UNIT IV: Erosion,Transportation and Depositional landforms: Fluvial, Glacial, Aeolian, karst.

Fluvial Processes and Landforms

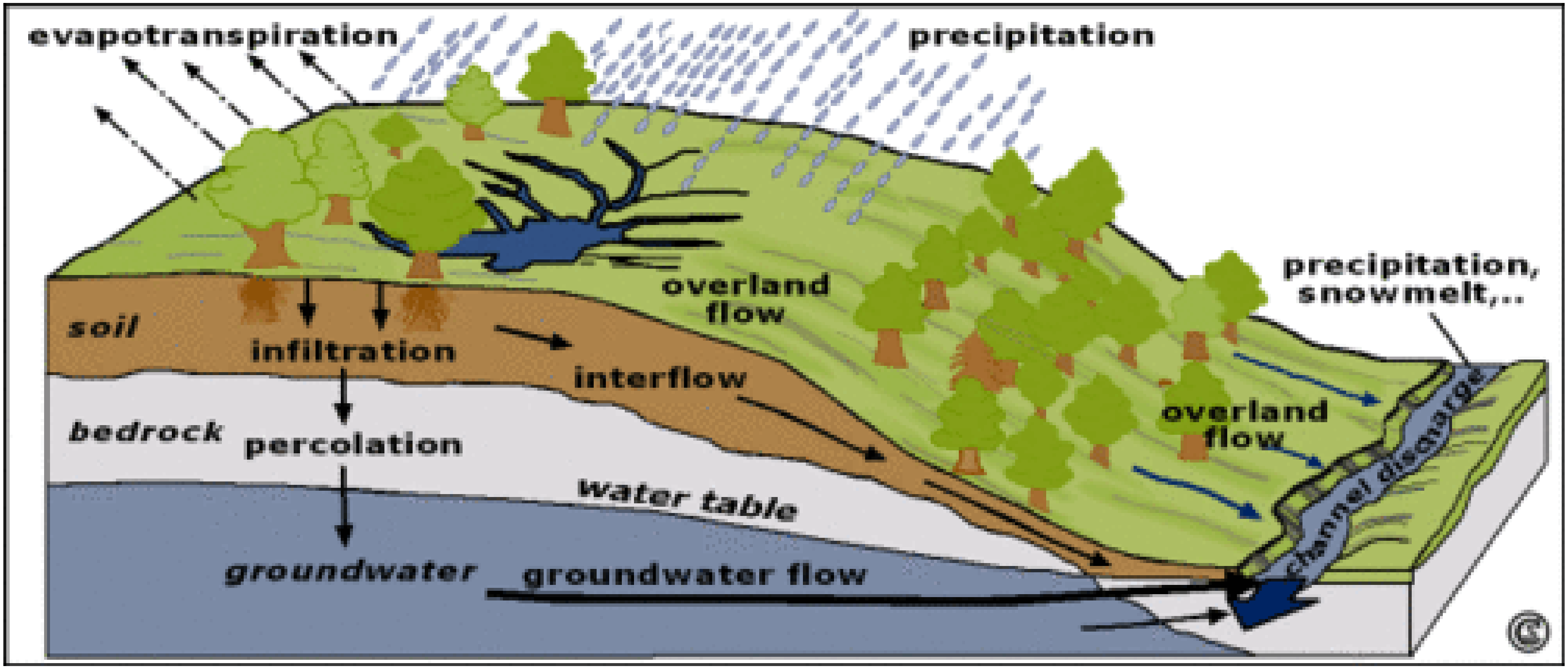
- The term ‘fluvial’ (from Latin *fluvius*, river) refers to the work of rivers but in the context of landscape development it includes the work of both overland flow and stream flow.
- Thus landforms shaped by running water are called fluvial landforms. It constitutes the largest proportion of the environment 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’.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groundwater
groundwater flow

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 independent of one another but are inter-dependent.

❖ Through the joint action of these activities the river 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 plateaus.

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 materials is 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

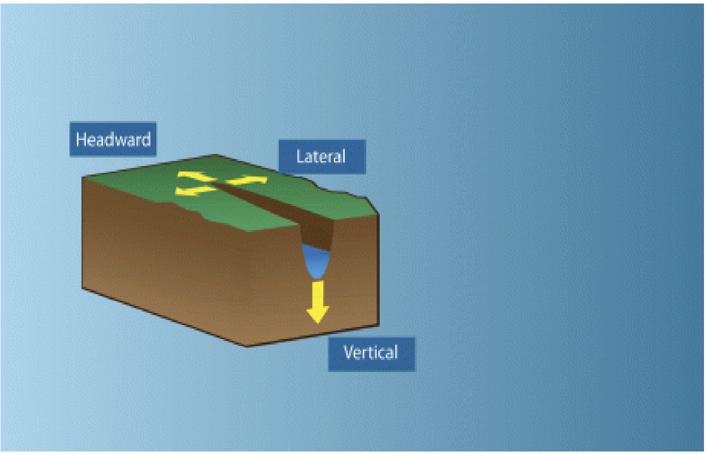
- The point of origin of a river is called its ‘source’ and the point where it ends is called its ‘mouth’
- The course of a river from the source to its mouth may be divided into three parts – upper, middle and lower
- For example, the Ganga has its upper course above Hardwar, its middle course from 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.

Fluvial Landforms

Erosional & Depositional

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 inter-stream areas, disappear. The stream divides turn sharp.
- Waterfalls and rapids disappear.
- Meander and slip off slopes are the characteristic features of this stage

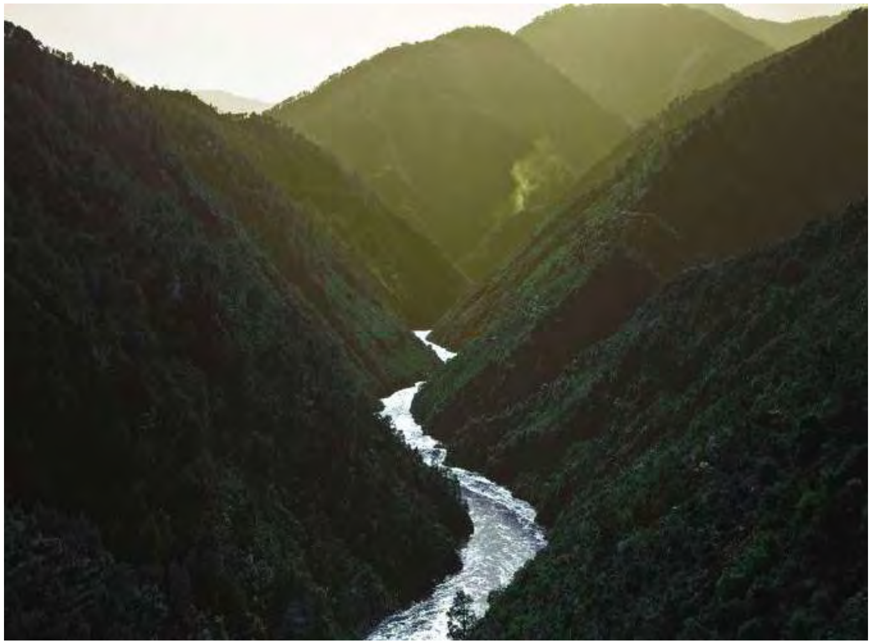
Old (Lower Course)

- 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.

