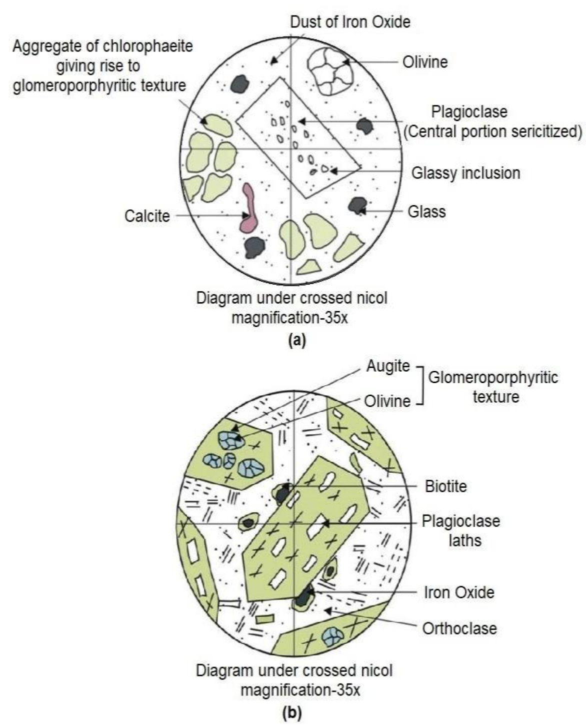


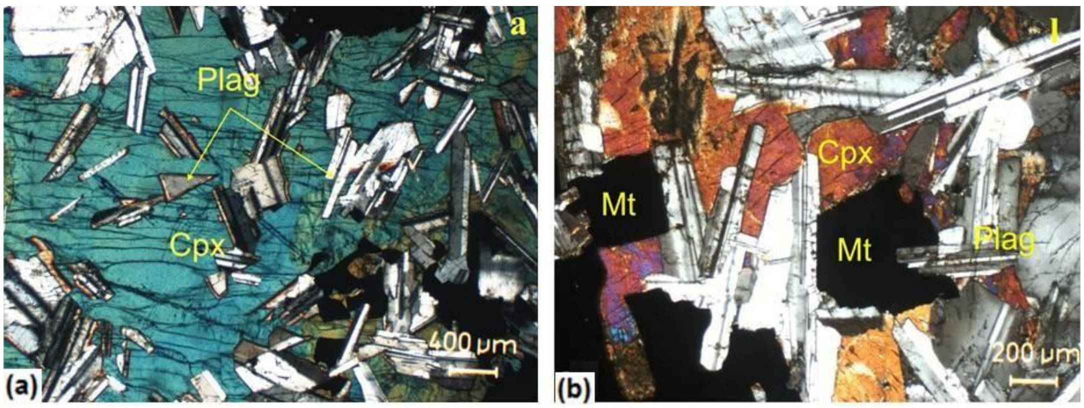
Fig. 2.8: Types of Porphyritic texture: a) Sketch of vitrophyric texture showingphenocrysts in glassy groundmass; and b) Photomicrograph of glomeroporphyritic texture showing cluster of plagioclase crystal as phenocryst in groundmass consisting of fine-grained plagioclase, augite, palagonite and iron oxide.



Sketches showing: a) Porphyritic texture in basalt, euhedral grains of plagioclase occur as phenocrysts, and b) Glomeroporphyritic textureshowing cluster of olivine grains as phenocryst in the groundmass ofaugite in alkali gabbro

a) **Poikilitic texture**: In this texture the larger grain encloses smaller mineralgrains. The larger or host or house crystal is known as **oikocryst** and theenclosed crystals are known as **chadocrysts**. Poikilitic texture can be of three types:

1. **Ophitic texture**: This is the most common texture found in fine to medium grained mafic rocks like dolerite and basalts. The microscopicview exhibits that augite encloses smaller laths of plagioclase feldspar(Fig. 2.10a and b).
2. **Subophitic texture**: When the crystals of augite grains are smaller and partially enclose the plagioclase laths then the texture is known assubophitic. Ophitic and subophitic textures resulted due to nearly simultaneous crystallisation of plagioclase and pyroxene minerals that differ in their crystallisation properties (Fig. 2.10b).
3. **Hyalophitic texture**: It is similar to ophitic texture, but the difference isthat the diversely oriented plagioclase grains are completely surrounded by the glass.



Photomicrographs showing: a) ophitic, a big plate of Cpx, i.e. augite encloses laths of plagioclase, and b) subophitic texture.

b) **Intersertal/ Intergranular texture**

The mafic rocks like basalt, often shows a variety of textures depending on the mutual relationship between the grains and the groundmass, which comprise mainly plagioclase, pyroxene and glass. The volcanic glass may be replaced by secondary alteration products like palagonite. When the corners of randomly oriented plagioclase laths touch each other to form a network and the polygonal interstitial spaces are filled by granular anhedral pyroxene, the texture is known as intergranular texture (Fig.2.11). When the interlath polygonal spaces are filled-up by glass or its devitrified product, the texture is known as intersertal texture.

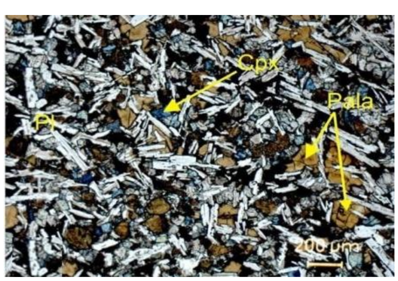


Fig. 2.11

Intergrowth Textures

Intergrowth texture results from intergrowth which means the state of interlocking of grains of two different minerals. Intergrowth texture results due to simultaneous crystallisation of two mineral components of the magma at a particular temperature or due to eutectic crystallisation of the two mineral components of magma at a particular temperature. Let us discuss.

1) **Graphic texture**: Graphic texture is commonly found in granites and results from the intergrowth between quartz and orthoclase. The quartz blebs are aligned parallel to a well-defined crystallographic orientation giving rise to theeffect of cuneiform writing on a background of K-feldspar (host). It resemblesancient German alphabets. Quartz is disposed in the form of prismatic wedge-shaped areas intersecting at an angle of about 60^o. When this textureis observed in hand specimens (Fig. 2.12), it is called **graphic texture** and when it is in a microscopic level called as **micrographic** (term used for texture observed under microscope) and the rock is called **granophyre**. Sometimes such type of an intergrowth is ultra-small and can be seen under the scanning electron microscope under high resolution.

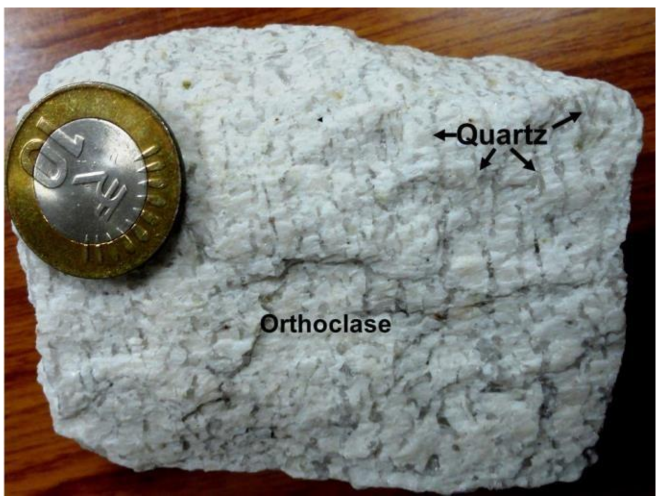


Fig. 2.12: Hand specimen of a granite showing graphic texture. Notice theelongated belbs of grey quartz in the host of white orthoclase.

2) **Myrmekitic texture:** Myrmekitic texture results from the intergrowth of quartz and plagioclase (usually oligoclase). The intergrowth of quartz is inthe form of worm-like rods within the plagioclase. It is also referred ~~as~~ to **symplectite**. It is found in some granite and metamorphic rocks.

3) **Corona texture**: It refers to those resulting from reactions in magmas andexhibit concentric arrangement of characteristic minerals. The zone of reaction products surrounding a mineral is called a **reaction rim** or **kelyphitic borders**. For example, olivine is enclosed with the rim of pyroxene. There may be a number of successive rings around the central mineral.

Miscellaneous Textures

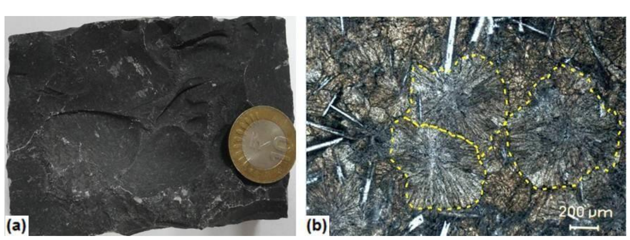
Directive/ Flow texture: The term directive indicates directional arrangements of mineral grains, indicating flows or bands. When the magmaduring the process of its crystallisation undergoes flow movement, the crystallising minerals tend to arrange themselves in a regular directive bandswhich results in a flow texture. The direction of the flow may be interrupted by early formed crystals, but the flow bands will produce stream line without distorting the bigger crystals, such texture is known as **flow texture.**

Trachytic texture: This texture is particularly observed in some volcanicrocks such a trachyte. In basaltic rock, the calcic plagioclase, glassy andcryptocrystalline material show parallel or sub-parallel alignment and preferred orientation due to flowage of magma in molten state which is referred as to **trachytic texture**.

Eutaxitic texture: This term is used for the parallel alignment of pumice fragments in welded ignimbrites which are pyroclastic rocks. Ignimbrite is formed by the widespread deposition and consolidation of ash flows. The wavy laminations swirl around volcanic lithic fragments, indicating flow pattern in the dark bands. The stretched lithic, pumice and crystal fragmentsare aligned and welded together with a devitrified, cryptocrystalline and microcrystalline groundmass.

Spherulitic texture: More rapid cooling and crystallisation of viscous magma yields spherulitic texture. Spherulitic aggregates are radiating arraysof fibrous or needle-like crystals. This texture is common in glassy felsic volcanic rocks (Fig. 2.16b).

Spinifex texture: This texture is characteristic of komatiitic rock (an ultramafic rock of volcanic origin). Spinifex texture is defined as randomly oriented, extremely fine-grained, slender hollow crystals or acicular olivinephenocryst formed by rapid cooling or quenching of ultramafic lavas.

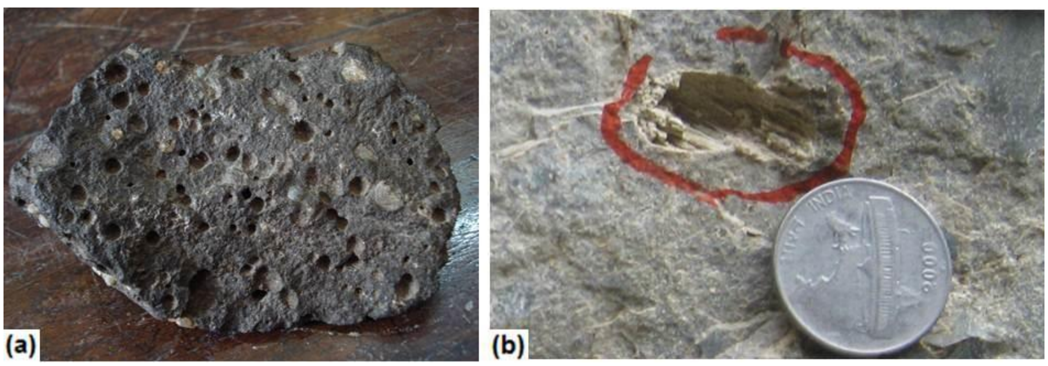


STRUCTURES OF IGNEOUS ROCKS

The term structure is very much different from texture. Structure is used for larger features of a rock, observed in the field on large outcrops like flow banding, layering, vesicles, etc. If you observe a basaltic outcrop you would describe its structure as vesicular or amygdaloidal. Even today, the petrologists use the terms texture and structure interchangeably.

Vesicular and Amygdaloidal Structures

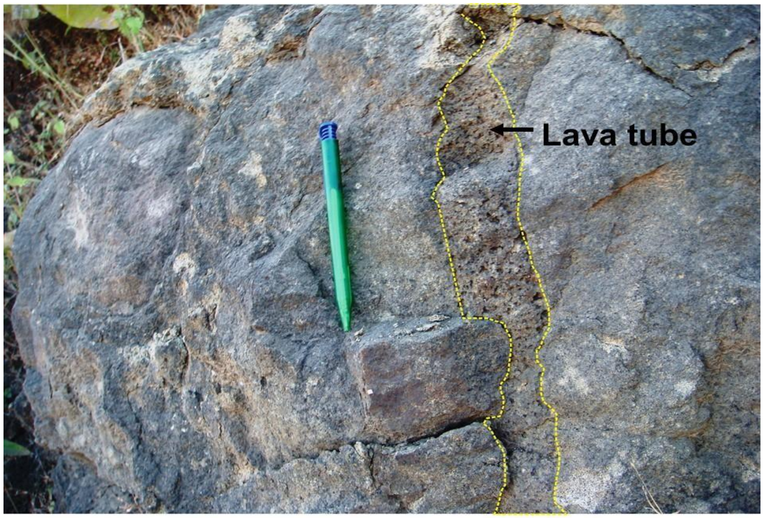
The lavas are heavily charged with gases and other volatiles. When the lava is erupted on the surface, the volatile constituents escape from the fluid with the decrease of pressure, thus forming cavities, bubbles or vesicles of variable dimensions and shapes, such as spherical, elliptical, cylindrical or irregular in shape. The individual openings are known as vesicles and the structure as a whole is known as vesicular structure (Fig. a and b). But, if the vesicles are filled-up by some low temperature secondary minerals such as quartz (Fig. a), calcite (Fig. b), zeolite, chalcedony it is termed as amygdale.Volcanic rocks containing amygdales are said to have amygdaloidal structure. They are called so because their shapes sometimes suggest resemblance to almonds.



Volcanic rock showing vesicular and amygdaloidal texture: a) Noticevesicles and vesicles filled-up with quartz; and b) Vesicular cavity is filled-up with calcite crystal, encircled with red.

Scoriaceous and Pumiceous Structures

Lava which is heavily charged with volatiles and gaseous constituents, on consolidation and cooling gives rise to 'scoria' and the resulting structure is called **scoriaceous structure**. Scoria is a clinkery looking extrusive, highly vesicular basalt. If the vesicles are so abundant that they make up over 50% ofthe rock and the rock has a density greater than 1, then the rock is said to be scoriaceous. **Pumice** is a volcanic rock containing numerous irregular shaped cavities or vesicles that remain after trapped volatiles escape from the cooling lava. Such structures are characteristic of highly siliceous lavas because they are highly charged with volatiles. If vesicles are so abundant that they make up over 50% of the rock and the rock has a density less than 1 (i.e. it would float inwater), then the rock is known as pumiceous. Vugs are angular cavities in a rock formed by collection of volatile fluid between existing crystals the resulting structure is known as **vuggy structure**.



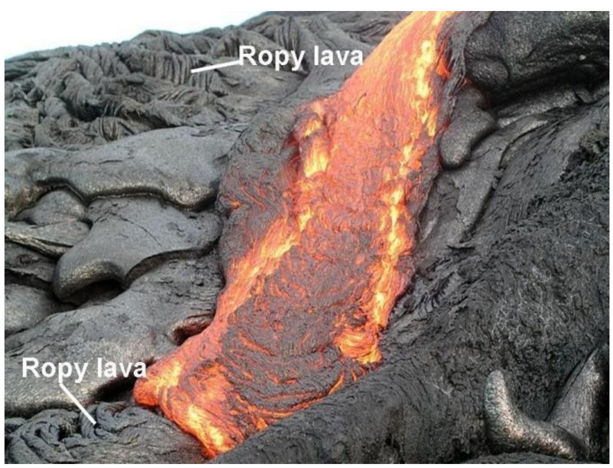
Lava Tunnel

On cooling and consolidation of lava, the enclosed fluid lava drains out through some channel ways known as lava tunnel. The hardened basaltic flows commonly contain cave-like tunnels called lava tubes that are supposed be conduits carrying lava (Fig. 2.18). These conduits develop in the interior of a flow where temperatures remain high long after the molten material on the surface hardens. Lava tubes are important features because they serve as insulated pathways that facilitate advancement of lava to great distances from its source.

Blocky and Ropy Lava

They are two different appearances represented by lava flows. The surface is covered with the mass of rough jagged, angular blocks of all dimensions with dangerously sharp edges and spiny projections. This is known as blocky lava or 'aa' structure. On the other hand, very mobile lavas solidify with comparatively smoother surface often highly glazed which exhibit wrinkled, ropy or corded forms that often resemble with the twisted braids of ropes. The structure is known as ropy lava is also called 'pahoehoe' (Fig. 2.19). Blocky and ropy lava flows as described above are known by their Hawaiian names,

i.e. aa and pahoehoe flows. Pahoehoe means "on which one can walk." Both the lavas can erupt from the same vent. However, pahoehoe lavas form at higher temperatures and contain more fluid than aa lava flows. Apart from this pahoehoe lava flow can change into an aa lava flow, although the reverse doesnot occur.



Platy and Sheet Structure

The development of different set of parallel partings or joints giving rise to plates of rock mass, often intersected by closely spaced, irregular joint planes or surfaces is known as platy structure. The development of one set of well- defined horizontal joints or surfaces is known as sheet structure.

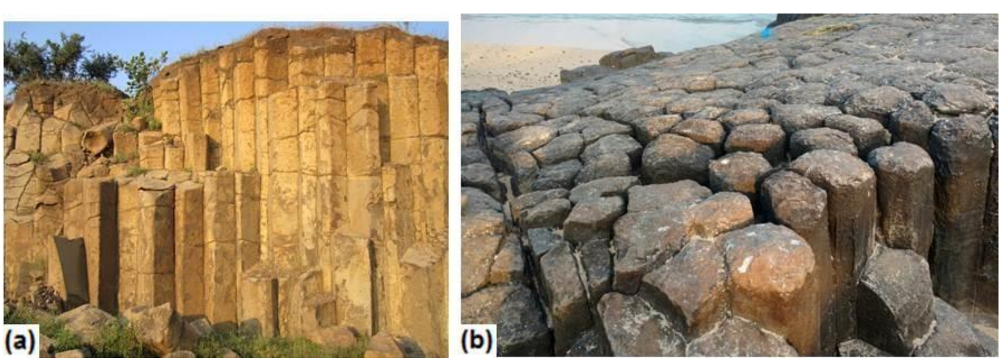
Pillow Lava

This is a peculiar ellipsoidal pillow-shaped structure (Fig. 2.20), which occurs mostly in basic/mafic lavas. Such types of lavas appear as pile of small masses like pillows or cushions. They are produced by extrusion of lava under water logged sea water or sediment, rain-soaked air or beneath the ice-sheets.

Pillows generally have a vesicular crust or glassy skin. Chilled margins develop at the peripheral portion of pillow due to sudden cooling.

Columnar/Prismatic Structure

When the uniform cooling and contraction in a homogeneous magma takes place, the parting planes tend to take on a regular columnar or prismatic form (Fig. 2.21a and b) which is characterised by four, five or six sides. Columnar structure is formed due to the development of centres of nucleation- contractions at equally-spaced intervals on the cooling surfaces.



Lava Flow Structure

The eruption of lava on the surface faces difficulty in movement due to viscosity. This results in the formation of dissimilar elongated lenticular patches arranged parallel to the flow of the lava. This is known as directional or flow structure.

Flow structures in rhyolite

Rift and Grain

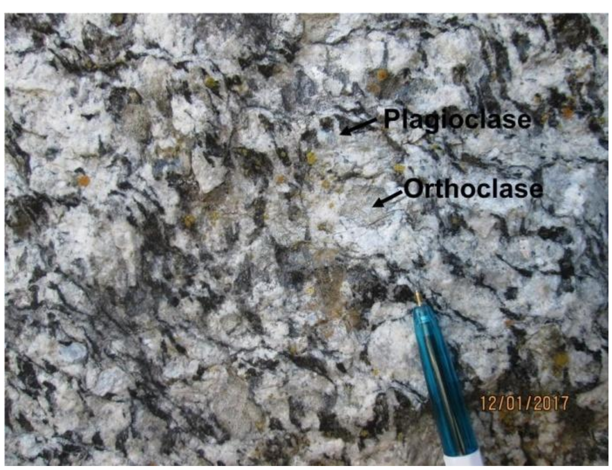
These structures developed due to three sets of mutually perpendicular, equally spaced joints, producing cubical blocks known as mural jointing. This rift and grain structure is taken into advantage by quarrymen to dress down big blocks of granite into smaller ones.

Perlitic Structure

This refers to produce spherical balls having a pearl-grey luster. The concentric shelly cracks formed by rapid cooling of viscous lava or magma.

Rapakivi Structure

Rapakivi is a term derived from the Finnish language which means ‘rotten or crumbled stone’. This term is used for rounded crystals of potassic feldspar mantled by white rims of sodic feldspar. They consist of orthoclase crystals as large as 4 cm in diameter in fine grained mantled plagioclase. Mostly this structure is found in granitic rocks.

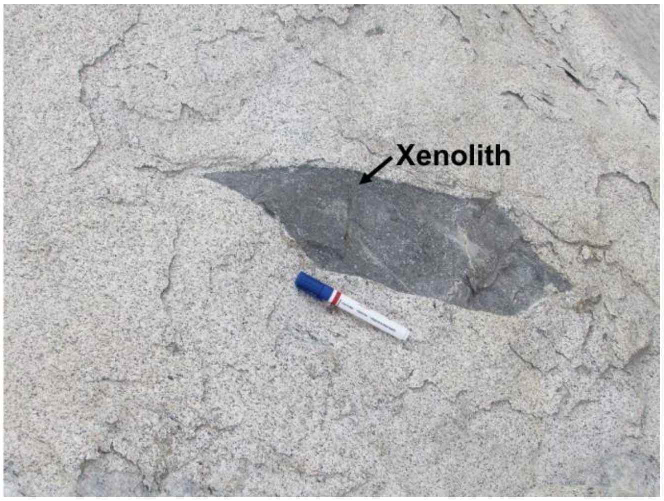


Rapakivi structure where large orthoclase ovoids mantled byplagioclase.

Xenoliths

Xenolith is an accidental foreign rock fragment trapped in another rock of igneous origin (Fig. 2.24). Xenolith itself may be igneous, sedimentary or metamorphic in origin. The term xenolith literally means 'foreign rock' but, some xenoliths are not entirely foreign to their hosts. They may be genetically related and known as cognate because both of them may have crystallised from the same magma. The unrelated xenoliths are always older than their host rocks because they existed before the magma around them was solidified.

Xenocrysts differ from the xenoliths. Xenolith is the term used for rock fragment, whereas, xenocryst refers to individual mineral fragment. The xenocryst term is used for the crystals that was accidentally incorporated in the magma and preserved in partly resorbed state. They can have foreign source or can be derived from the same country rock. Cognate are the xenocrysts genetically related to the enclosing rock.



Basaltic xenolith in granite.

STRUCTURES OF SEDIMENTARY ROCKS

Structures of sedimentary rocks formed by the deposition of sediments or fragments by the process of ETD

Sedimentary structures are classified into different types based upon the deposition of sediments they are

1. Stratification
2. Graded bedding
3. Cross bedding
4. Ripple marks
5. Mud cracks
6. Rain drop marks
7. Cast and mould
8. Tool marks
9. Track and Trails
10. Burrow marks

Stratification

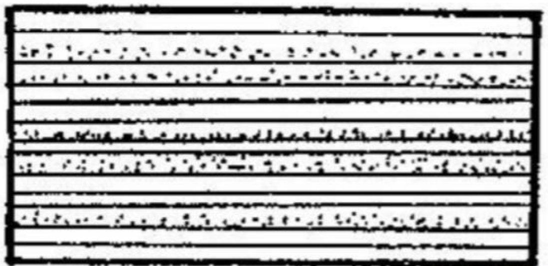
Stratum- bed Strata- Series of beds

Stratification is defined as the deposition of sediments or fragments in the series of beds.

These beds having different in mineralogy, clast size, degree of sorting and color of the different layers.

Thickness of beds are very less is called "Lamination"

Beds/strata/bedding planes

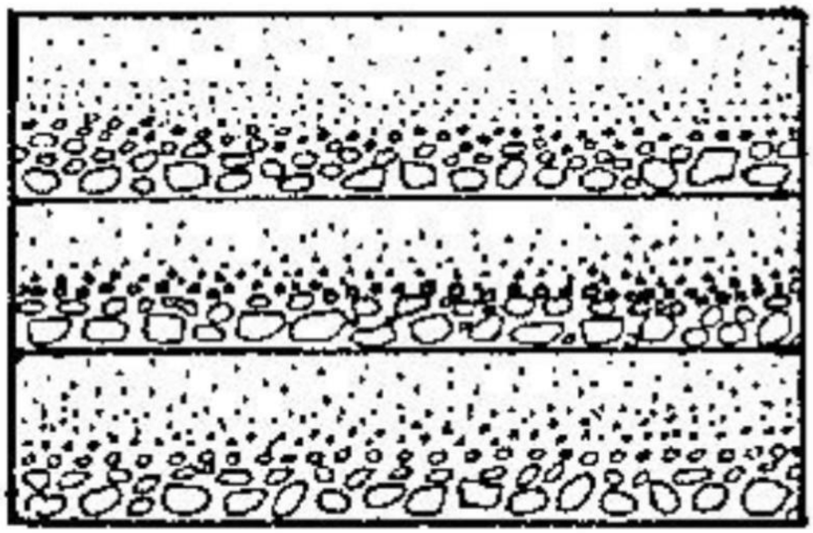


Graded Bedding

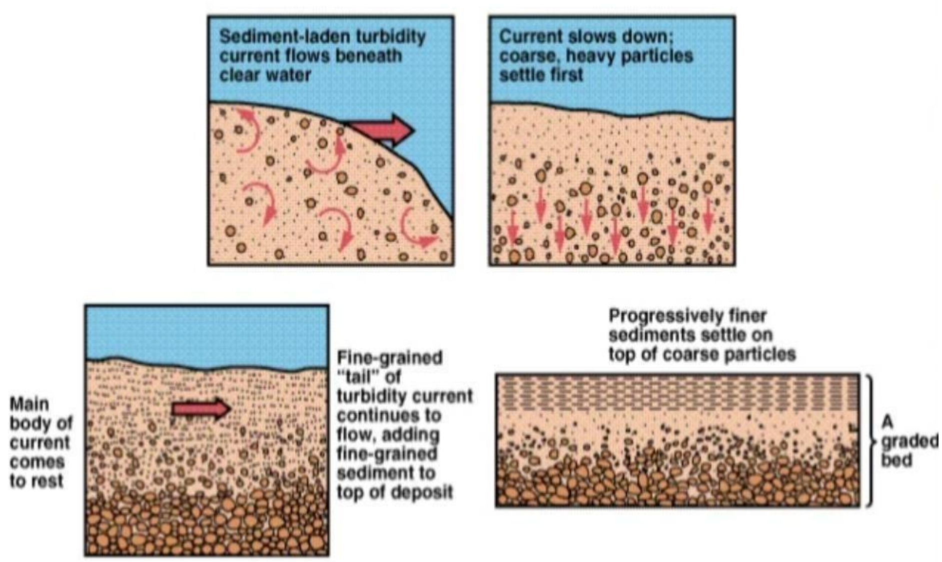
The velocity of the transporting agent decrease the larger or more dense particles are deposited first, followed by similar particles

The bedding showing a decrease in grain size from the bottom of the bed to the top of the bed.

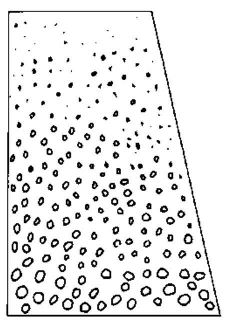
Graded bedding



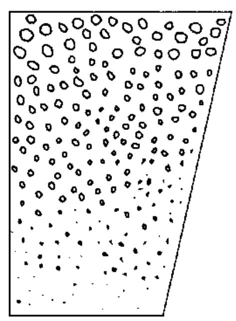
Development of Graded Sediment Bed



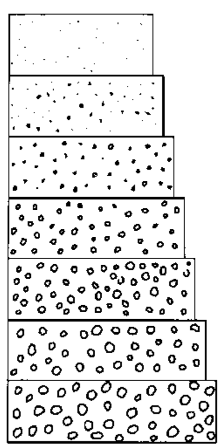
A Graded Bed



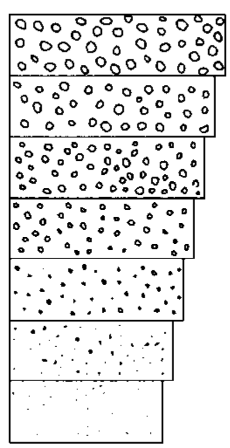
Normal grading in a bed



Reverse grading in a bed



Fining-up of a series of beds

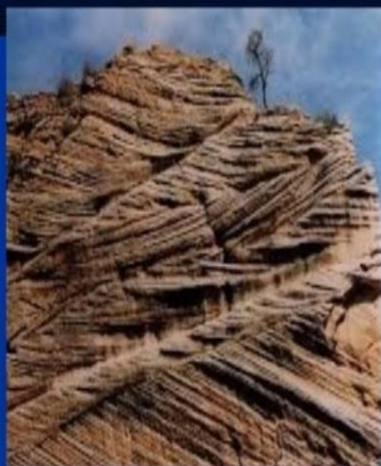


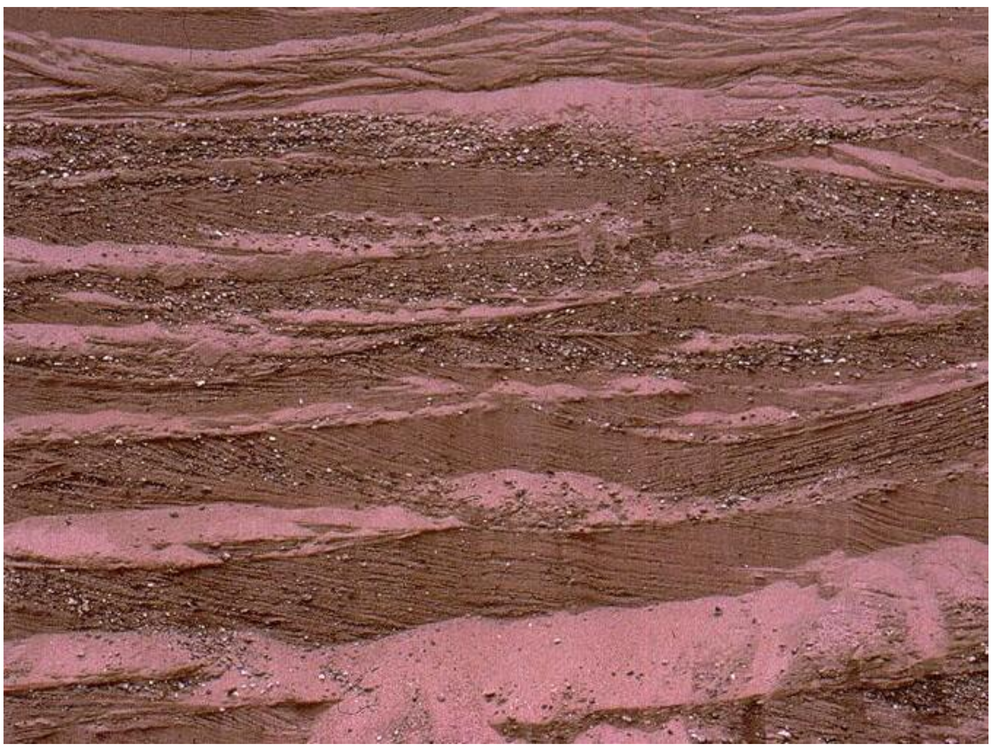
Coarsening-up of a series of beds

Cross Bedding

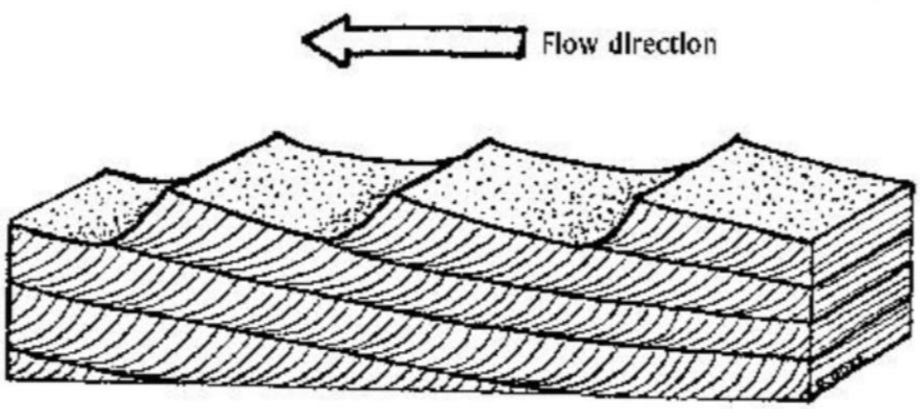
Consists of set of beds that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition.