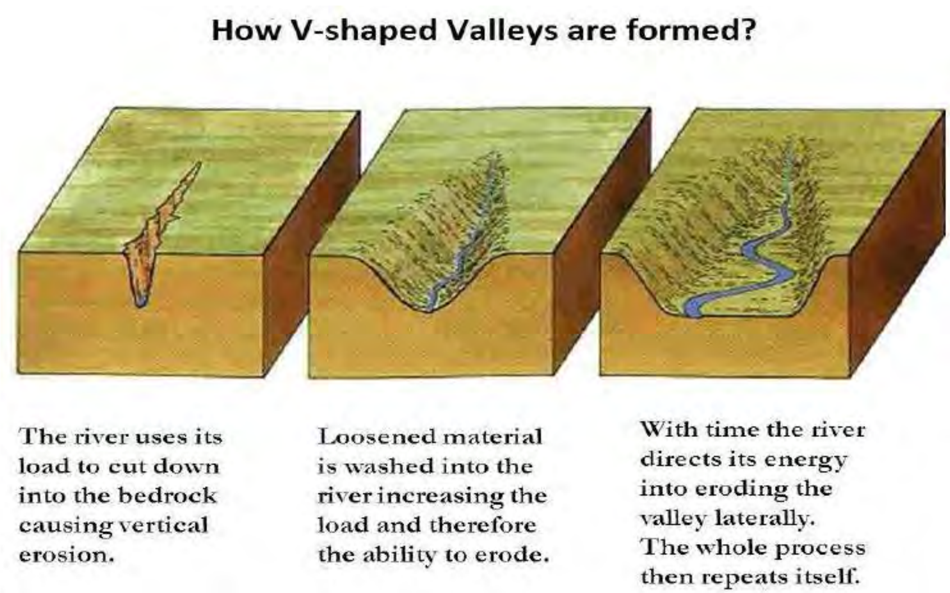
Fluvial Erosional Landforms

- 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

1) 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

2) 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

3) 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

Cascade

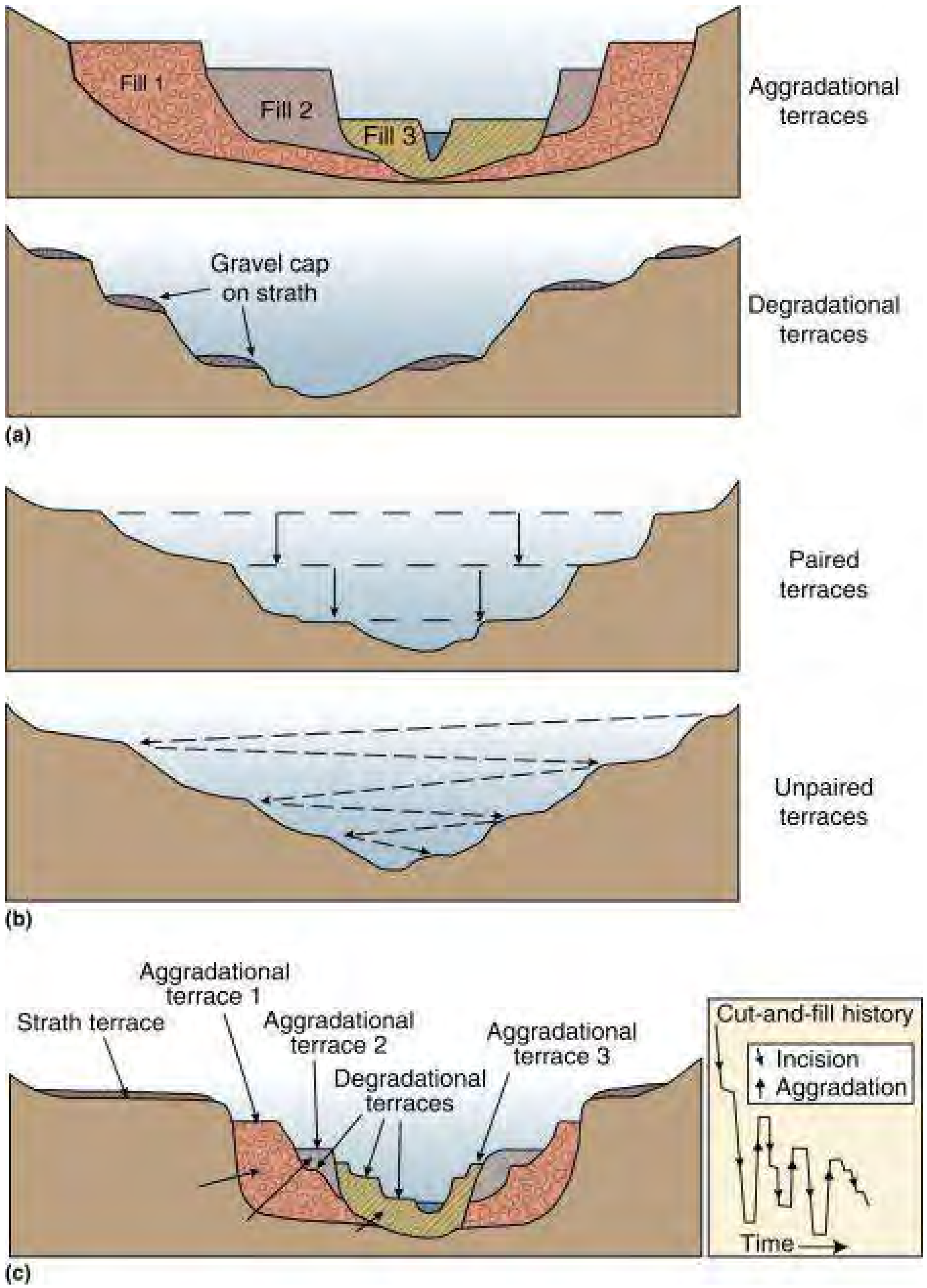
Waterfalls

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

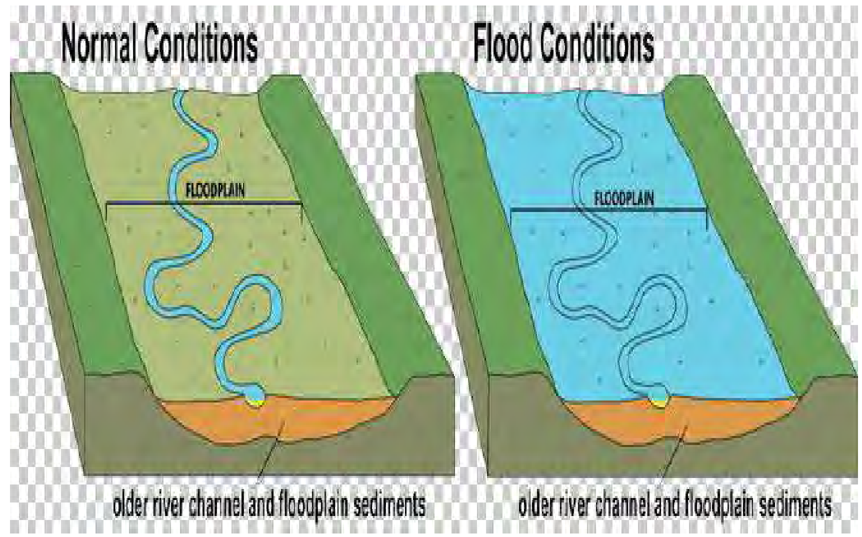
- Rocks and cliffs are continually weathered and eroded in the youth stage or upper course of the river.
- The river moving downstream on a level plain brings down a heavy load of sediments from the upper course.
- The decrease in stream velocity in the lower course of the river reduces the transporting 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 continuous fans.
- 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.

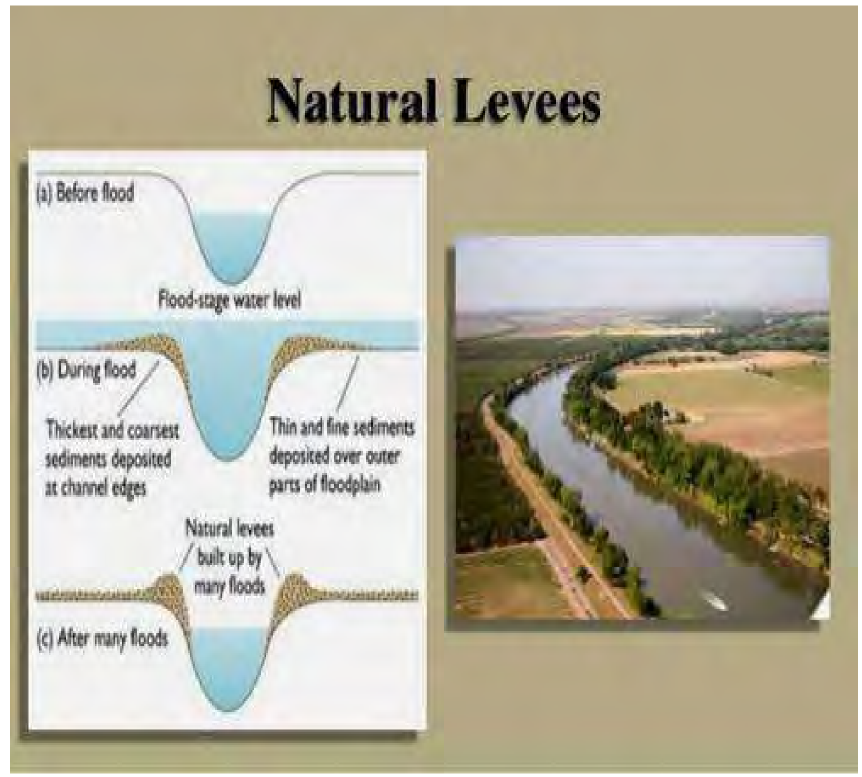
Floodplains

- 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 slow-moving 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 as ridges.
- 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 .

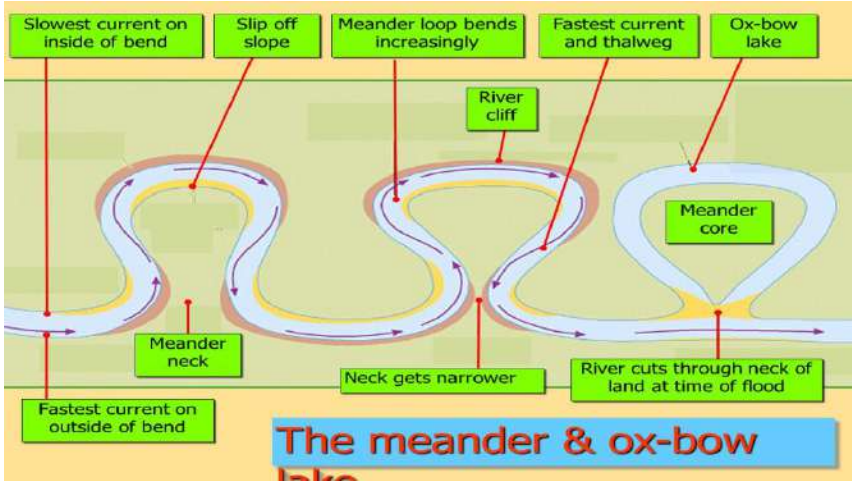


Point Bars

- 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

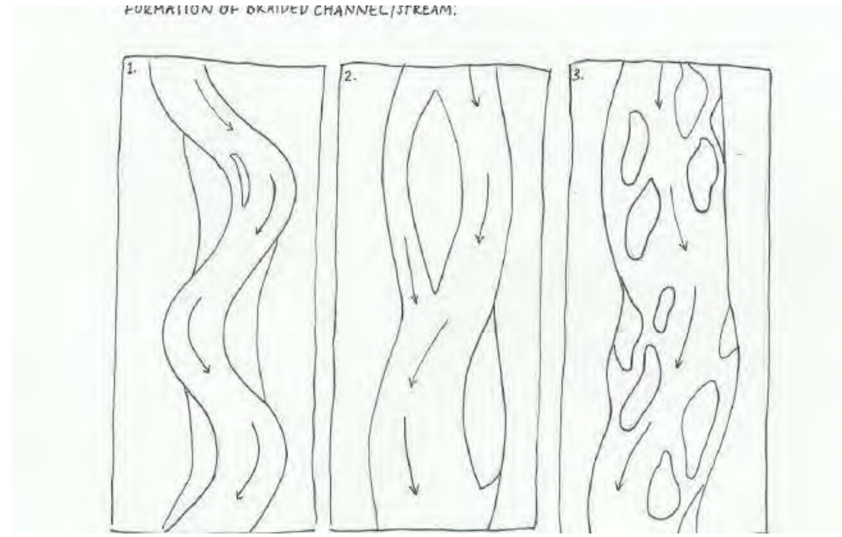


Oxbow Lakes

- 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.



Types of Deltas

- There are great variations in size, shape, growth and importance of Deltas. A great number of factors influence the eventual formation of deltas such as depth of the river, sedimentation, sea-bed, character of tides, waves and currents etc. owing to these factors several types of deltas can be found.

Deltas

- Deltas are fan-shaped alluvial areas, resembling an alluvial fan
- This alluvial tract is, in fact, a seaward extension of the floodplain
- The load carried by the rivers is dumped and spread into the mouth of the river at sea. Further, this load spreads and piles up as a low cone
- Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest sediments are deposited first and the finer sediments are carried out further, into the sea.
- Deltas extend sideways and seaward at an amazing rate
- As the delta grows, the river distributaries continue to increase in length and Delta continues to build up into the sea.
- Some deltas are extremely large. For example, the Ganges delta is as big as the whole west of Malaysia

- **Bird’s foot delta** It s a kind of delta featuring long, stretching distributary channels, which branch outwards resembling the foot of a bird. Deltas that are less subjected to wave or tidal action culminate to a bird s foot delta. Example the Mississippi River has a bird s foot delta extending into the Gulf of Mexico
- **Arcuate delta** Arcuate is the most common type of delta. This is a fan-shaped delta. It s a curved or bowed delta with the convex margin facing the sea. Arcuate deltas have a smooth coastline due to the action of the waves and the way they are formed. Examples - The Nile, Ganges and Mekong river deltas
- **Cuspate delta** A few rivers have tooth-like projections at their mouth, known as the cuspate delta. Cuspate deltas are formed where the river flows into a stable water body (sea or ocean). The sediments brought down by the rivers collide with the waves. As a result, Sediments are spread evenly on either side of its channel. Example Ebro river delta in Spain

Bird’s foot delta

Cuspate Delta

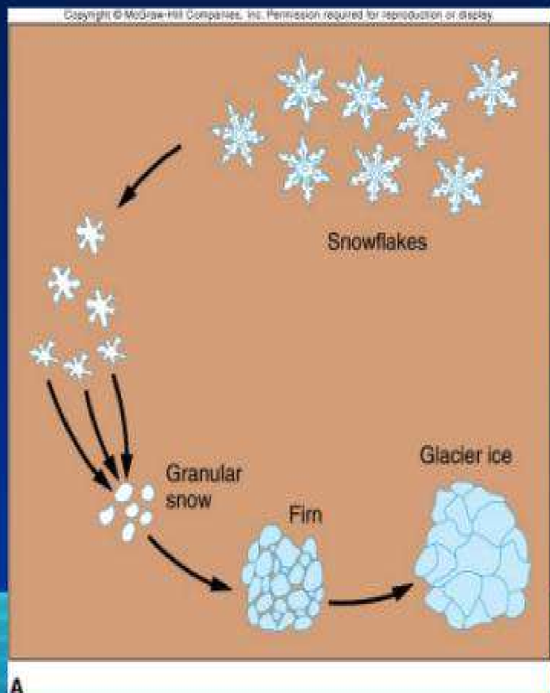
Arcuate Delta

- **Estuarine delta** some rivers have their deltas partly submerged in the coastal waters to form an estuarine delta. This may be due to a drowned valley because of a rise in sea level. Example Amazon river delta
- **Conditions favourable for the formation of delta**
- Active vertical and lateral erosion in the upper course of the river to provide extensive sediments to be eventually deposited as deltas
- The coast should be sheltered preferable tideless
- The sea adjoining the delta should be shallow or else the load will disappear in the deep waters
- There should be no large lakes in the river to filter off the sediments
- There should be no strong current running at right angles to the river mouth, washing away the sediments

Glacier

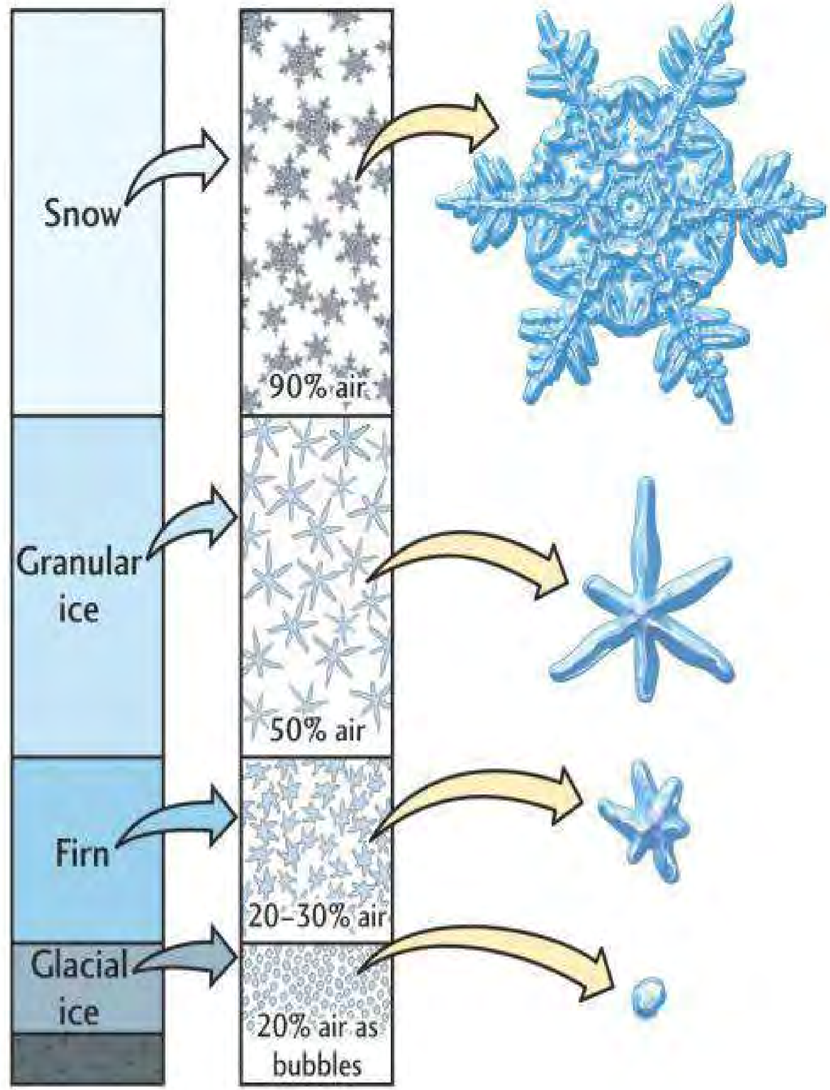
- A glacier is a large mass of ice that is persistently moving under its own weight over the land or as linear flows down the slopes of mountains in broad trough-like valleys
- Glaciers are formed in the areas where the accumulation of snow exceeds its ablation (melting and sublimation) over many years, 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.