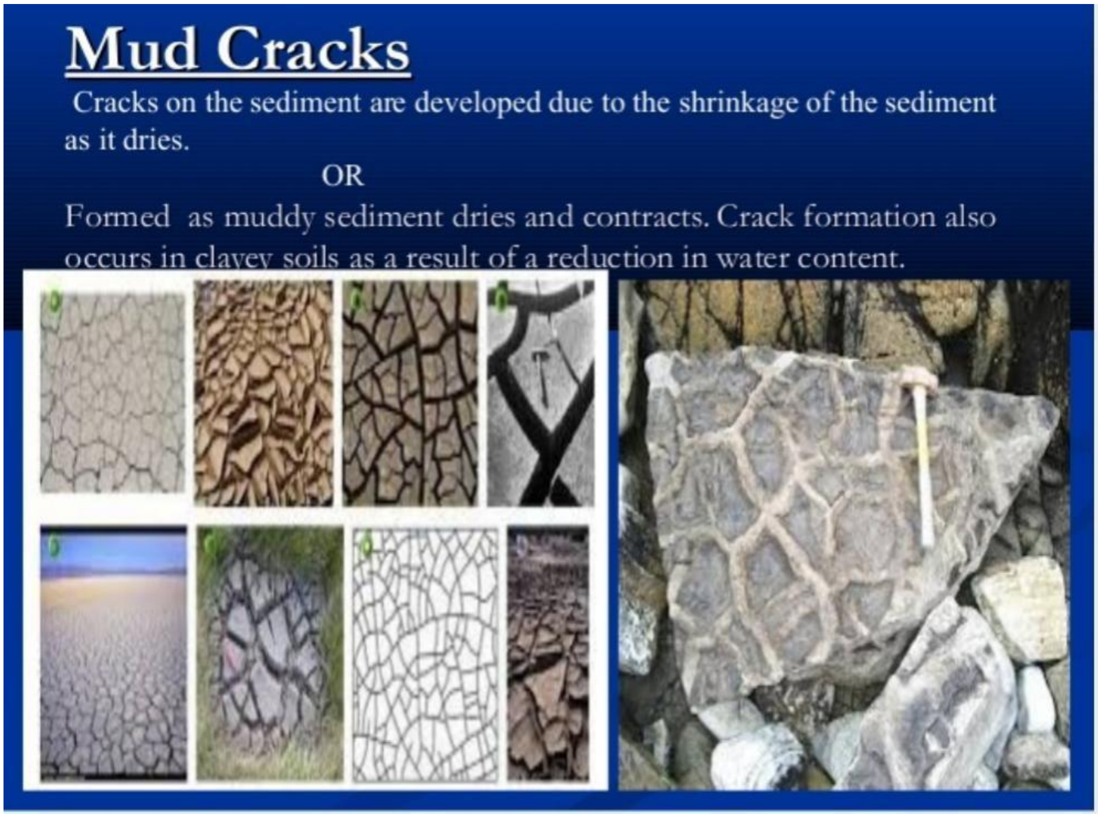
Crass bedding very common in beach deposits, sand dunes, river deposits.



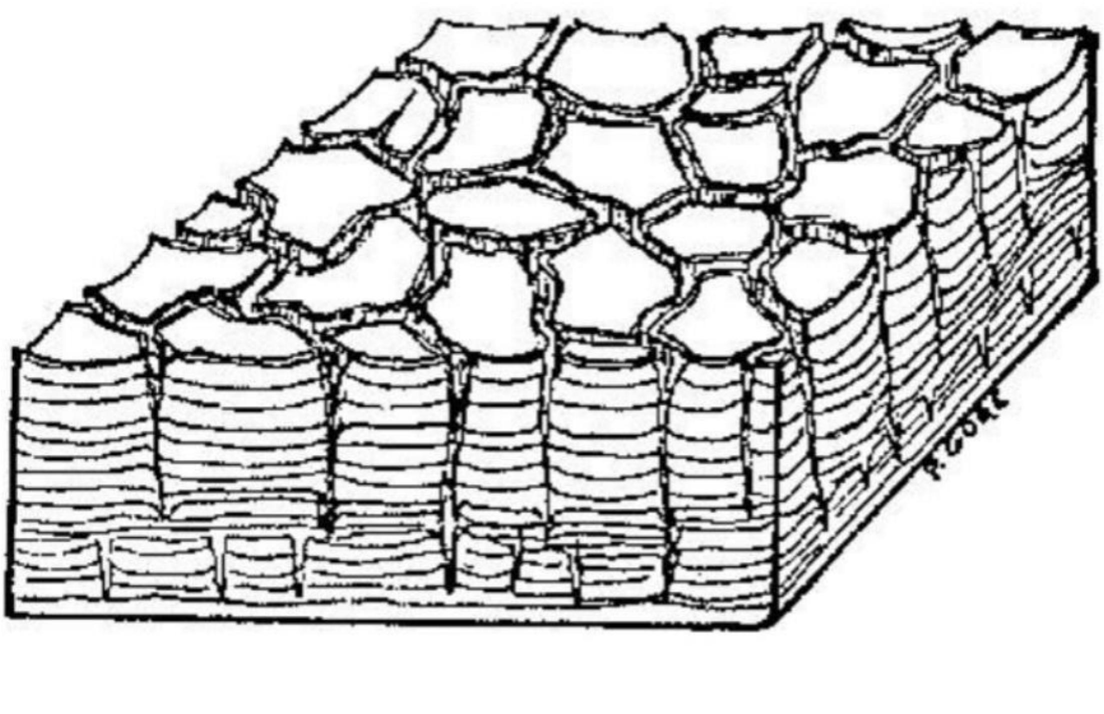


Ripple marks and cross bedding





Mudcracks/dessication marks



Cast and Molds

Any depression formed on the bottom of a body of water may become a mold, later get deposited into the depression and will acquire the shape of that depression called cast.

The body of sediment that gets the shape of the mold is cast.

Tool Marks

Scratch marks on the bottom of the water resulting due to any object carried along by currents are called tool marks.

Rain prints or rain drop points

Pits created by falling rain

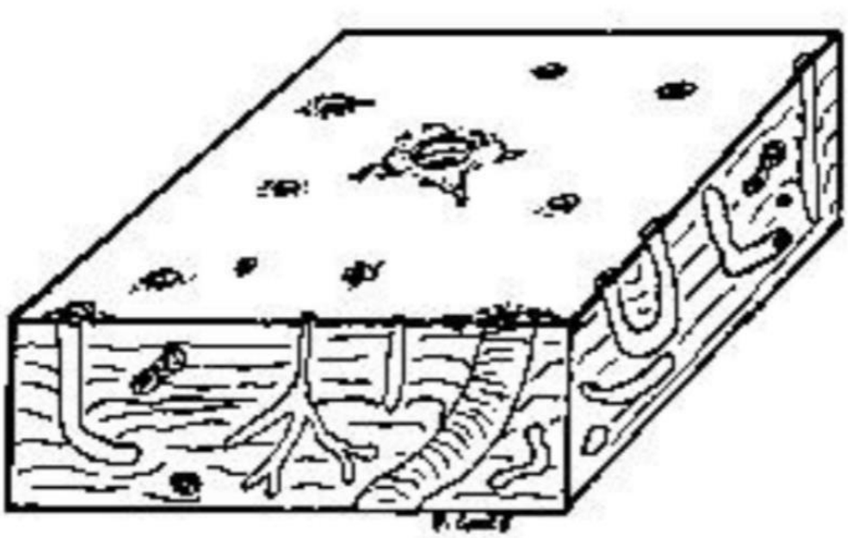
Tracks and Trails

These features are formed when organisms move across the sediment as they walk, crawl or drag their body parts through the sediment.

Burrow marks

Formed by any organism that burrows into sediment.

Burrows and rootlets



Metamorphic Structures

Texture or fabric = small-scale features that are penetrative (occurs in virtually all of the rock body at the microscopic level).

• Structure = larger-scale features; found in hand-sample, outcrop, or regional scale.

• Microstructure = advocated term (instead of texture) for microscope-scale features.

Texture: Is a term that describes the size, shape and orientation of the grains constituting a rock, as well as the relationship between these grains.

Structures of metamorphic rocks (macrotextures):

(i) Slaty cleavage: A pervasive, parallel foliation (layering) of fine-grained platy minerals (chlorite) in a direction perpendicular to the direction of maximum stress. It produces the rocks slate and phyllite.

(ii) Schistose: A schist has a lepidoblastic foliation if this foliation is defined by oriented micas, and a nematoblastic foliation if such a foliation is defined by the orientation of prismatic minerals as amphiboles and pyroxenes.

(iii) Gneissic: A complex banded texture made of schistose layers or bands alternating with bands commonly characterized by a granoblastic texture.

(iv) Granoblastic: granular, interlocking equidimensional grains of subequal size; no preferred orientation or cleavage.

(v) Hornfelsic: Fine-grained, granular interlocking grains, possibly of variable shapes and sizes. No preferred orientation.

(vi) CataclasticCataclastic Structure

• produced under stress and in absence of high temperature, whereby rocks are subjected to shearing and fragmentation.

• Only the durable mineral partly survive the crushing force and the less durable ones are powdered.

• Thus, when resistant minerals and rock fragments stand out in a pseudo porphyritic manner in the finer materials, it is known as 'porphyroclastic structure.' Phenocrysts are called 'porphyroclasts'.

• Argillaceous rocks develop slaty cleavage, harder rocks may be shattered and crushed forming crush breccia and crush conglomerate.

• When the rocks are highly crushed into fine grained rocks, they are known as mylonites. Since these structures are formed due to cataclasis, they are, as a whole, known as cataclastic structure

CHAPTER -3

STRUCTURAL GEOLOGY

Structural geology is the study of the internal structure and deformation of the Earth's crust. Structural geologists use a variety of techniques, including field observations, mapping, geophysical methods, and laboratory experiments, to study the way in which rocks are deformed and the processes that control deformation.

Structural geology is an important field because it helps us understand the processes that shape the Earth's surface, such as mountain building, faulting, and folding. It also has practical applications in fields such as civil engineering, where the characteristics of rocks and the forces that act on them are important for the design of structures such as bridges and buildings.

Some of the main topics studied in structural geology include:

1. Faults and fractures: the characteristics and behavior of fractures in rocks, including the types of movements that occur along them and the processes that control these movements.
2. Folds: the characteristics and behavior of folds in rocks, including the types of folds that occur and the processes that control their formation.
3. Stress and strain: the forces acting on rocks and the way in which they deform in response to these forces.
4. Rock deformation: the processes that cause rocks to deform, including plastic deformation and brittle deformation, and the mechanisms by which these processes occur.
5. Tectonics: the study of the large-scale movements of the Earth's crust, including the forces that drive these movements and the effects they have on the Earth's surface.

What is structural geology ?

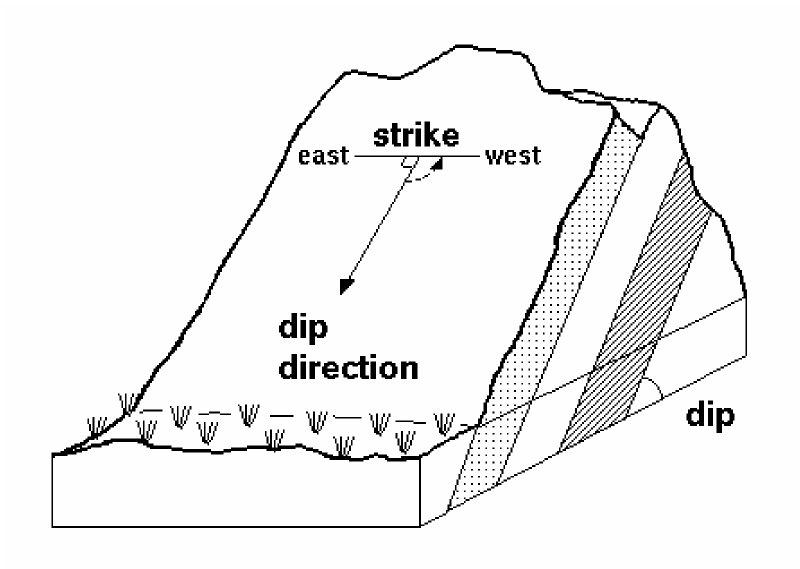
It is the branch of geology that studies the 3D geometry from micro to macro scale of rocks to explain the deformation processes the rocks experienced since their origination.

It introduces the physical side of Geological Sciences and emphasizes:

- **Geometry** (shape, orientation, position, size, etc.)
- **Motion** (beginning and ending positions and paths of particles and bodies—deformation or change in geometry)
- **Mechanics** (explanations of why the geometry and motion are asthey are)

STRIKE AND DIP

The term dip and strike apply to any structure and together their values constitute a statement of the attitude (orientation) of the plane in space. The planer feature most frequently encountered in many areas is the bedding plane; it is also the one dealt with most in beginning structural geology. Other features representing the plane are Joints and faults.



STRIKE - The bearing of the line of intersection of plane and horizontal plane is called strike. Bearing is the horizontal angle between a line and a specified coordinate direction, usually true north.

DIP – The inclination of the line of greatest slope of an inclined plane. It is measured perpendicular to strike. The amount of inclination of plane with respect to horizontal plane is called amount of dip and the geographical direction in which the plane is inclined is called the direction of dip.

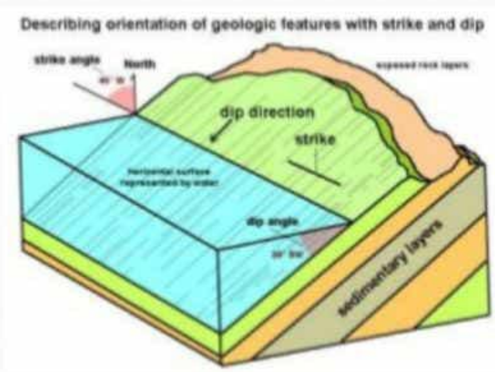
A bed will be used in this description. For a recently created flat bed it would have a dip of 0° and a directionless strike. When it is tilted it gains a direction. The bed is usually not homogeneous since it usually folds when tilting, fractured, or compressed. A strike of 000° means the bed is dipping east; 090° for south; 180° for west; and 270° for north. A dip of 0° means its flat and 90° for a vertical bed.

Dip

- It means slope or inclination.
- The angle of inclination of a bedding plane with horizontal plane is called amount of dip.
- The direction along which the inclination of the bedding plane occurs, is called dip direction.
- So dip is expressed both as amount and direction.
- The direction angle is measured with clinometer.
- The direction is measured with a compass.

Strike

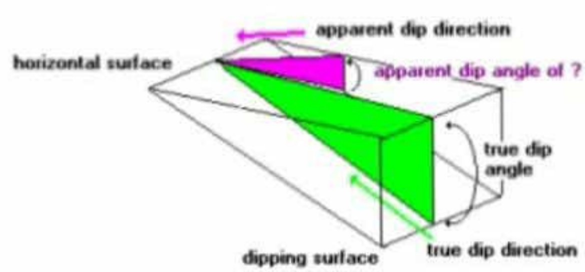
- It's defined as the direction of a line formed by the intersection of a bedding plane and a horizontal plane.
- It's always at right angle with the true dip direction.
- It is a horizontal line on a surface of rock beds.



True Dip and Apparent Dip

- Dip is always between 0 and 90°
- True dip is measured in vertical plane that is perpendicular to strike line
- Apparent dip is measured in vertical plane that is at arbitrary angle to strike line
- Apparent dip is always less than True Dip

- The true dip is the maximum angle, which an inclined bed makes with the horizontal. It is measured at right angles to the strike.
- If the angle measured in any direction, it will have value less than the true dip, which is known as apparent dip.
- The inclination of bed to the horizontal in any other direction than the direction of true dip- apparent dip.