Formation of Glacier



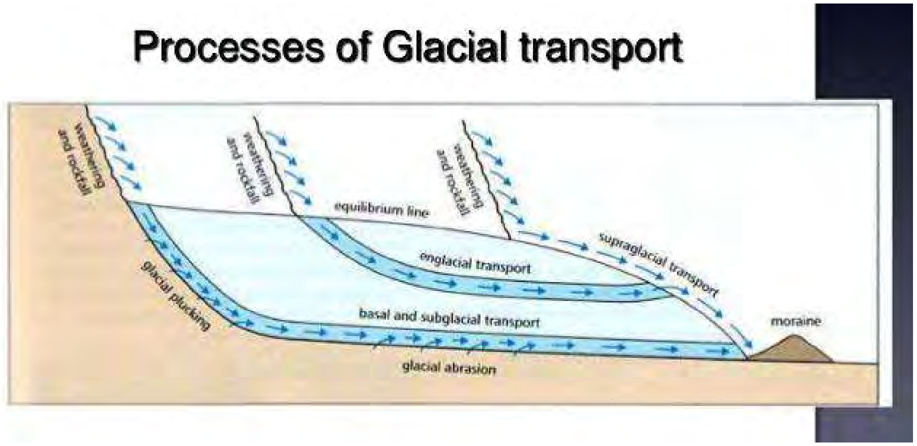
Snowflake ---> Granular snow ---> Firn ---> Glacial ice

Changes are due to increased pressure because of accumulation of overlying snow.



- 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'



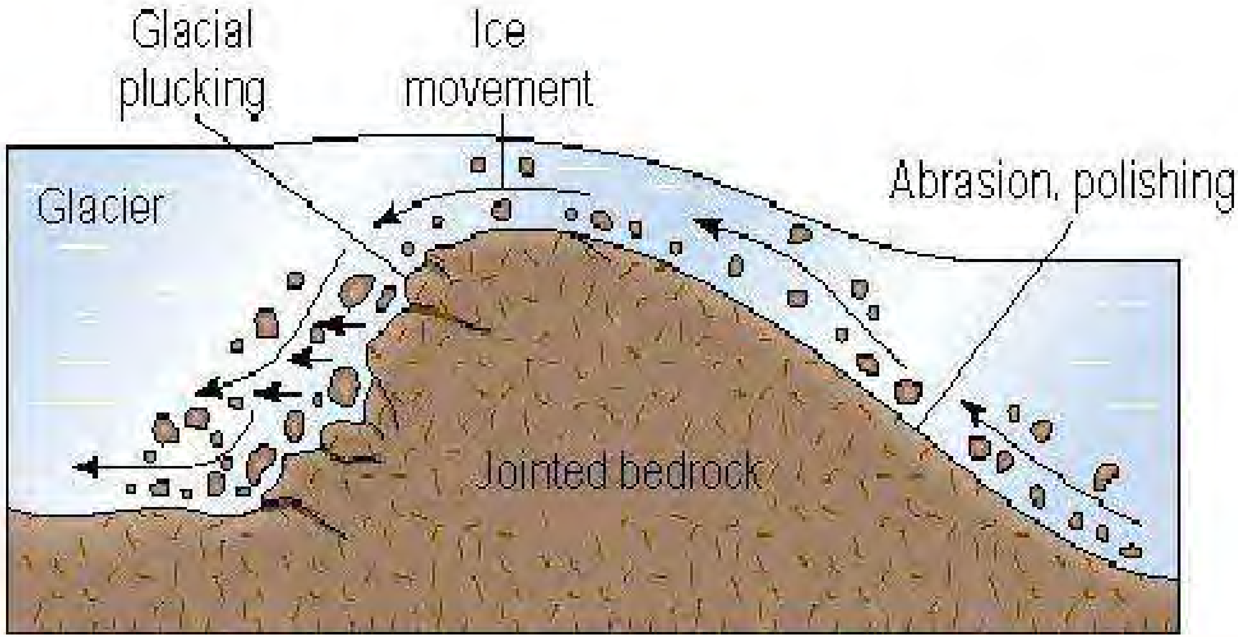
- Deposition: the glacial debris transported by the glacier ice and its associated meltwater is deposited either in the bed or along the sides or in the terminal zone of the glacier.
- Moraine is the term used to describe the rock debris transported and deposited by glacier.
- Glacial Till : Unassorted materials
- Outwash plain: assorted materials

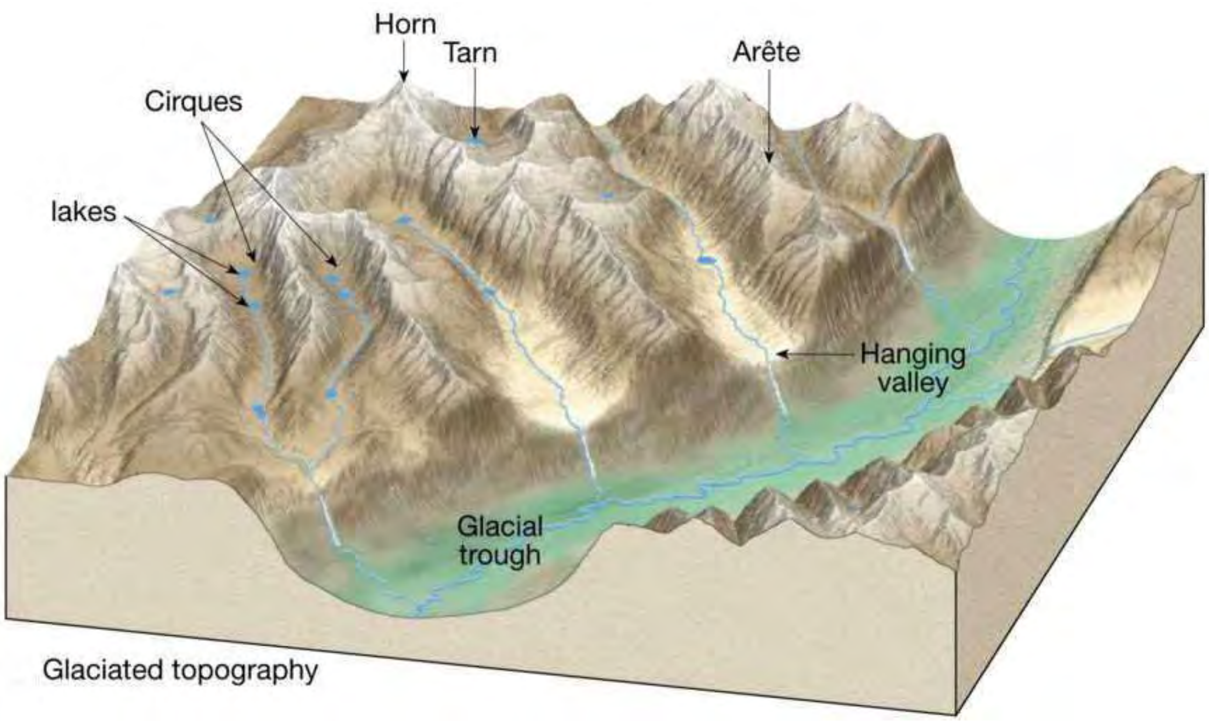
Types of Glaciers

- 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.





Glaciated topography

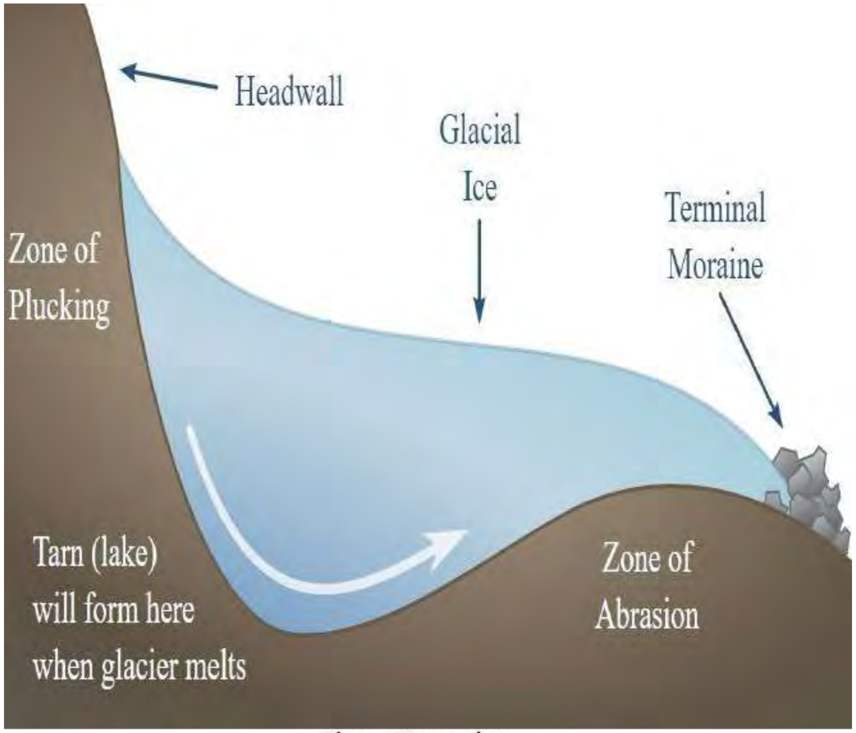
Glacial Landforms

- 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 head-ward 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 head-wards towards one another
- The divides between Cirque side walls or head walls get narrow because of progressive erosion and turn into serrated or saw-toothed ridges referred to as aretes with very sharp crest and a zig-zag outline.

Glacial Valleys

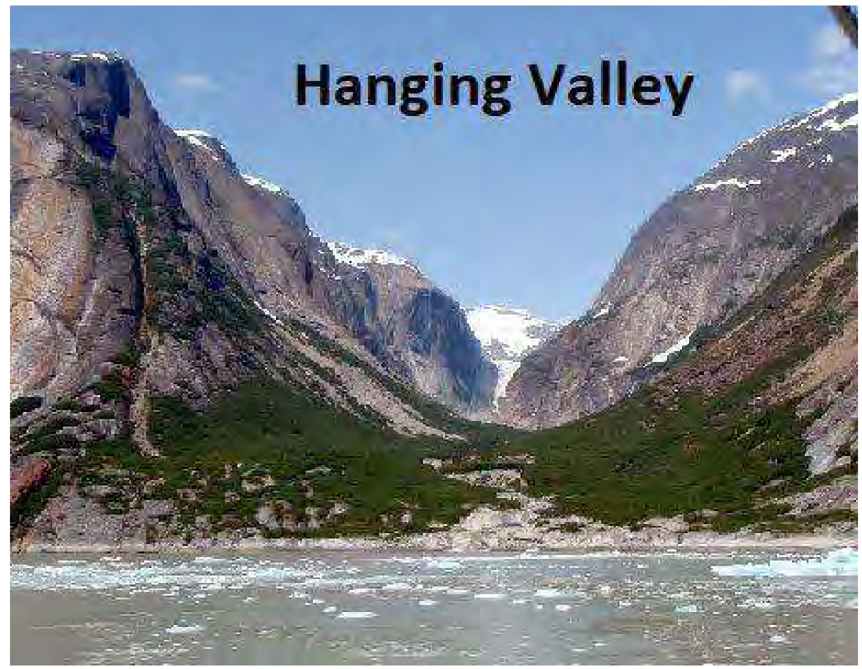
- Glaciated valleys are trough-like and U-shaped with wide, flat floors and relatively smooth, and steep sides.
- When the glacier disappears, and water fills the deep narrow sections of the valley, a ribbon lake is formed.

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.

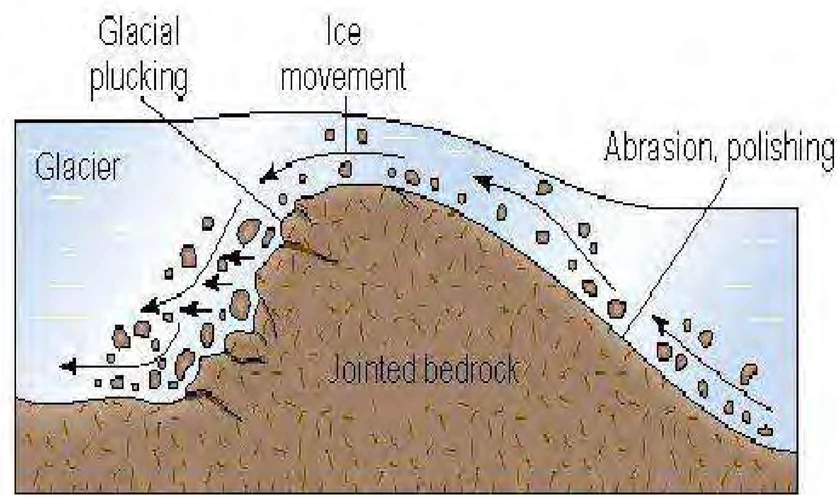
Hanging Valleys

- A hanging valley is a tributary valley that is higher than the main valley. Hanging valleys are common along glaciated fjords and U-shaped 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 down-glacier 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.



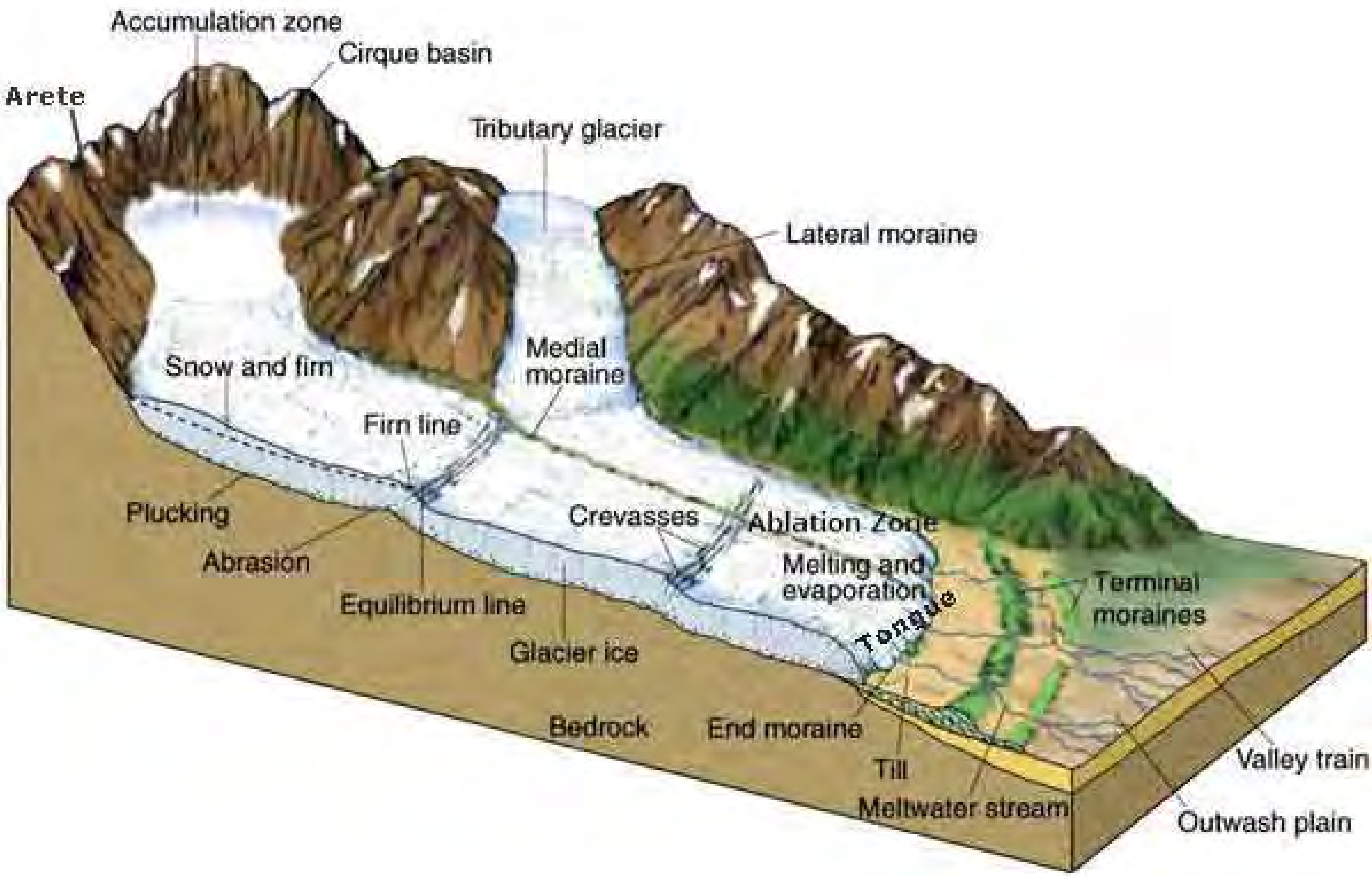
Depositional Landforms

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.