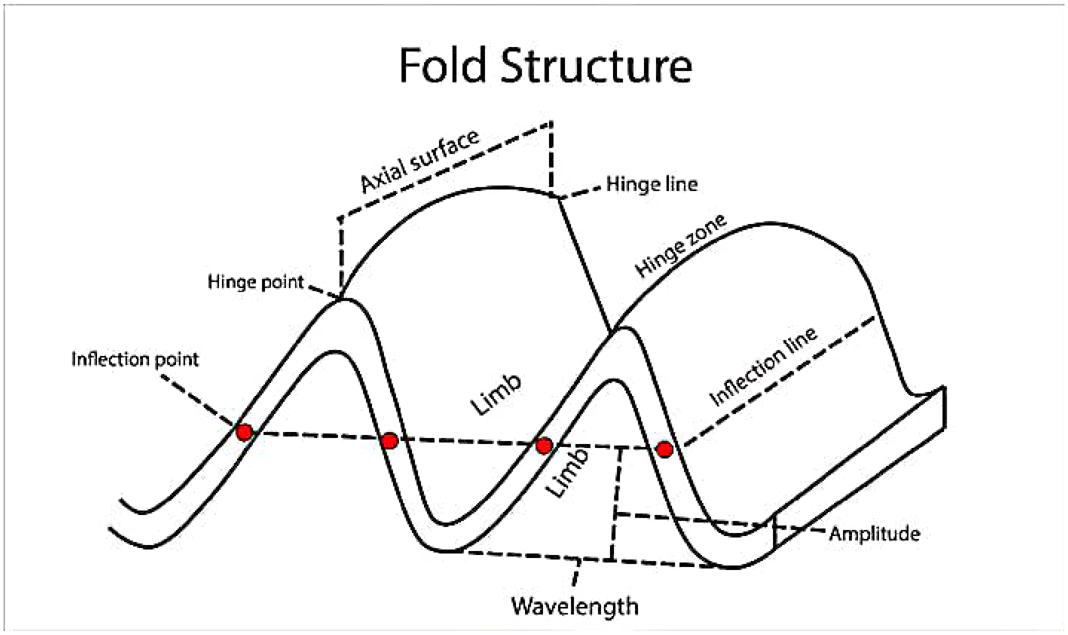
Fold and its types

- ✓ ***Folds may be defined as the undulations or bends or curvatures developed in the rocks of the crust of the earth as a result of stresses to which these rocks have been subjected from time to time in the past history of the earth***
- ✓ Folds may occur in various dimensions,eg few cm long or runs for thousands of km
- ✓ Bend of the fold may be gentle or steep, this depends upon the
  - Strength of the forces involved ,Ability of the rock to resist being deformed, Arrangement of rock layers, Nature of movement that causes the folding
- ✓ The process of development of folds in the rocks is called ***FOLDING***

PARTS OF FOLD

1. **Limbs:**
   - Sides of a fold
2. **Hinges**
   - The maximum curvature point (where one limb ends and other limb starts) of fold is called as hinge
   - When rocks occur in a sequence and their all hinge points are joined together, they make a line, called the hinge line.
3. **Axial surface**
   - When hinge line is traced throughout the depth of the folded sequence a surface is obtained which may be planar or non- planar. It is referred to as axial surface.

4. **Axial Plane**
   - It is the imaginary plane containing all the hinges of a fold
5. **Axis of fold**
   - It is defined as a **line drawn parallel to the hinge line of a fold** or it is the line representing the intersection of axial plane of a fold with any bed of the fold.
6. **Plunge of a fold**
   - The **angle of inclination of the fold axis with the horizontal** as measured in a vertical plane is termed as the plunge of the fold
7. **Crest and trough**
   - The line running through the highest points in an up arched fold defines its **crest.**
   - Line running through the lowest points in a down arched fold makes its **trough...**



CLASSIFICATION OF FOLDS

- Most of the folds may be simple or complex modification of two basic types of folds: **Anticlines** & **Synclines**

1. **Anticlines**
   - The strata are up-arched, these become **convex upwards**
   - Geologically older rocks occurs in the interior of the fold, oldest at the core of the fold and the youngest at outermost flank.
   - The limbs dip away from each other at same angle or in same direction at different angle w.r.t axial plane
   - Symbolically it is indicated by: ←•→
2. **Synclines**
   - These folds are reverse of anticlines.
   - The strata are down-arched, these become **convex downwards**
   - Geologically younger rocks occur in the core of the fold and the older rocks form the outer flanks
   - The limbs dip towards a common center
   -
   - Symbolically it is indicated by: →•←

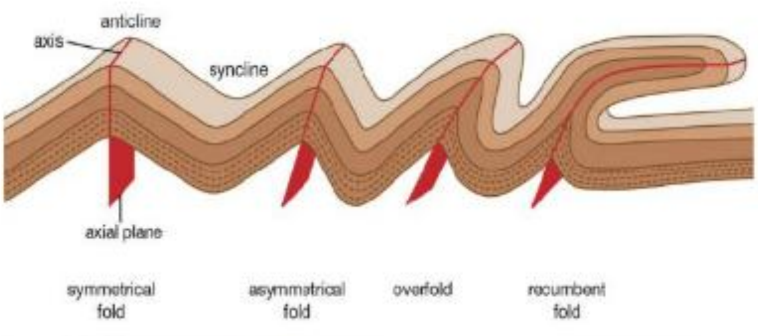
Classification based on Position of axial plane

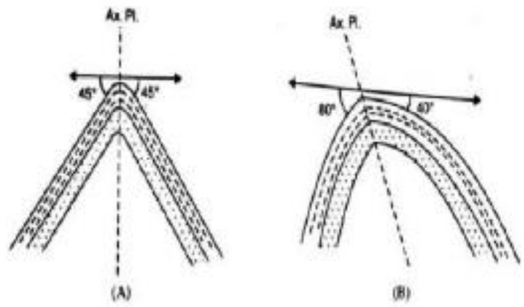
1. Symmetrical folds

These are also called normal or upright folds. In such a fold, the axial plane is essentially vertical. The limbs are equal in length and dip equally in opposite directions

2. Asymmetrical folds

All those folds in which the limbs are unequal in length and these dip unequally on either side from the hinge line are termed as asymmetrical folds.





Anticlines–Symmetrical and Asymmetrical

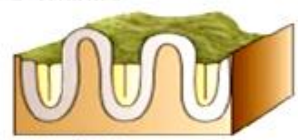
3. Overturned folds

These are folds with inclined axial planes in which both the limbs are dipping essentially in the same direction. The amount of dip of the two limbs may or may not be the same.

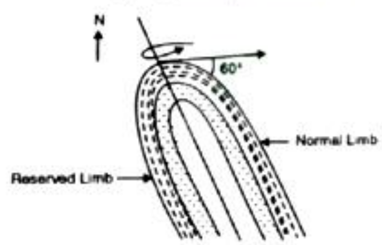
Overturned

4. Isoclinal folds

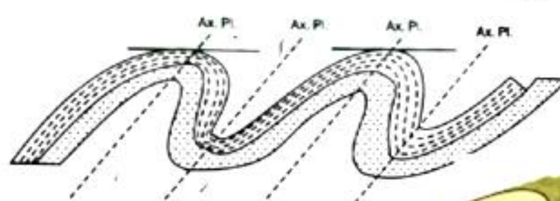
These are group of folds in which all the axial planes are parallel, meaning that all the component limbs are dipping at equal amounts.



Isoclinal



Overfold



Isoclinal Folding

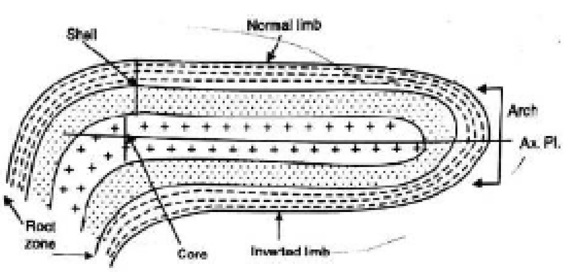
5. Recumbent folds

In these folds axial planes acquires almost horizontal attitude.

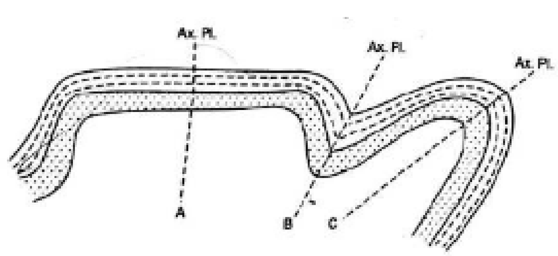
Recumbent

6. Conjugate folds

Pair of fold that may have mutually inclined axial planes are called conjugate folds.



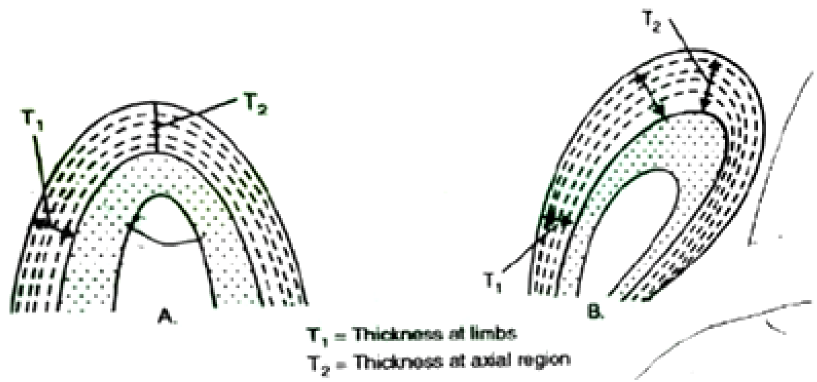
Recumbent Fold



Conjugate Folding

Classification based on degree of compression

- Layers of rocks may be compressed only slightly or very severely during the process of folding depending upon the intensity of forces acting on the rocks.
- In the first case, a bend or fold may be caused without causing any appreciable variation in the thickness of the rock anywhere **(Open fold)**
- But, when folding is due to very severe forces, the process may actually involve plastic movement of the rock masses resulting in thinner limbs and thicker crests or troughs **(Closed folds).**



Classification based on behaviour with depth

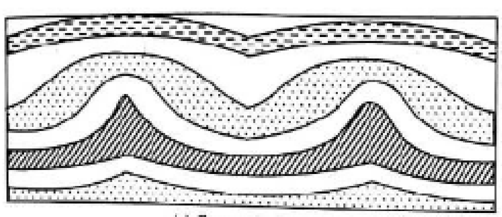
1. Concentric folds

The thickness of the involved layers remained uniform and constant even after folding.

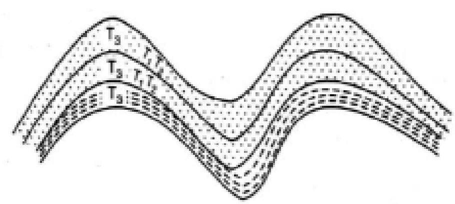
2. Similar folds

The folds in which the degree of folding is observed to be similar for indefinite depths are grouped as similar folds.

These folds have thin limbs and thick crest & trough



(a) Concentric folding.

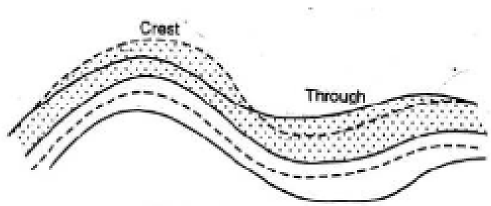


(b) Similar folding.

3. Supratenuous folds

These are folds showing differences in thickness at the crestal and trough regions

They are not induced by folding process but essentially being due to erosional and depositional processes operating in the folded regions.



(c) Supratenuous folding.

Classification based on Relative curvature

On the basis of relative curvature in the outer and inner arcs of a fold:

1. **Class 1 folds:**

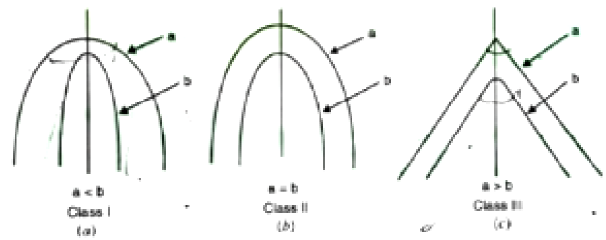
The folds in which degree of curvature in the outer arc of the fold is less than that of the curvature of the inner arc

2. **Class 2 folds**

All those folds in which degree of curvature of the inner and outer arcs are equal

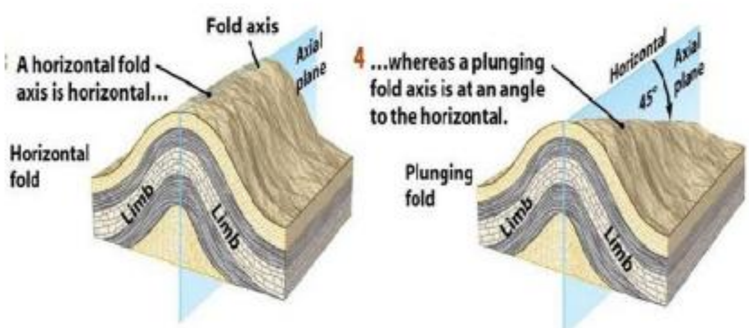
3. **Class 3 folds:**

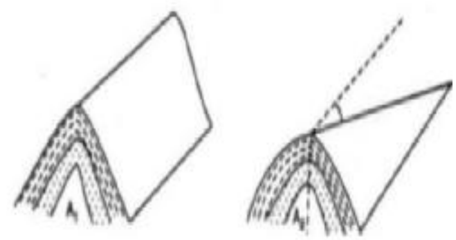
Degree of curvature of the outer arc is greater than that of inner arc



Classification based on plunge

1. **Plunging fold:** in which fold axis is not horizontal
2. **Non-plunging:** fold axis is horizontal

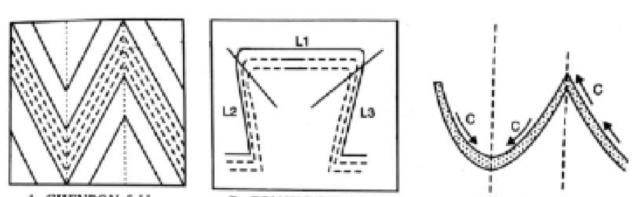




Classification based on the profile of fold surface

Shape of the fold is made a convenient basis for classification of folds.

1. **Cheveron folds:** These are characterized with well- defined, sharp hinge points and straight planar limbs.
2. **Conjugate folds:** These are composite folds characterized with 2 hinges 3 planar limbs in which the central limb is exceptionally flattened.
3. **The cylindrical folds:** resemble sections of pipes and have very well defined axes of folds repeated parallel to each other



A. CHEVRON fold (Limbs – Planner) Hinge – Acute

B. CONJUGATE fold (Three planner limbs) and two hinges

C. CUSPATE fold (Inner surfaces concave) upward – anticline and downward – syncline

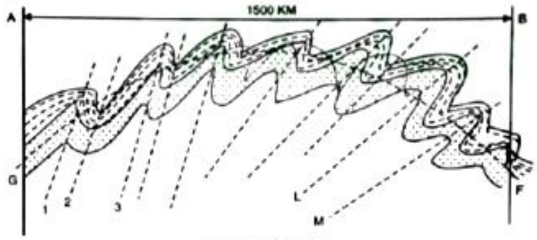
Classification based on mode of occurrence

1. Anticlinorium:

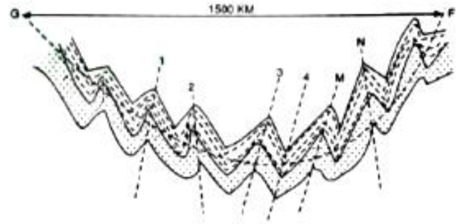
- It is system of exceptionally large sized folds running often for several hundred in length and several kilometers in width.
- It is anticlinal in nature, i.e. the strata as a whole have been up arched.

2. Synclinorium:

- It is the reverse of anticlinorium and may be defined as an extensive system of folds having a clearly down-arched folding trend.



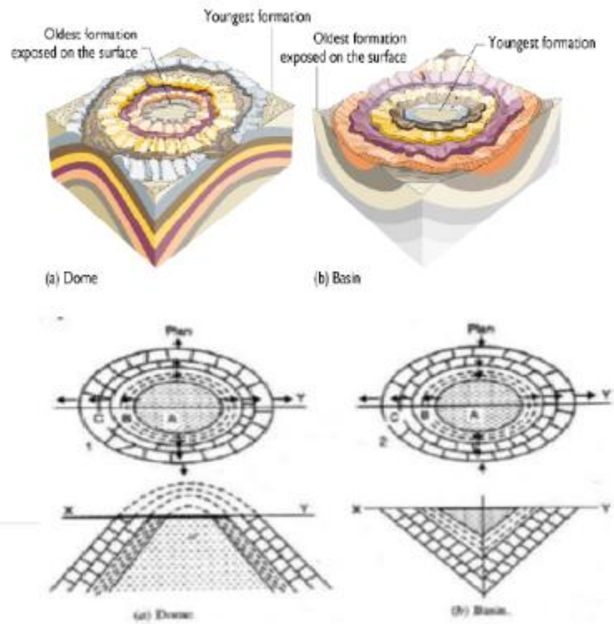
A-B Anticlinorium



G–F Synclinorium
GF = General Fold Line 1-2-3 etc. Indicate Local Axial Planes

3. Domes and basins

- **Domes** are a group of strata centrally uplifted in such a way that seen from the top, these **dip away in all directions. Older rocks occurs in center**
- **Basins** are the reverse of the domes and may be defined as a group of strata that are centrally depressed in such a way that the involved layers **dip towards a common central point** from all sides. **Younger rocks occur in center**



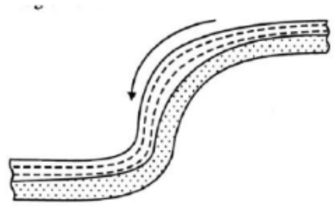
Miscellaneous types

1. Monocline

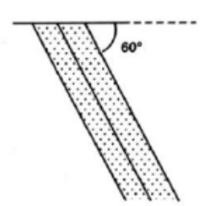
In this a single bend for a limited length and attain the horizontal attitude once again.

2. Homocline

Here, strata dipping in the same general direction at a uniform angle, especially when such structure is established to be a limb of a major fold.



Monocline



Homocline

FAULTS AND FAULTING

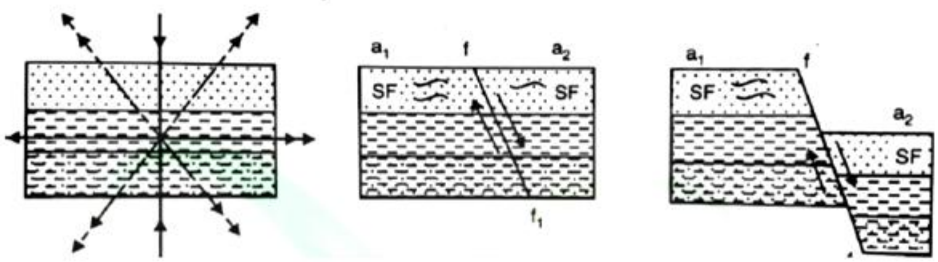
- Those fractures (cracks) along which there have been relative movement of the blocks past each other are termed as faults.
- Fault is always a crack or surface of rupture or a simple fracture surface.
- The entire process of development of fractures and displacement of the blocks against each other is termed as FAULTING.

Development of faults

A. A sequence of 3 layers of rocks occurring somewhere within the earth comes under the influence of stresses

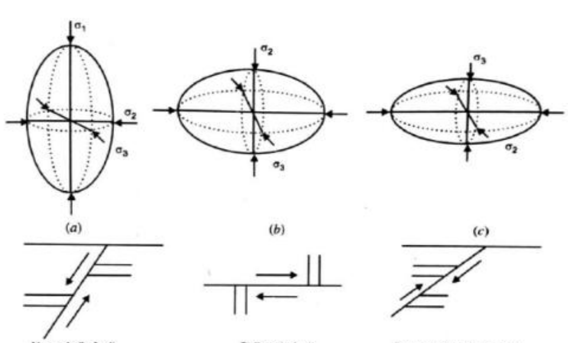
B. The stresses produces a **fracture *ff₁*** dividing the original layers into 2 distinct parts: $\mathbf{a_1}$ **&** $\mathbf{a_2}$.

C. Under the influence of the same stresses or others developing subsequently, the block a_2 is moved down-slope



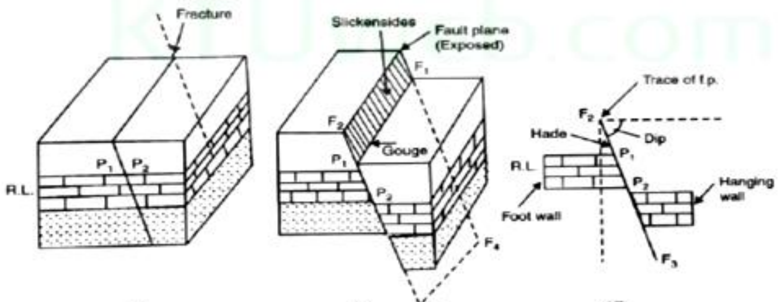
CAUSES OF FAULTING

- Faults are generally caused under the influence of stresses acting upon the rocks of the crust of the earth.
- Any rock on or below the crust may withstand all the operating stresses up to a limit, which depends upon its cohesive strength and internal friction.
- But when that limit is crossed by the operating stresses, the rock yields by fracturing or breaking along certain directions.
- Immediately after the development of these fractures, the blocks created along the fractures suffer sudden displacement along those fractures under the influence of the same stresses that caused the fracturing of the rocks.
- Depending upon the magnitude and direction of the stresses the faults may be of different types. These are shown in the figure.



Relationship Between Principal Stresses and Type of Faulting.
(a) Maximum Principal Stress σ_1 is vertical. (b) Intermediate Principal Stress σ_2 is vertical.
(c) Least Principal Stress σ_3 is vertical.

SOME IMPORTANT PARTS



1. **Fault plane:**

- Fault plane is the planar surface of fracture along which relative displacement of the blocks takes place during the process of faulting.
- When it is not planar, the same surface is simply described as fault surface.

2. **Dip and Hade**

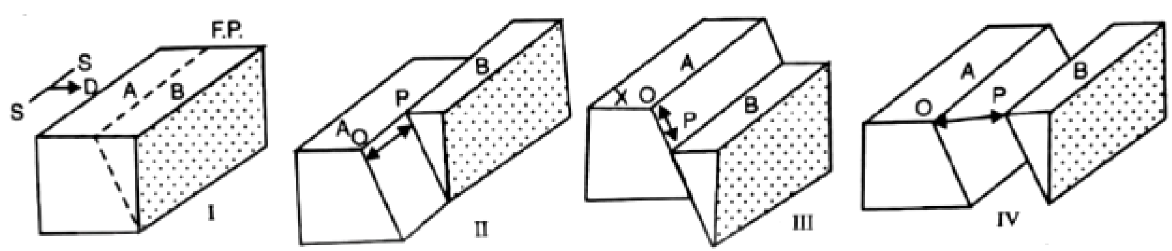
- Fault plane may be vertical, horizontal or inclined at any angle with the horizontal.
- The **dip** of the fault is its inclination with the horizontal.

3. **The walls**

- The blocks which have suffered displacement along the fracture are conveniently called **walls.**
- The term **hanging wall** is used for that faulted block lies on the upper surface of the fault plane (although it may be at a lower elevation compared to the other block, the foot wall)
- The term **foot wall** is used for that faulted block which lies on the under surface of the fault plane

4. **Slip and separation**

- The **slip** is defined as a relative displacement of any 2 points as measured along the fault plane. It may be expressed in mm, m or even km
- Types of slip
  - (a) In the **dip slip**, the displacement has essentially taken place along the dip of the fault.
  - (b) In the **strike slip** the displacement has occurred along the direction of the strike of the fault
  - (c) If the displacement takes place oblique to both these directions it is called **oblique-slip**



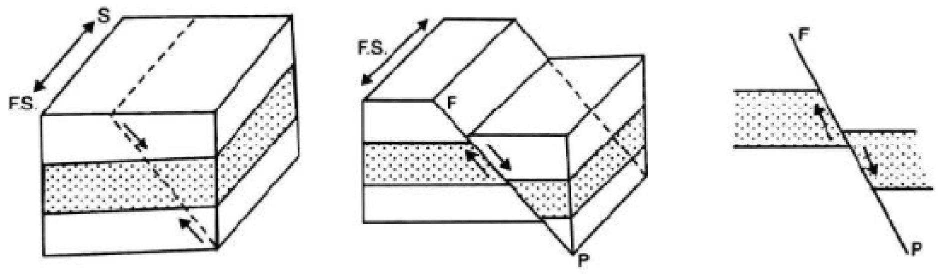
Slip and Separation
I–Before faulting; II–Strike slip; III–Dip slip; IV–Oblique slip

CLASSIFICATION OF FAULTS

Classification Based on the apparent movement

Based on apparent movement of disrupted blocks along the fault plane,

1. **Normal faults**
   - Fault in which **hanging wall has apparently moved down with respect to foot wall** is called Normal fault. That is when the fault satisfies the definition of hanging wall standing at a lower position with respect to the foot wall it is called normal fault.



(a) (b) (c)

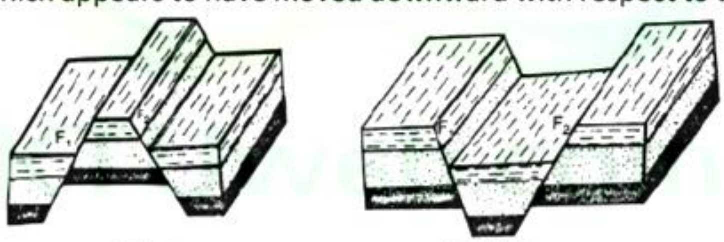
Normal Faulting

- It may be following types:

  Horst and Graben

  Horst: When 2 normal faults appear on either side of a central wedge shaped elongated block in such a way that the central wedge appears raised high up with respect to the sides, the outstanding structure is called a horst

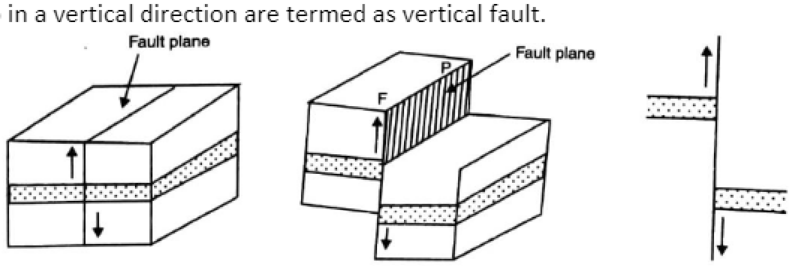
  Graben: It is almost reverse of a horst. It may described as an elongated wedge shaped central block, which appears to have moved downward with respect to the side blocks.



(a) Horst. (b) Graben.

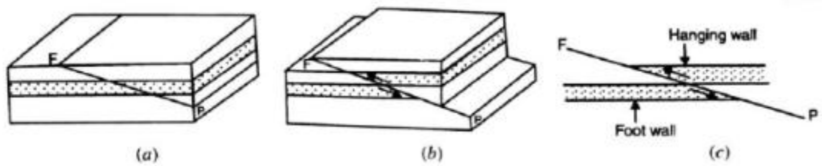
Vertical faults

Faults in which the **fault plane is vertical or nearly so** and resulting movement of blocks is also in a vertical direction are termed as vertical fault.



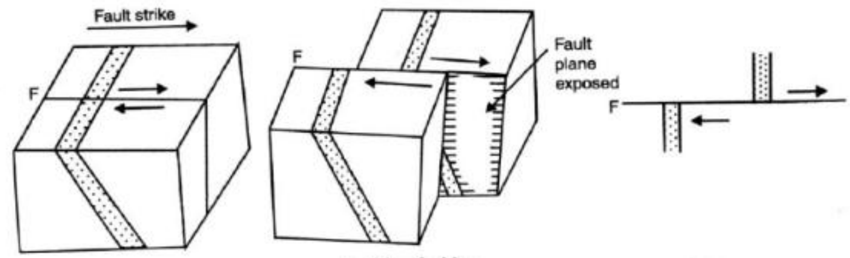
(a) (b) (c)

2. **Reverse faults**
   - Fault in which the hanging wall appears to have moved up with respect to the foot wall.
     1. (i) Reverse faults – Dip > 45°
     2. (ii) Thrust fault – 45° > Dip >10°
     3. (iii) Overthrust fault – Dip < 10°

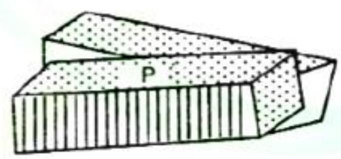


Reverse Fault

3. **Strike- slip fault**
   - Faults in which faulted blocks have been moved against each other in an essentially horizontal direction. The fault plane is almost vertical.



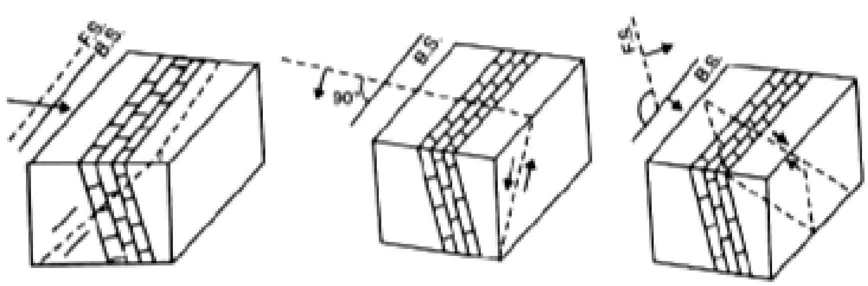
4. **Hinge faults**
   - These are also called pivotal or rotational faults. Here movement of blocks is rotational rather than translational about a point called hinge point.



Hinge Fault

Classification Based on Attitude of fault

Based on attitude (dip & strike), faults are classified as



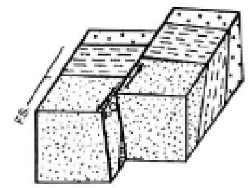
(1) Strike faults **(2) Dip faults** **(3) Oblique faults**

1. **Strike faults:**
   - Faults that develop parallel to the strike of the strata. i.e. strike of the fault and layers are parallel
2. **Dip fault:**
   - Faults that develop parallel to the dip of the strata.

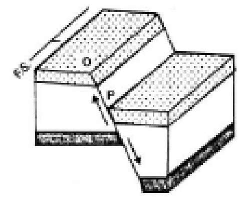
3. **Oblique faults:**
   - Also called diagonal faults. Here, fault strike makes an oblique angle with the strike of the rocks.

<u>Classification Based on Slip</u>

1. **Strike slip faults**
   - Faults in which the net slip is parallel to strike of the faults, slip along the sip is almost absent
   - Rake = 0º



2. **Dip-slip faults**
   - Faults in which the net slip has taken place parallel to the dip of the fault
   - Also called as normal-dip faults
   - Rake = 90º



<u>Classification Based on Mode of occurrence</u>

(a) Parallel faults:

A group of faults occurring in close proximity having their fault planes striking essentially in the same direction and having parallel and equal dips form what are commonly called parallel faults.

(b) Enechelon Faults:

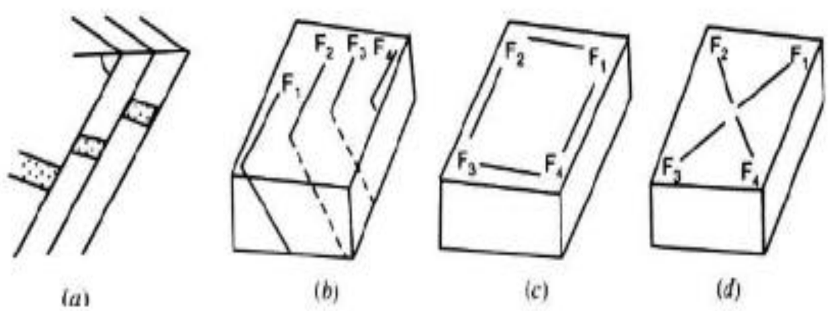
It is defined as a group of small sized faults that overlap each other in the region of their occurrence.

(c) Peripheral faults:

When in any given region the majority of faults are concentrated along the border or margin of the area, the faulting is termed peripheral.

(d) Radial faults:

A group of faults that appear emerging outward from a common central region are classed as radial faults



JOINTS AND JOINTING

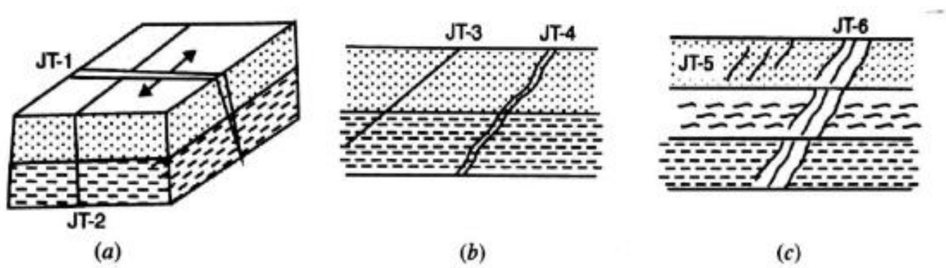
- Joints are of great practical importance for all those dealing with rocks as site, material of construction, etc.
- Joints are defined as **divisional planes or fractures along which there has been no relative displacement.**
- These fractures **divide the rocks into parts or blocks** and unlike the faults, the parts have not suffered any movement along the fracture plane.

BASIC TERMS

- Joints may be open or closed in nature
  - **Open joints** are those in which the **blocks have been separated** or opened up for small **distances** in a direction at right angles to the fracture surface. These may be gradually enlarged by weathering processes and develop into fissure in the rocks.
  - In **closed joints**, there is **no separation**. Even then, these joints may be capable of allowing fluids (gases and water) to pass through the rock.
- Joints may be **smooth or rough** on the surface and the surface may be **straight or curved** in outline.