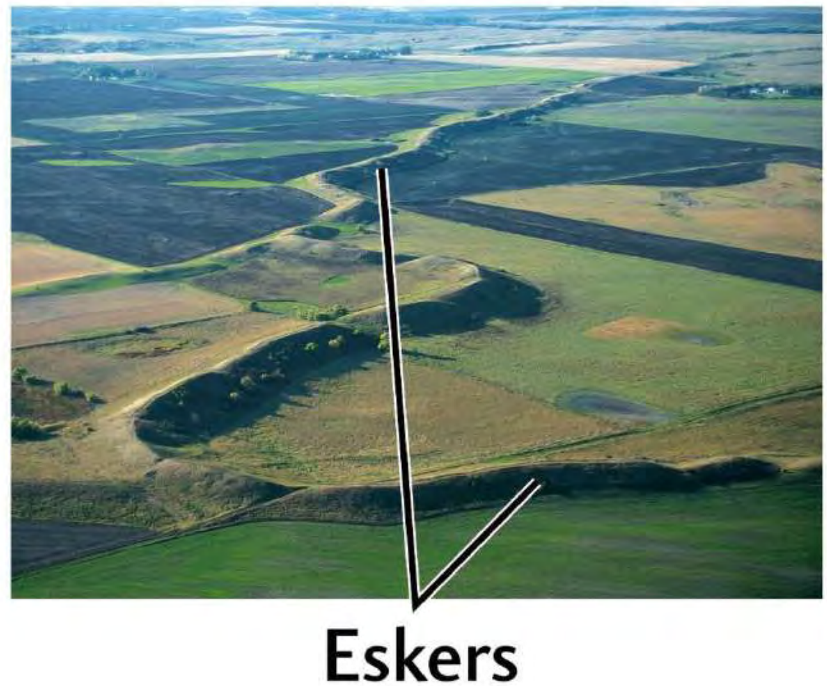
Moraines

- 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


Accumulation zone
Cirque basin
Arete
Tributary glacier
Lateral moraine
Medial moraine
Snow and firn
Firn line
Plucking
Abrasion
Equilibrium line
Crevasses
Ablation Zone
Melting and evaporation
Tongue
Terminal moraines
Glacier ice
Bedrock
End moraine
Till
Meltwater stream
Valley train
Outwash plain

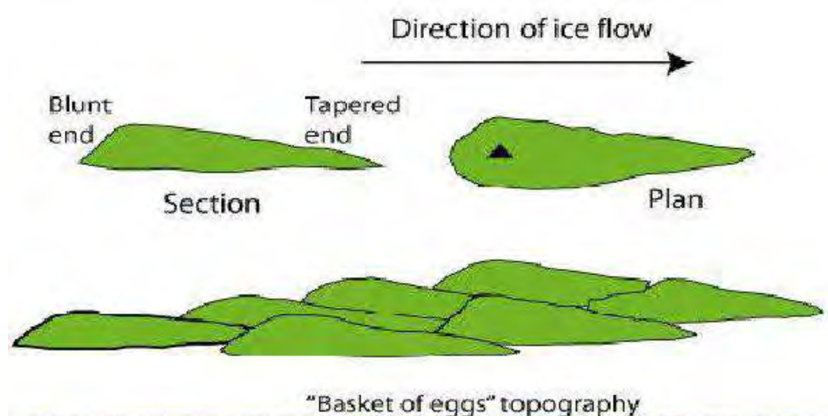
Eskers

- 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.



Drumlins

- Drumlins are smooth oval shaped ridge-like 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.



Aeolian Landforms

- 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

1. Attrition,
2. Deflation
3. 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 range of temperature 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’

Deserts

- Deserts are regions with very less precipitation concentrated to a very short duration. Around 20% of the geographical areas in the world are deserts.
- There is a certain definite pattern to the location of the world deserts
- Almost all the deserts are confined within the 15 to 30-degrees Latitude on both sides of the equator.
- Deserts are generally located in the west coasts of the continent as the Tradewinds are off-shore
- They are bathed by cold currents which produce a desiccating effect so that moisture is not easily condensed into precipitation

Type of deserts

- The works of wind and water in the erosion of elevated uplands, transporting the eroded material and depositing them elsewhere has given rise to five distinct kinds of desert landscape

Rocky desert

- Rocky deserts are also known as Hamada .
- They consist of large stretches of bare rocks, swept clear of sand and dust by the wind
- The exposed rocks are thoroughly smoothed and polished
- The region is bare and sterile
- Example the best known rocky deserts are those of the Sahara deserts

Stony desert

- It is also known as Reg
- Pebbles and gravels form an extensive sheet of the landscape of these areas.
- Stony deserts are more widespread than sandy deserts, contrary to the general idea of deserts associated with sandy landforms.
- Example Sturt Stony desert, Australia

Sandy deserts

- The commonly accepted idea of a desert is the sandy landscape with dunes.
- Vast stretches of dunes are deposited by winds, in these types of desert.
- The wind direction can be observed from the patterns of the ripples on dunes.
- Example Thar desert in India is a sandy desert

Badlands

- Badlands are arid regions where the hills are badly eroded under the action of water due to occasional rainstorms or flow of river streams
- They are represented by gullies and ravines
- Example famous ravines of Chambal in India, ravines in South Dakota, USA etc.

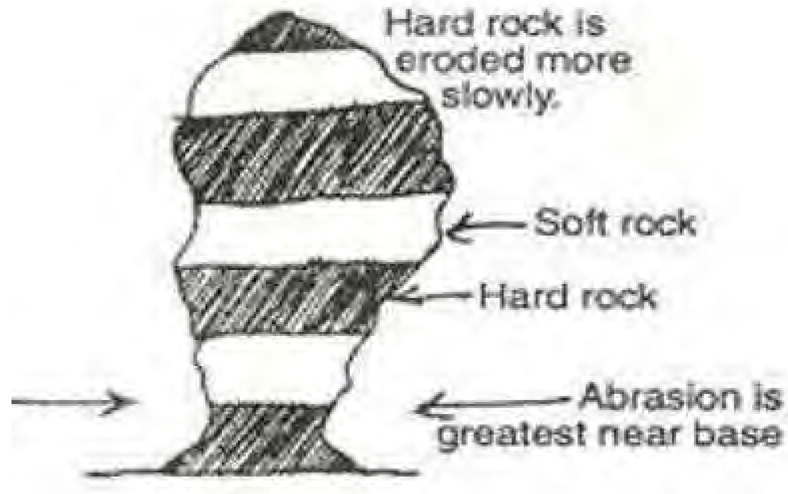
Mountain deserts

- Mountain deserts are found are found on highlands such as plateaux and mountain ranges
- Erosion has dissected the desert highlands into harsh, serrated outlines of chaotic peaks and craggy ranges
- They have steep-sided slopes and sharp and irregular edges carved by the action of frost
- Example Tibesti Mountains in the Sahara desert

Landforms of wind erosion

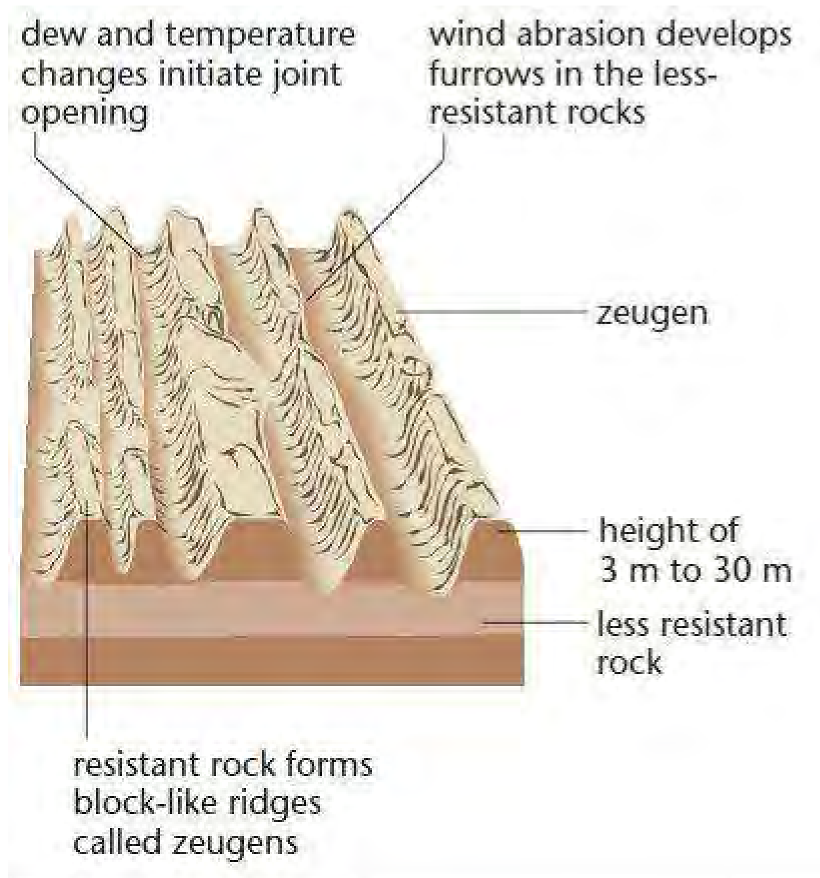
Rock pedestal or mushroom rocks

- 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.