BASIC TERMS

- Joints may be open or closed in nature
  - **Open joints** are those in which the **blocks have been separated** or opened up for small **distances** in a direction at right angles to the fracture surface. These may be gradually enlarged by weathering processes and develop into fissure in the rocks.
  - In **closed joints**, there is **no separation**. Even then, these joints may be capable of allowing fluids (gases and water) to pass through the rock.
- Joints may be **smooth or rough** on the surface and the surface may be **straight or curved** in outline.
- Joints that extends over small depths and confined only to a part of a layer or mass of rock – **Discontinuous Joints**
- The joints Extends for considerable depth in the rock mass are referred as **continuous joints**. The more prominent continuous joints are often called the **master joints.**



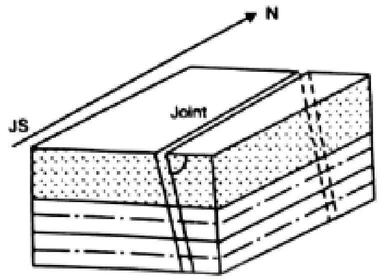
Nature of Joints
JT-1, Open joint   JT-2, Closed joint,
JT-3, Smooth joint   JT-4, Rough joint,
JT-5, Small joint   JT-6, Master joints

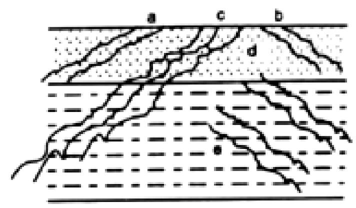
Attitude of Joints (Dip & Strike)

- Inclination of joints with the horizontal is called dip
- Strike is the direction of intersection of a joint plane with a horizontal plane.

Grouping of Joints

- Joints general occur in groups of two or more joint planes
- A **Joint set** is a group of two or more joint surfaces trending in the same direction with almost same dip
- A **Joint system** is a group of two or more joint sets.





(a) A Single Joint Plane Striking NS and Dipping 80°
(b) a, b and c Joint sets, a + c Joint system I, b + d + e Joint system II

CLASSIFICATION OF JOINTS

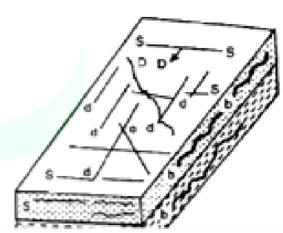
Classification based on regularity in their occurrence

1. **Systematic joints (regular joints)**
   - These show a distinct regularity in their occurrence.
   - Such joints occur as parallel or sub-parallel joint sets and they repeats in the rocks at regular intervals.
2. **Non- systematic (or irregular joints)**
   - These joints do not possess any regularity in their occurrence and distribution.
   - They appear at random in the rocks and may have incompletely defined surfaces.

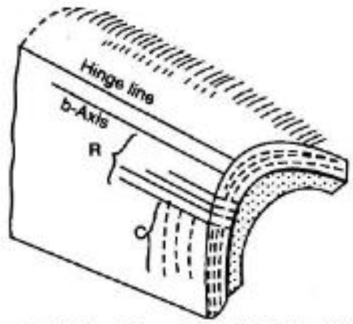
Classification based on geometry

In stratified rocks, joints are classified on the basis of relationship of their attitude with that of rock which they occur as,

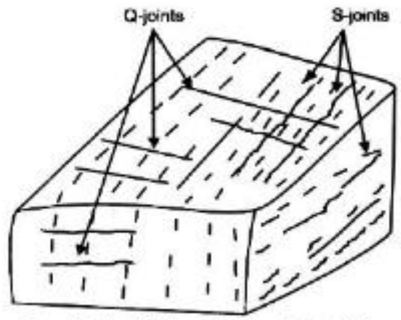
1. **Strike joints** in which the joint sets are parallel to the strike of the rocks.
2. **Dip joints** in which the joint sets are parallel to the dip direction of the rocks.
3. **Oblique joints** are those joints where the strike of the joints is at any angle between the dip and the strike of



5. **Radial joints** are those in which joints running parallel to hinge line in folded region
6. **C-joints** are those in which joints running parallel to the layers of folded region
7. **Cross or Q joints** which are joints traversing the linear structures at right angles.
8. **Longitudinal or S joints** are those joints which are traversing parallel to the linear structure.



Radial Joint (R) and Parallel Joint (C)

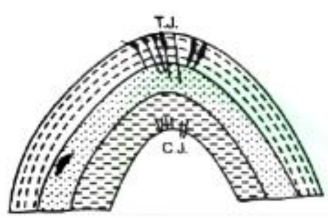


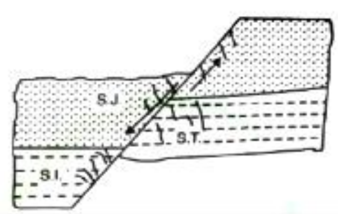
Longitudinal (S) and Cross Joints (Q)

<u>**Classification based on genetics (origin)**</u>

The force responsible for the development of joints may be tensile, compressive or shear.

1. **Tensile joints**
   - These joints are developed due to the tensile forces acting on the rocks.
   - The most common location of such joints in folded sequence is on the outer margins of crests and troughs.
   - Joints produced in many rocks during the weathering of overlying strata and subsequent release of stresses by expansion are also thought to be due to the tensile forces.
2. **Shear joints**
   - These are commonly observed in the fault planes and shear zones
   - In the folded rocks these joints are located in axial regions.
3. **Compression joints**
   - These joints occur in the core regions of the folds where compressive forces are dominant.





UNCONFORMITY AND ITS TYPES

WHAT IS UNCONFORMITY?

An unconformity is a buried erosion surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous. In general, the older layer was exposed to erosion for an interval of time before deposition of the younger, but the term is used to describe any break in the sedimentary geologic record.

The rocks above an unconformity are younger than the rocks beneath unless the sequence has been overturned An unconformity represents time during which no sediments were preserved in a region. The local record for that time interval is missing and geologists must use other clues to discover that part of the geologic history of that area.

DURING UNCONFORMITY

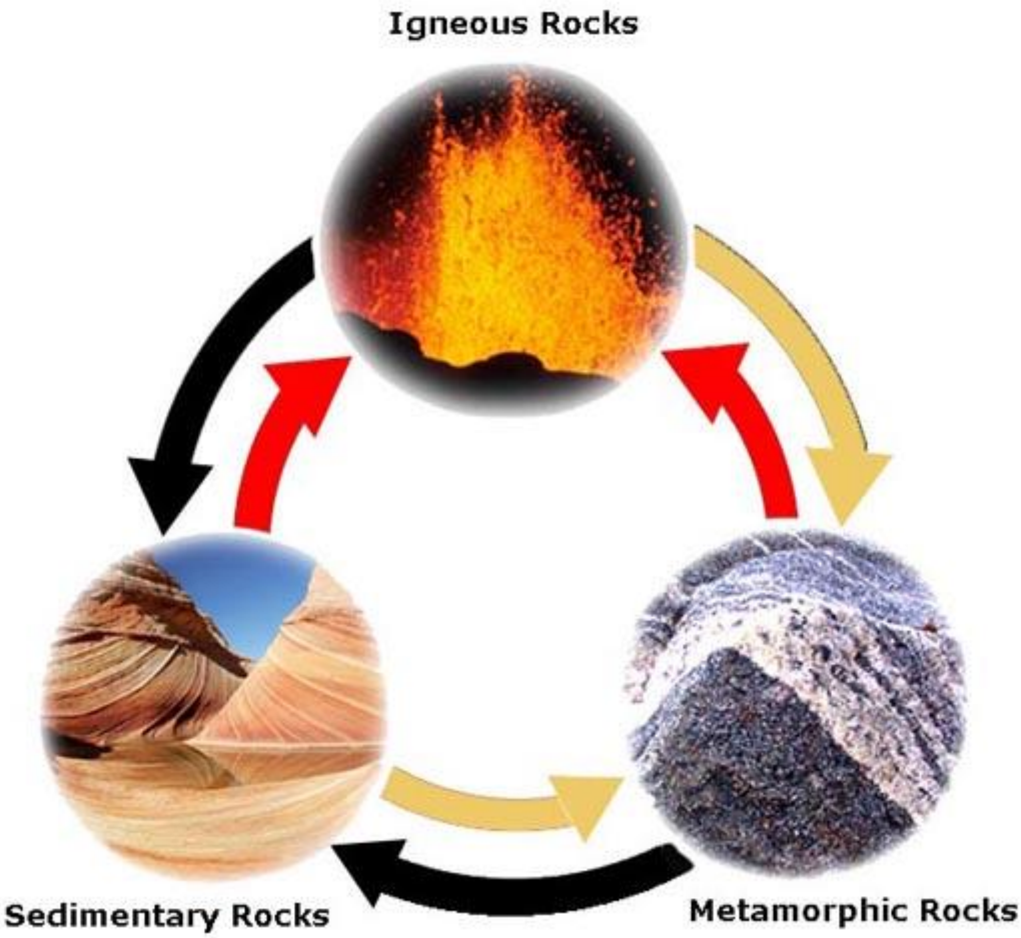
- Horizontal or conformable beds are formed
- Break in sedimentation or deposition occurs
- Next phase of deposition or sedimentation cycle, where new sedimentation produce another set of conformable beds.

SEVERAL STAGES OF DEVELOPMENT IN UNCONFORMITY

- ✓ The first stage : Formation of older rocks
- ✓ The Second stage : Uplift & Erosion
- ✓ Final stage : deposition of the younger strata

ROCKS TAKING PART IN UNCONFORMITIES

- SEDIMENTARY ROCKS
- VOLCANIC ROCKS
- PLUTONIC ROCKS
- METAMORPHIC ROCKS

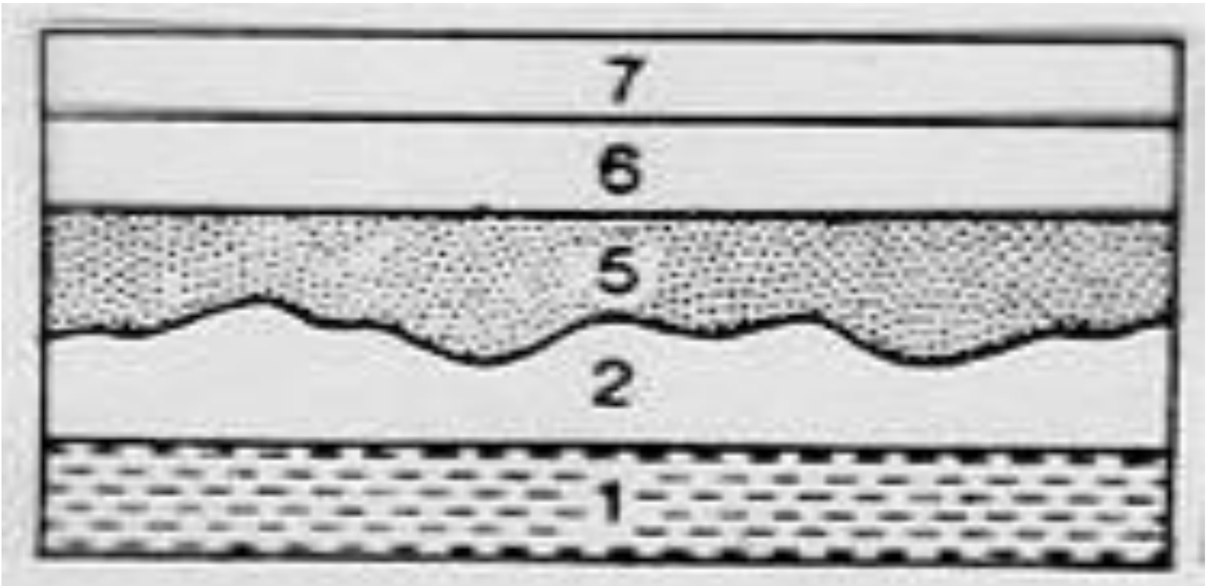


TYPES OF UNCONFORMITIES

- DISCONFORMITY
- NONCONFORMITY
- ANGULAR UNCONFORMITY
- PARACONFORMITY

- DISCONFORMITY

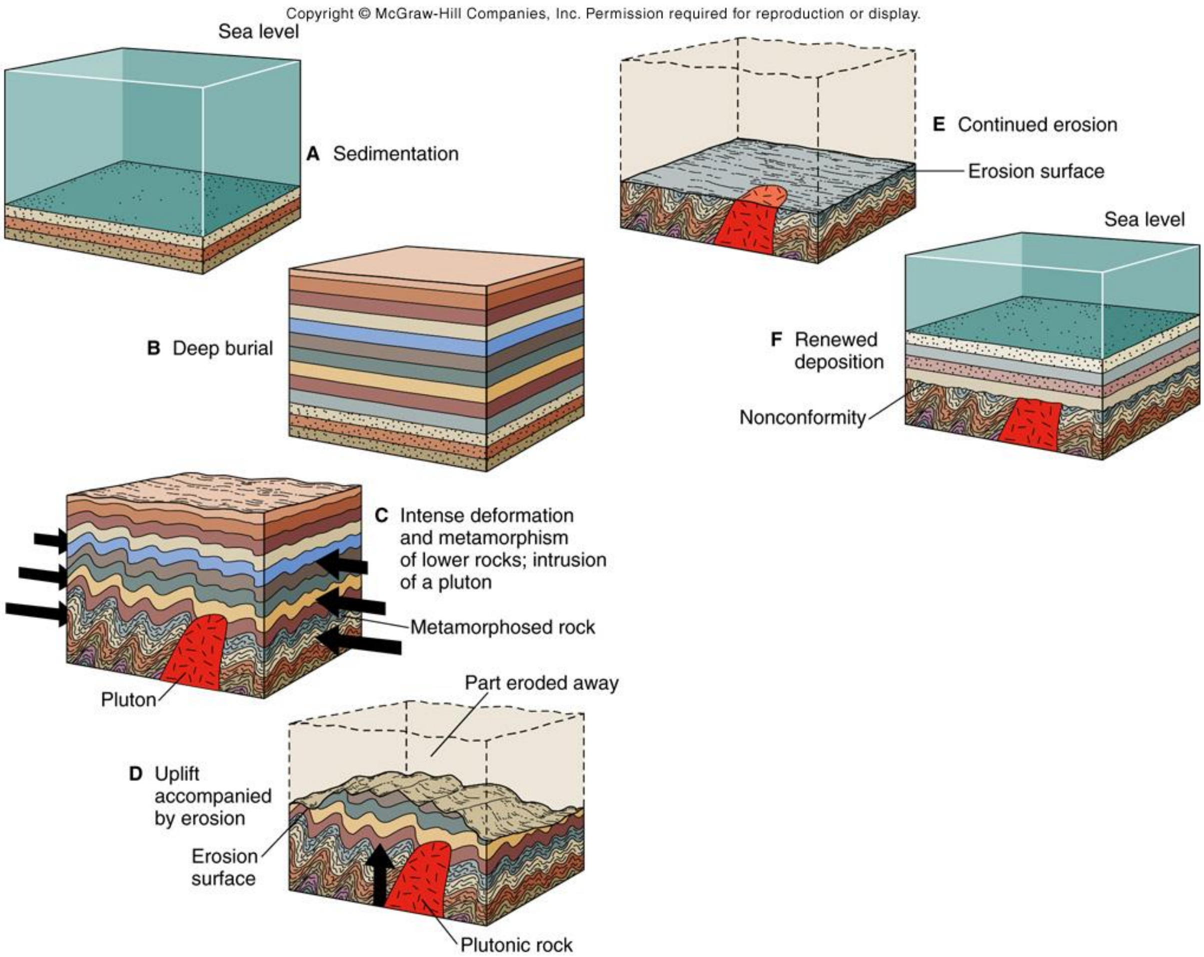
A disconformity is an unconformity between parallel layers of sedimentary rocks which represents a period of erosion or non-deposition. Disconformities are marked by features of sub-aerial erosion. This type of erosion can leave channels and paleosols in the rock record.



▪ NONCONFORMITY

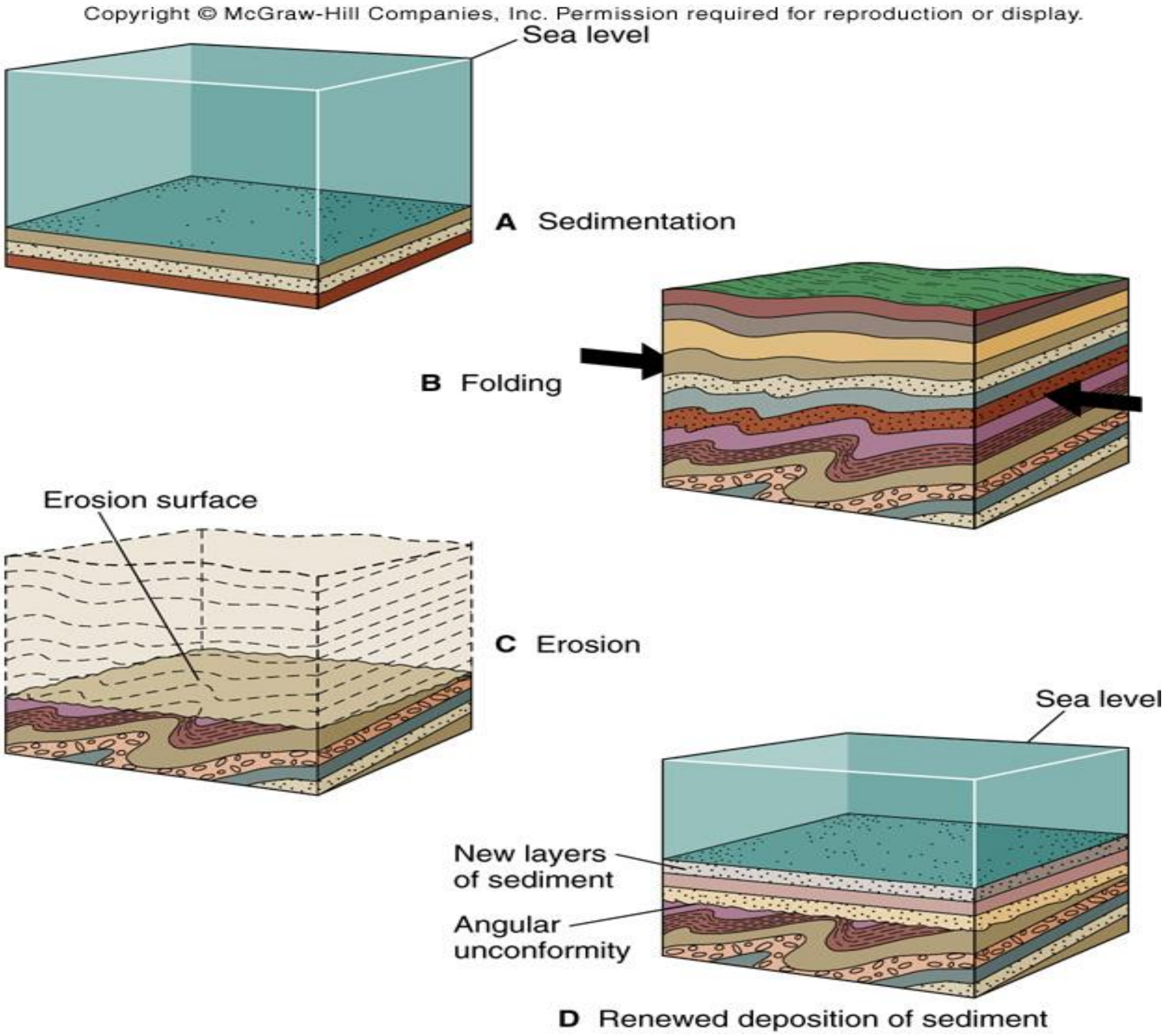
A nonconformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock. Namely, if the rock below the break is igneous or has lost its bedding by metamorphism, the plane of juncture is a nonconformity.

<u>DIAGRAM SHOWING NONCONFORMITY</u>



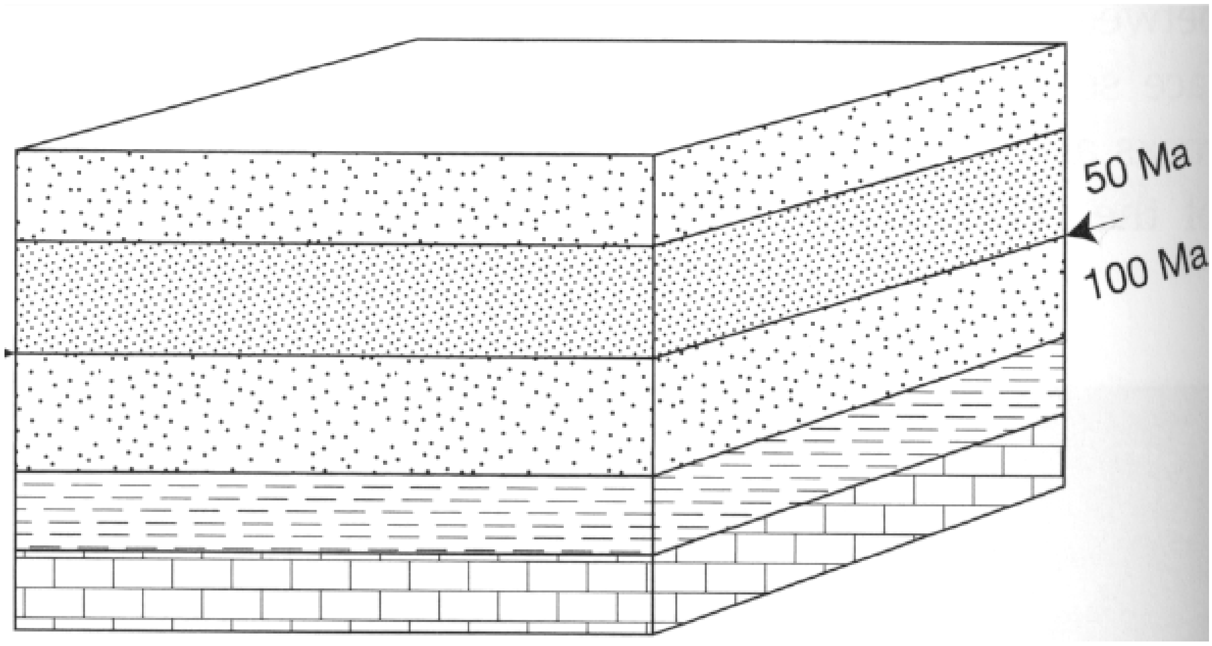
- ANGULAR UNCONFORMITY

An angular unconformity is an unconformity where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers, producing an angular discordance with the overlying horizontal layers. The whole sequence may later be deformed and tilted by further orogenic activity.



- PARACONFORMITY

A paraconformity is a type of unconformity in which strata are parallel ; there is little apparent erosion and the unconformity surface resembles a simple bedding plane. It is also known as nondepositional unconformity or pseudoconformity.



RECOGNITION OF UNCONFORMITY

Uncoformities may be recognized in various ways If the unconformity is an angular one, the lack of parallelism of the beds on opposite sides of the contact will be radially apparent. This may be observed in a vertical section , such as cliff, or on the surface of the outcrop. The lowest above the unconformity may consist of conglomerate, pebbles, derived from the underlying formations

Under favourable conditions disconformity may be radially recognized in outcrops, road cuts and quarries. If there is a sharp contrast and colour between the rocks above and below the unconformity, if the disconformity is somewhat wavy, and especially if there is a thin conglomerate just above the disconformity.

Non conformities must be distinguished from the intrusive igneous contacts. The rocks above the nonconformity may contain fragments of the older igneous rock, either as radially recognized pebbles & boulders or as small fragments recognized only under the microscope.

DISTINGUISHING FAULTS FROM UNCONFORMITY

Every effort should be made in the field to observe the actual contact. If it is an unconformity, small ridges of the older rock may project into the younger rocks, and a conglomerate or sandstone with fragments of the older rock, may lie above the contact. Slickensides , gouge & breccias would be absent from an unconformity , but would likely be present a long a fault. Some faults , however are sharp, knife like contacts devoid of such features. Additional complexity is introduced by the fact that faults may follow unconformities particularly angular unconformities

SIGNIFICANCE OF UNCONFORMITY

- An Unconformity represents a time gap in the depositional history of an area.
- The divisions of geologic time paleontological studies, and stratigraphic studies are usually based on unconformity surface
- Oil traps and aquifers are often met with an unconformity surface.
- Unconformity areas are usually considered as weak zones for engineering projects
- Detailed study of an unconformity often helps to establish the paleo-environmental deposition history and paleogeography of a region

- Unconformities are the record of major episodes of uplift, erosion & subsidence During the growth of the continents as earth history progressed. They are therefore important evidence for crustal mobility throughout earth history.
- crustal deformation, erosion, and sea level variations.
- It provides evidence that many life forms have become extinct
- Structural Geologists are more concerned with unconformities.
- Major use in Dating Orogenic and Epeirogenic movements.
- Unconformities are important for the students of stratigraphy, sedimentation, and historical geology.

STUDY OF MINERALS

DESCRIPTION:

Mineral – A mineral is a naturally occurring, inorganic,homogenous solid substance having a definite chemical composition and regular atomic structure. The mineral are the broadly devided in two groups :

1) Rock forming mineral: these are found in the rock of earth crust.

2) Ore forming mineral: these are the economical mineral & not abundance found in rock.

Mineral group:-

No.	**Mineral group**	**Example**
1	Oxides	Quartz, Magnetite, Hematite, Limonite
2	Silicates	Feldspar, Mica, Hornblende, Augite
3	Carbonates	Calcite, Dolomite, Siderite
4	Sulfides	Pyrites Galena
5	Sulphates	Gypsum
6	Chlorites	Rock Salt

Common methods of study for the identification of minerals

Method	**Principle**
X-ray analysis	Based on the study of atomic structure, distinctive for every mineral. Its limitation is expensive, time consuming.
Chemical analysis	Based on the study of chemical composition. Its limitation is expensive, time consuming and not suitable for minerals exhibiting polymorphism (two or more minerals exhibit

	different physical properties in spite of possessing the same chemical composition).
Optical study	Based on the net effect of chemical composition and atomic structure. Its limitation is expensive
Study of physical properties	Based on the consistency in physical properties which are due to the definite chemical composition and regular atomic structure. Its limitation is liable for erroneous inference, sometimes.

LABORATORY STUDY

In laboratories minerals can be identified preferably by the method of study of physical properties.

Advantages:

- The unique advantage is that the minerals can be studied in the field itself.
- It does not require any additional requirements, chemicals or equipment.
- It involves no loss or wastage of minerals. Hence repetitive study is possible.
- Immediate inference is possible.
- It is the cheapest and simplest method.

Physical properties of minerals: - The physical property of mineral are determined in hand specimen. They are important in identification of the mineral in the identification of mineral in the field, color streak luster, hardness, habit, fracture cleavage odor, feel tenacity, specific gravity etc.

PHYSICAL PROPERTIES OF MINERALS

The following are the physical properties identified in the laboratory

1. Form

The form represents the common mode of occurrence of a mineral in nature.

Form	Description	Example
Lamellar form	Mineral appears as thin separable layers/ plates which may be curved or straight.	Different varieties of Mica, Gypsum
Tabular form	Mineral appears as slabs of uniform thickness.	Feldspars
Fibrous form	Mineral appears to be made up of fine threads.	Asbestos
Pisolitic form	Mineral appears to be made up of small spherical grains	Bauxite
Oolitic form	Similar to Pisolitic form but rains are of still smaller size.	Lime stones
Rhombic form	Rhombic shape	Calcite
Bladed form	Mineral appears as cluster or as independent rectangular grains	Kyanite
Granular form	Mineral appears to be made up of innumerable equidimensional grains of coarse or medium or fine size	Chromite, Magnetite
Columnar form	Mineral appears as long slender prism	Topaz
Prismatic form	As elongated	Apatite, quartz
Spongy form	Porous	Pyrolusite
Crystal form	Polyhedral, Geometrical shape	Garnets, Galena
Amorphous /Massive form	No definite shape for mineral.	Jasper, Graphite
Concretionary Form	Porous and appears due to accretion of small irregularly shaped masses.	Laterite
Nodular form	Irregularly shaped compact bodies with curved surfaces	Flint
crystalline	When the minerals are in form of imperfectly developed crystals	
Foliated	An aggregate of thin separable sheets	mica
Botryoidal	An aggregateslike bunch of grapes.	Psilomelane
Acicular	An aggregates of needle like crystals	
Reniform	Kidney shaped aggregates	
Mammillary	Consists of larger and mutually interfering prominences	Malachite

Stalactite	Cylindrical or conical form of minerals generally due to deposition by dripping water.	

2.Color :-It is not much important property for identification of the mineral because many of are colorless & shade of colored mineral may varied with composition but certain mineral have got the characteristic Color & only in case is helpful.

Name of the Mineral	**Colour**
Olivine	Olivine green
Biotite, Graphite, Magnetite	Black
Chlorite	Green
Garnet	Red
Kyanite	Blue
Amethyst	Violet
Quartz	Colorless, White, Green, Violet, Grey, yellow, Pink, etc..
Feldspar	White, Grey, Shades of Red, Green, Dirty white, etc
Calcite	Colorless, white, shades of Red, Grey, Yellow, etc

3.STREAK:-

The colour of mineral powder is called as streak the streak isobtain rubbing a mineral against an unglazed porcelain plate called streak platethe study of streak is most useful in case of the color mineral obtain often givesmuch lighter streak than their body colour streak is useful for the identification ofsilicates, carbonates & transparent mineral because they give white streak.

Name of the Mineral	**Body Colour**	**Streak**
Hematite	Steel Grey	Cherry Red
Chromite	Black	Dark Brown
Magnetite	Black	Black
Graphite	Black	Black
Molybdenite	Black	Greenish Black

4. LUSTER:-

Luster is defined as “the general appearance of a mineral surfacein reflected lights”. The various type of lusters are as follows.

Lustre	Description	Example
Metallic Lustre	It is the type of shining that appears on the surface of a metal.	Galena, Gold, Pyrite
Sub metallic Lustre	If the amount of shining is less when compared to metallic luster.	Hematite, Chromite, Magnetite
Vitreous Lustre	Shining like a glass sheet.	Quartz, Feldspar
Sub Vitreous Lustre	Less shining when compared to vitreous lustre.	Pyroxenes
Pearly Lustre	Shining like a pearl	Talc, Muscovite mica
Silky Lustre	Shining like silk	Asbestos
Resinous Lustre	Shining like a resin	Opal, Agate
Greasy Lustre	Shining like grease	Graphite
Adamantine Lustre	Shining like a diamond	Garnet, Diamond
Earthy or Dull Lustre	No Shining	Bauxite, Magnesite

5. Cleavage:-

The definite direction or plane along which a mineral tends to break easily is called cleavage of that mineral. It occurs as innumerable parallel planes along which the mineral is equally weak. Such parallel planes of weakness are referred to as a set.

Cleavage	Example
One set of cleavage	Mica, Chlorite, Talc
Two sets of cleavages	Feldspars, Pyroxenes, Amphiboles
Three sets of cleavages	Calcite, Dolomite, Galena
Four sets of cleavages	Fluorite
Six sets of cleavages	Sphalerite
No cleavage	Quartz, Olivine, Garnet

6. Fracture:-

Fracture is the nature of the randomly broken surface of a mineral.

Fracture	Description	Example
Even fracture	If the broken surface is plain and smooth.	Magnesite, Chalk
Uneven fracture	If the broken surface is rough or irregular.	Hornblende, Bauxite
Hackly fracture	If the broken surface is very irregular like end	Asbestos, Kyanite

	of a broken stick.	
Conchoidal fracture	If the broken surface is smooth and curved	Opal
Sub Conchoidal fracture	If the curved nature is less prominent.	Agate, Flint, Jasper

7. HARDNESS:-

The resistance of a mineral to abrasion or scratching is called ashardness of that mineral. Hardness is determined by rubbing a mineral ofunknown hardness against of known hardness the numerical value of hardness isdetermined by using MOHS SCALE of hardness.

Name of the Mineral	**Hardness**	**Chemical Composition**
Talc	1	Magnesium Silicate Hydroxide Mg3Si4O10 (OH)2
Gypsum	2	Calcium Sulfate Hydrate $CaSO_4$ l $2H_2O$
Calcite	3	Calcium Carbonate $CaCO_3$
Fluorite	4	Calcium Fluoride CaF_2
Apatite	5	Calcium Phosphate $Ca_5(PO_4)_3$(OH- ,Cl- ,F-)
Feldspar	6	Potassium Aluminum Silicate $KALSI_3O_8$
Quartz	7	Silicon Dioxide SiO_2
Topaz	8	Aluminum Silicate Fluoride Hydroxide Al_2SiO_4(OH- ,F-)2
Corundum	9	Aluminum Oxide Al_2O_3
Diamond	10	Carbon C

Mohs Hardness Scale

Name	Scale Number
Netherite	11
Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

Common Object

- dat pricky boi / 1000
- Masonry Drill Bit / 8.5
- Steel Nail / 6.5
- Knife / 5.5
- Penny (Copper) / 3.5
- Fingernail / 2.5

8. Specific gravity or Density:-

Specific gravity or Density of minerals depends on their chemical composition and atomic structure.