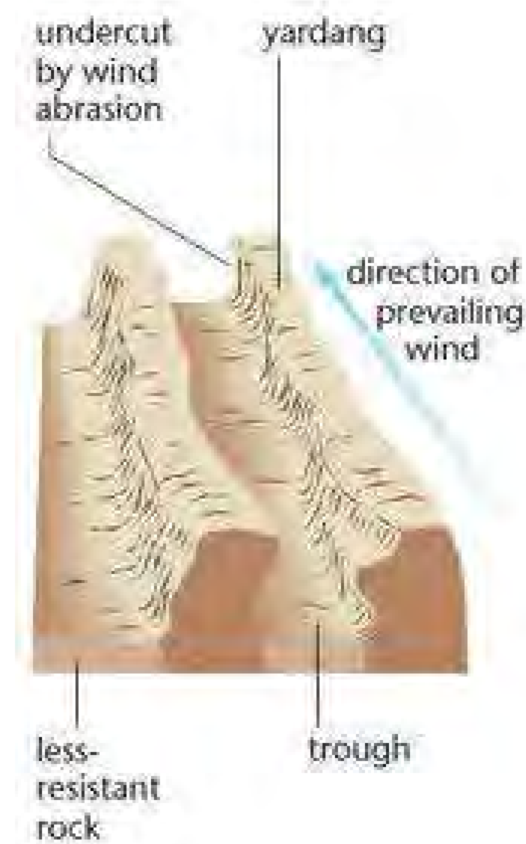
Zeugen

- 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 flat-topped 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

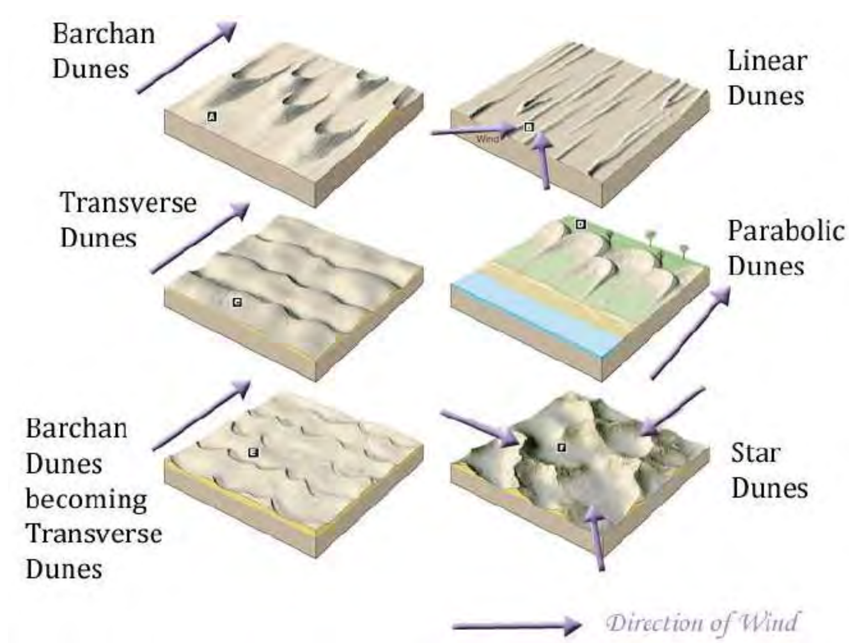
- Ventifacts are pebbles faceted by sand blasting
- They are shaped and polished by wind abrasion
- Mechanically weathered rock fragments are moved by wind in open settings to blast against the rock formations carving facets
- If wind direction changes another facet is developed
- Such rocks have characteristic 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.

Landforms due to water action

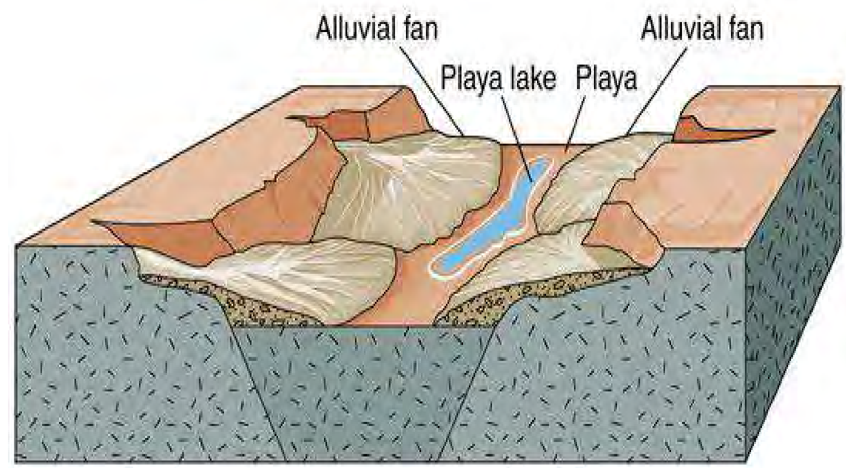
- Desert areas have scanty rainfall. However, there are deserts without rainfall also.
- However, occasional and sudden rainfalls in torrential downpours may produce devastating effects due to flash floods etc.
- Loose materials such as gravel, sand and fine dust are swept down the hillsides. They cut deep gullies and ravines forming badland topography
- There are so much fine materials in the flash floods that the flow becomes liquid mud

Bajada

- The Bajada is a depositional feature made up alluvial material laid down by the intermittent streams
- Bajada is formed by the coalescence of alluvial fans
- These fan-shaped deposits form from the deposition of sediment by a stream from upland region onto flat land at the base of a mountain
- Bajadas are common in arid areas where a large quantity of sediment is deposited by flash floods
- Bajadas frequently contain playa lakes

Playa

- In arid areas drainage from upland regions into the lower depression, in times of sufficient water, create shallow water body or a temporary lake
- Such types of shallow lakes are called as playas where water is retained only for short duration due to evaporation
- Quite often the playas contain good deposition of salts.
- The playa plain covered up by salts is called alkali flats.



Pediments and Pediplains

- A pediment is an erosional plain formed at the base of the surrounding mountain scarps
- They are gently inclined rocky floors close to the mountains at their foot with or without a thin cover of debris.
- They form through the erosion of mountain front through a combination of lateral erosion by streams and sheet flooding.
- Through parallel retreat of slopes, the pediments extend backwards at the expense of mountain front
- Gradually, the mountain gets reduced leaving an inselberg which is a remnant of the mountain.
- That s how the high relief in desert areas is reduced to low featureless plains called pediplains.

Karst Landforms

Introduction

- Karst is an Yugoslavian word.
- Limestone is an organically formed sedimentary rock. In its pure state, limestone is made up of calcite or calcium carbonate but where magnesium is also present it is termed as dolomite. Limestone is soluble in rainwater.
- On the Adriatic coast in Yugoslavia and the adjoining areas in Italy there is a limestone plateau known as Karst which provides the best example of landforms produced by the solution action of underground water.
- This region is 500 km long from N.W to S.E. Along the coast and is about 80 km wide.
- This plateau is about 2,500 metres high above sea level.
- Also found in Causses region of southern France, Andalusian region of Spain, Yucatan and Tabasco in Mexico, Jamaica, northern Pureto Rico, Western Cuba, Southern China, Vietnam and Malaya, Indiana-Kentucky region of U.S.A.,
- India: Jabalpur and adjacent areas in Madya Pradesh, Rohtas Plateau in Bihar, Kumaun Himalayas near Almora, parts of Jammu and Kashmir and Meghalaya