Density	Range	Example
Low density	Specific gravity less than 2.5	Gypsum (2.3), Graphite (2-2.3)
Medium density	Specific gravity between 2.5 and 3.5	Quartz (2.7), Feldspar(2.5)
High density	Specific gravity greater than 3.5	Chromite (4.5- 4.8)

9. Degree of transparency:-

Degree of transparency is tested along the thin sharp edges of mineral keeping it against a powerful source of light. Depending upon the resistance offered by the minerals to the passage of light through them the transparency is classified.

Degree of Transparency	Example
Transparent	Thin layers of Muscovite, rock crystal
Translucent	Agate, Calcite
Opaque	Galena, Pyrite

10. Special properties:-

Some minerals exhibit unique characters which enable them to be identified easily.

Name of the Mineral	Special property
Talc	smooth touch or soapy feel
Graphite	Marks on a paper easily
Pyrolusite	Soils the fingers
Halite	Saline taste
Magnetite	Strongly attracted by any ordinary magnet
Chalk	Rough feeling of touch, adheres strongly to the tongue

OPTICAL PROPERTIES OF MINERALS

INTRODUCTION

The light has a dual nature. Firstly, light behaves like a particle. In this behavior light particle known as photon act as a compact entity and can knock out loosely metalic bonded electrons from large atoms like Cs and Rb. This effect is known as photoelectric effect.

Secondly, light behaves like a wave and bends around corners and passing through small holes produces interference and diffraction patterns. In optical mineralogy most phenomena can be explained by the wave nature of light.

In the wave theory of light, the light waves are defined by oscillating electric **E□** and magnetic **H□** vectors perpendicular to each other and are also oriented perpendicular to the propagation direction of light-ray. So to simplify, we can consider an oscillating light vector; **L□** which is a resultant of the **E□** and **H□**vectors. In this way a light wave forms a sine wave. The light wave vibration has a characteristic wavelenght (λ). In fact considering the whole **electromagnetic spectrum** including cosmic rays-X-rays at the short λ's region to radio waves and microwave radiation at long λ's region; visible light is only a small part of this spectrum. The λ range of visible light is from approximately 390-710 nm (nanometer=10^{-9} m). This range of light corresponds to 390-440 nm Violet; 440-500 nm Blue; 500-570 nm Green; 570-590 nm Yellow; 590-650 nm Orange; 650-710 nm Red.

Because light vector, **L□** is actually an oscillating electromagnetic wave, it will interact with the electric field produced by the nuclei and electrons of atoms that make up the matter. The more nuclei and electrons there are in a given volume the more light wave is slowed down. Thus, light travels fastest in perfect vacuum c=300.000 km/sec and slower in all substances. Eg., (1) In two polymorph of **Sil** and **Kya** having same composition Al_25i0_5 but different densities $\rho_{\mathbf{Sil}}$=3 .23 g/cm^3, $\rho_{\mathbf{Kya}}$=3.53 g/cm^3 light will travel slower in denser medium $v_{\mathbf{Sil}}$=181.000 km/sec, $v_{\mathbf{Kya}}$=175.000 km/sec. Eg. (2). If two minerals have approximately same number of atoms per unit volume, the mineral that contains more electron per unit volume have smaller velocity of light. Consider **Per** (MgO) and **Wüs**tite (FeO) which have similar molar volumes. However, MgO has (12+8=20 electrons) whereas, FeO has (26+8=34 electrons). Hence $v_{\mathbf{Per}}$ =173.000 km/sec, $v_{\mathbf{Wüs}}$=129.000 km/sec.

OTHER WAVE PROPERTIES OF LIGHT WAVES

When light rays move away from a source in a medium, at a given moment these rays will have traveled and define a 3-D surface known as **Ray Velocity Surface** (**RVS**). In isotropic minerals these rays will have travelled same distance, independent of the direction they travel hence spherical **RVS** forms. However, in anisotropic minerals, because the minerals have different atoms along different directions, light will travel at different velocities along different crystallographic direction, hence **RVS** surface is not spherical, but will form complex double surfaces.

Tangent to the **RVS** along any light ray is known as the **wave front.** Followed from above discussion in isotropic minerals wave front is perpendicular to the ray (or propagation direction) and its **wave normal** will be along the propagation direction. However, in anisotropic minerals wave front is perpendicular to the propagation direction only at special directions, but will be at an angle in other directions. Similarly, wave normal will be along the propagation direction only at special crystallographic direction, but will be at an angle in other directions.

REFLECTION-TOTAL REFLECTION-REFRACTION-INDEX OF REFRACTION

When light ray travels from one isotropic medium into another isotropic medium certain changes occur to the direction of propagation at the interface. If light travels from a less dense isotropic medium to higher density isotropic medium some of the rays will be reflected at the interface while others will enter into the denser isotropic medium. According to **law of reflection,** the angle of the incident ray with the normal will be reflected with the same angle back to the former isotropic medium-with the same velocity. However, light entering into denser isotropic medium bends closer to the normal at the interface and the velocity of light will drop. This is known as **refraction.** According to the **Snell's Law** sin**i**/sin**r**=**RI** of the latter isotropic medium. This can also be expressed as $\mathbf{RI}_{medium}$=velocity of light in vacuum/velocity of light in the isotropic medium, $\mathbf{RI}_{medium}=c/v_{nedium}$ ie., RI of a medium is inversely proportional to the speed of light in that medium. Higher **RI** means lower speed of light in that medium.

If light travels from a higher **RI** isotropic medium to lower **RI** isotropic medium same laws apply, but in this case refracted ray moves away from the normal to the interface. At a certain critical angle of incidence, no light will pass through the interface into low **RI** isotropic medium. This is known as **total reflection** which is used to determine **RI**'s of isotropic media**.** Measured **RI** of minerals has a fundamental importance. This parameter, especially in solid solution series is very important, as it may be used to determine the composition of the solid solution species. **RI**’s of diffrent polymorphs also show linear relationship when compared with density of the polymorphs.

There is a direct relationship between the optic properties of minerals and their symmetry, where light is affected similarly in the same crystal system. The specific parameter that seems to control the interaction of light with solid matter is the number of unique crystallographic axes within a crystal system. The six crystal systems can be divided into three groups based on the number of the unique optical axes they have.

***Cubic-Isometric System; Isotropic:** Isotropic crystals: **1** unique optical axis, and 1 **RI**=**n**; cubic crystals & amorphous substances (gases and liquids).

***Tetragonal-Hexagonal Systems; Anisotronic:** Uniaxial crystals: 2 unique optical axes, and 2 **RI**'s=ω and ε.

<u>*Orthorhombic-Monoclinic-Triclinic Systems: Anisotropic</u>: Biaxial: 3 unique optical axes,and 3 **RI**'s=α**,** β**,** and γ

RELIEF-TWINKLING-BECKE LINE

Relief is a function of the difference of a **RI**'s of a crystal and those of its surroundings. The effect of relief is to make the mineral to stand out from its surroundings. In most thin sections which consist of a basal glass slide (1→l 5 mm thick), a cover glass (0.17 mm thick) and ground down mineral or rock chip (0.03 mm thick) that is sandwiched between these glasses and glued with Canada Balsam **CB (RI=1.537)** or epoxy resins (**RI**=1.52→l.54).

If the immediate surrounding of the mineral is the **CB** and if the **RI** contrast between the mineral and **CB** is <0.04 low relief; 0.04-0.12 moderate relief; and >0.12 high relief is observed. A crystal with low relief does not stand out from its surrounding and its cleavages and fractures arc indistinct, whereas a crystal with high relief stands out strongly and its cleavages and fractures are sharply defined.

In anisotropic minerals where there are more than one **RI** is present, relief changes with respect to the crystallographic orientation. This effect is most obvious with mineral having large difference in their **RI**'s. Eg., **Cal** with ε=1.486<**CB** and moderate relief (0.051); and ω=1 .658>**CB** and high relief (0.121). Therefore, **Cal** mineral with its cleavage and composition planes of its polysynthetic twinning seems to stands out strongly and dissappears when observed under the polarizing microscope as the stage is turned**.** This is known as **twinkling.**

As we have seen in the above example ε gives a relief -0.051 while ω gives +0.121 reliefs. To determine whether the mineral has a positive or negative relief is important to distinguish various mineral species. The minerals boundaries with the surrounding minerals or with **CB** forms interfaces between two media with different **RI**'s. Same laws of reflection-total reflection and refraction applies when the interface is observed with relatively high power objective and diaphram under the stage is partially closed. There appears a bright fringe of light along the boundary. This fringe of light is called **Becke Line.** Becke line moves when the microscope stage is lowered or raised**.** The rule of thumb is**<u>: medium with higher RI acts like a bi-convex lense and converges light towards its centre when stage is lowered away from the objective lense</u>**. Therefore, Becke line test shows whether a mineral has negative relief (<**CB**) or positive relief (>**CB**).

Mineral grains, mounted between the lamella and cover glass, is submerged in various known **RI**-liquids, and Becke line test is applied until the mineral disappears, ie, has the same **RI** as that of the **RI**-liquid. **RI** of liquids are determined by Jelly-type or Abbe-type refractometer. This method is used easily for determination of **RI** of an isotropic mineral or substance with only one **RI**. However, for anisotropic minerals with more than one **RI** orientation of the mineral must be determined before applying this method.

DISPERSION

When natural white light consisting of different wavelenghts is refracted at the interface of two isotropic media or minerals, refracted rays with different λ's are seperated from red to violet with different refraction angles. Blue rays refracted more appears closer to the normal whereas red rays is slightly away from the normal**.** This is known as **dispersion**. **Dia** has the highest dispersive power, on the other hand **Flu** has the least dispersive power**.**

Dispersion in anisotropic media resolves two different sets of red and blue refracted rays, since anisotropic minerals have more than one **RI**.

POLARIZATION AND POLARIZED LIGHT

Light vector of natural light vibrates perpendicular to the direction of propagation, along all direction. If light is forced to vibrate along certain direction than the light is said to be **polarized,** and the phenomenon is called **polarization**.

The simplest polarization is produced when light is forced to vibrate in a single plane containing the direction of propagation. This is called **plane polarization, or linear polarization.** Here, light vector again vibrates perpendicular to the propagation direction but confined to the **polarization plane**.

When two plane polarized lights vibrating along their plane of polarizations meet along the same direction of propagation, where the planes of vibrations are perpendicular to each other two different kinds of polarized light is obtained, depending on the phase differences between them. If the phase difference is equal to ¼λ **circular polarized light** is obtained. If the phase difference is not equal to ≠¼λ, and ≠even multiples of ½λ's, then **elliptically polarized light** is obtained. Both circularly-and elliptically-polarized light can move clock-wise or anti clock-wise direction. There are three important methods of producing plane polarized light:

1. By reflection and refraction: When natural light strikes the interface between two media, it is split into plane polarized reflected light where the direction of vibration is perpendicular to the plane that is defined by the normal to the interface and the incident ray. Whereas the refracted ray is also plane polarized but vibrates along the same plane described previously**.** Best polarization is obtained when **i+r**=90° which is called the **Brewster Law.**

2. By absorbtion: Certain dichroic anisotropic minerals absorb light strongly in one direction, and let it pass with minimum absorbtion in a direction perpendicular to this direction**.** Hence plane polarized light is obtained. **Tou** crystals display this property best. Synthetic substances like **herapatite** (iodocinchonidine-sulphate) also shows this property.

3. By double refraction: When natural light enters into anisotropic uniaxial mineral like **Cal**, it splits into two rays which are plane polarized and their vibration planes are perpendicular to each other. Since they travel at different velocities, ε-fast (vibrating //[l] to c-axis) & ω-slow (vibrating ⊥[r] to c-axis), they also have different propagation directions. A **Cal** crystal suitably cut and glued together with **CB** (nicol prism) is used to separate ε and ω completely, where ω is totally reflected at crystal-**CB** interface whereas ε is refracted into the upper crystal**.**

In a polarizing microscope there are two polarizers, one below the stage converting natural light into E-W vibration plane called **polarizer** and an upper polarizer above the objective known as **analyser** with N-S vibration plane.

EXTINCTION-INTERFERENCE COLOURS-BIREFRINGENCE-RETARDATION

When natural light entering to the microscope passes through polarizer it becomes polarized E-W direction. If there is a colourless isotropic substance on the stage, ie, air, liquid, glass, or a mineral with only one **RI**, and if analyser is **out,** the E-W vibrating plane polarized white light from the polarizer passes through the ocular unchanged as a plane polarized white light. On the other hand, if the analyser is **in** position, there will no light observed at the ocular since there is no light available vibrating N-S direction to pass through the analyser. This phenomenon is known as **extinction,** and as the microscope stage is turned extinction is continuous and the mineral is said to be at **continuous extinction.**

Anisotropic minerals however behave differently since they have more than one **RI**. In fact, anisotropic crystals split incident E-W polarized light into two light waves that are constrained to vibrate perpendicular to one another. The orientations of the vibration directions of the two light rays being fixed relative to the crystal axes. If the analyser is **out,** these two rays passes through the ocular as two plane polarized white light. But if the analyser is **in** position and and if the vibration direction of the mineral is at an angle to E-W & N-S directions., a colourful disposition occurs on the mineral surfaces. These colours are **interference colours** which are completely different from normal colour of the mineral. Here the complementary phases of λ's are allowed to pass through the N-S vibration plane and interact to produce the interference colours. The components of the two differently vibrating white polarized lights are resolved along the N-S and E-W vibration directions. Components perpendicular to N-S is absorbed while those components vibrating parallel to the N-S analyser vibration direction is allowed to pass through the analyser**.** In the analyser, the components vibrating parallel to the vibration plane of the analyser interfere to produce interference colours**.** The strength of interference, also known as **retardation** is proportional directly to the differnce of **RI**'s indices of the relative crystallographic orientation of the section of the crystal or inversely proportional to the different ray velocities of corresponding ray velocities. Retardation is also directly proportional to the thickness of the mineral section; therefore, $\mathbf{\Delta}=t\ (|\mathbf{RI_1}-\mathbf{RI_2}|)$. Here retardation ($\mathbf{\Delta}$) is equal to the product of the thickness of the mineral section and the absolute difference in the **RI**'s related to that particular section. The difference $\mathbf{RI_1}-\mathbf{RI_2}$ is called the **birefringence** of the mineral and has maximum value when $|\varepsilon-\omega|$ or $|\alpha-\gamma|$, or for intermediate values of ε' and β the minerals will have smaller value of birefringence**.**

When unique vibration directions of the mineral is parallel to the E-W and N-S vibration direction of polarizer and analyser one of the plane polarized light rays emerging from the anisotropic crystal is absored completely at the N-S vibrating plane of analyser. Therefore, there will no interference at analyser, a single N-S vibrating light passes through, hence extinction occurs. At every 90° of revolution of the microscope stage alternately extinction and illumination are encountered, after the first extinction.

Sometimes high **RI** minerals and at other times minerals with perfect cleavage cause reflection of light from below which appear as tiny specks of illumination during extinction. This is called **mottled extinction,** a characteristic feature of micas.

The colour of maximum retardation is presented in charts ranging from first order to seventh order interference colours. Retardation orders are separated by the appearance of red (550 nm) colours. The colours become pale beige as the order of retardation increases. There is no true blue or green colour in the first order. When birefringence is very low anamolous interference colours of navy blue and olive green or purple is observed in first order.

If the composition or thickness of the crystal varies in the thin section, different interference colors may occur on the same crystal surface resulting a **patchy birefringence,** a characteristic feature of epidote.

COLOUR AND PLEOCHROISM

Colour of a transparent minerals in thin section is observed with analyser **out** position which then depends on the absorbtion of certain λ's of E-W vibrating plane polarized white light emerging from the mineral. The λ's that pass through the mineral interfere and produce characteristic colour of the mineral. The colour due to transmission of light through the mineral may be different from the colour of the mineral due to reflected light from the surface of the mineral, in hand specimen.

If the colourful mineral is isotropic, there is no change of colours when the stage of microscope is rotate, because the isotropic mineral has only one characteristic **RI**. However, if the colourful mineral is anisotropic, absorption of different λ's of E-W vibrating white plane polarized light is direction dependent, hence different colours appear as the stage rotated, because of anisotropic mineral's principle vibration direction is aligned alternatively parallel to the E-W direction. This phenomenon is known as **pleochroism**. Hence uniaxial crystals with two principle **RI**'s will have maximum two different colours, on the other hand biaxial crystals with three principle **RI**'s will have maximum three different colours, depending on the orientation of the section that is cut from the crystal**.**

If the composition of the crystal changes from centre to its edge roughly concentric colouring may occur which is called **compositional zonning.**

Colour of opaque minerals cannot be viewed with transmission polarizing microscopes. Since opaque minerals do not transmit light, whatever thin the section is. Therefore they appear black and collectively referred to as the **opaque minerals**, ie., **Mat, Pyt, Ilm**, etc. Opaque minerals are studied by reflection polarizing microscopes, or ore microscopes.