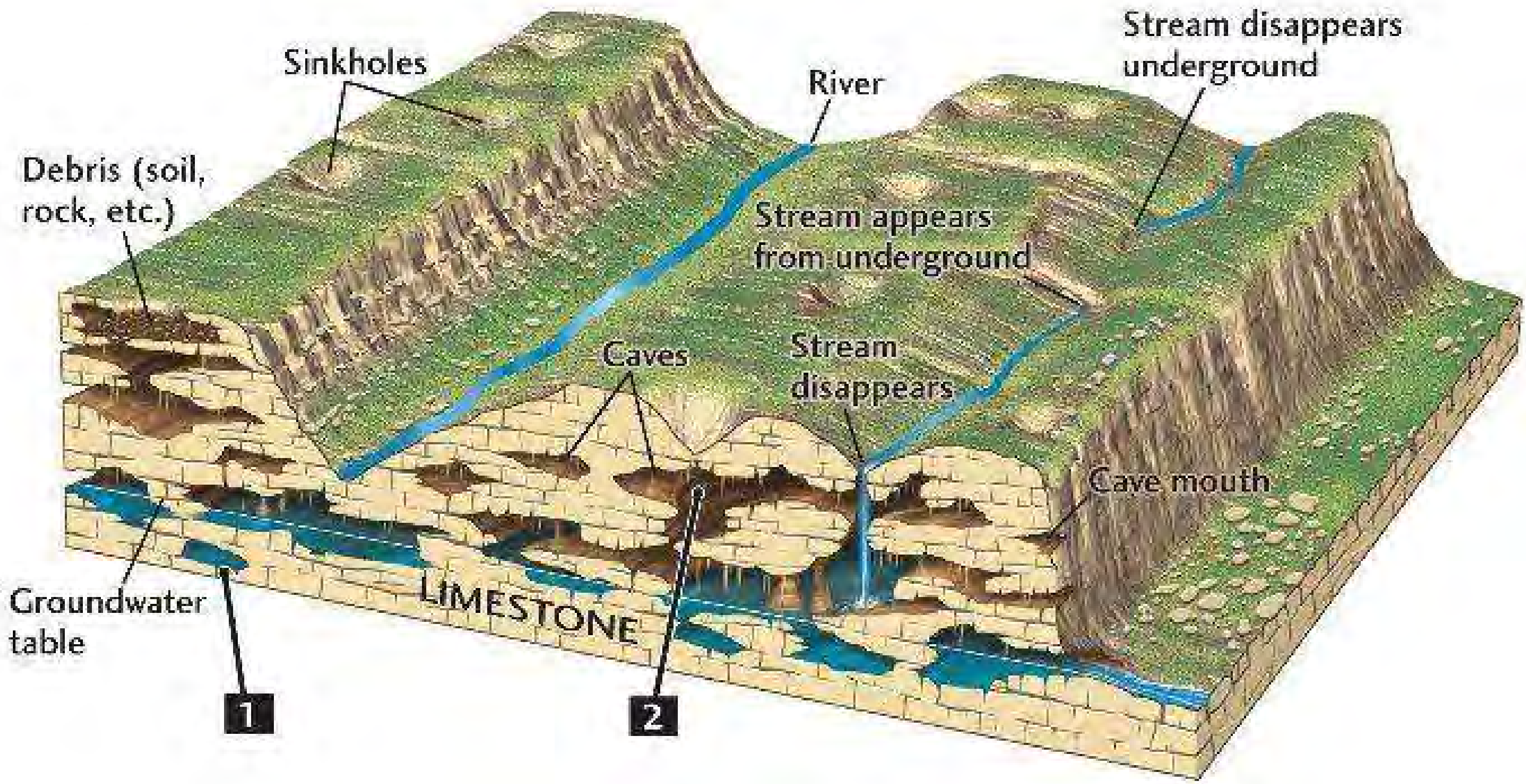
Conditions for the formation

- A region with a large stretch of water-soluble rocks such as limestone at the surface or sub-surface level
- The soluble rock should be dense, thinly bedded and well jointed and fractured to allow the easy passage of water.
- Areas where deep valleys are found close to a highland which has an extensive basement of limestone.
- Moderate to abundant rainfall for the supply of underground water.

Limestone Rocks

Mechanism of erosion in Karst region

- In Karst regions, rocks are permeable, thinly bedded and highly jointed and cracked.
- Thus there is the general absence of surface drainage as the surface water has gone underground
- After vertically going down to some depth, the water under the ground flows horizontally through the bedding planes, joints or through the materials themselves.
- Rocks are eroded due to this downward and horizontal movement of water.
- It is through the chemical process of solution and deposition by surface water and groundwater, varieties of landforms are developed in rocks like limestones or dolomites rich in calcium carbonate.


Sinkholes
River
Stream disappears underground
Debris (soil, rock, etc.)
Stream appears from underground
Caves
Stream disappears
Cave mouth
Groundwater table
LIMESTONE
1
2

Erosional Landforms

Terra Rosa

- When rainwater dissolves part of surface rock and enters the sub-surface, particles of red clay soil are deposited on the surface as well as in the opened joints. This is called terra rosa, and resembles lateritic soil.
- It may present on the steep slopes but can be seen in areas which are either flat or have gentle slope
- Sometimes it may be several feet thick and entirely cover the rocky surface.

Lapies/ Karren

- Where the limestone surface is not covered with terra rosa and the surface is undulating, solution action of water tends to enlarge the rock joints downwards
- These grooved, fluted and ridge-like features in an open limestone field are called lapies (French). In Germany, this kind of landform is called 'karren'
- These ridges or lapies form due to differential solution activity along parallel to sub-parallel joints.
- Eventually, the lapie field may transform into smooth limestone pavements.

Sinkhole

- When rainwater percolates into limestone, it enters the rock joints and removes the soluble elements by solution. The joints increase in size by solution and provide even easier passage for the water. The formation of holes along the joints are Sinkholes.
- A sinkhole is an opening more or less circular at the top and funnel-shaped towards the bottom
- There is a great variation in sizes of Sinkholes with areas from a few sq. m to a hectare and with depth from a less than half a metre to thirty metres or more.
- These holes grow in size through continuous solvent action
- They are also referred to as solution sinks
- Similar dry holes are met with in the chalk areas of Britain which are cylindrical and are called swallow holes, as these surface openings almost swallow the surface drainage during the rains.

Doline

- The enlarged funnel-shapped sinkholes are called dolines.
- They are also referred to as Collapse sinks .
- They are less common than sinkholes
- They might start as solution forms first, and if the bottom of a sinkhole forms the roof of a void or cave underground, it might collapse leaving a large hole opening into a cave or a void below
- They are usually 6 to 75 feet and have a diameter of 30 to 400 ft

Uvalas

- They are long, narrow to wide trenches, also referred to as Valley sinks .
- Several sinkholes and dolines may merge together as a result of subsidence to form a large depression called an Uvala.

Polje

- A polje is a very large, flat-floored depression in the karst region.
- They are often formed by merging of several uvalas or partly due to faulting
- The area of a polje may cover several sq.kms. The largest polje in Yugoslavia in the western Balkans is the Lvno polje which is 70 kms long and 5 to 11 kms wide.
- A typical polje is an elongated basin with a flat floor and steep sides
- Drier areas are fertile. Usually covered with thick sediments, they are used extensively for agricultural purposes

Ponor

- A ponor is a natural surface opening in the karst regions
- They are found directly underneath the sinkholes
- Vertical or inclined shafts leading from the sinkholes or dolines to the underground caves are known as ponor.

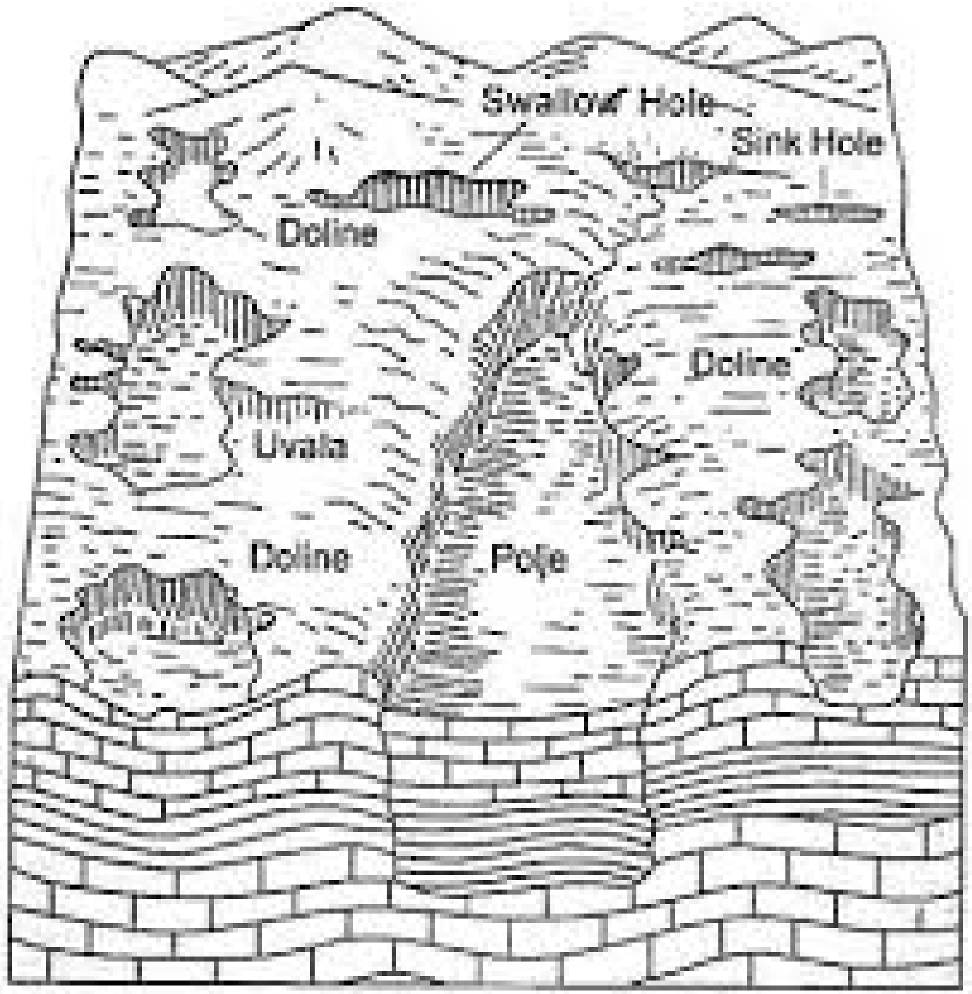


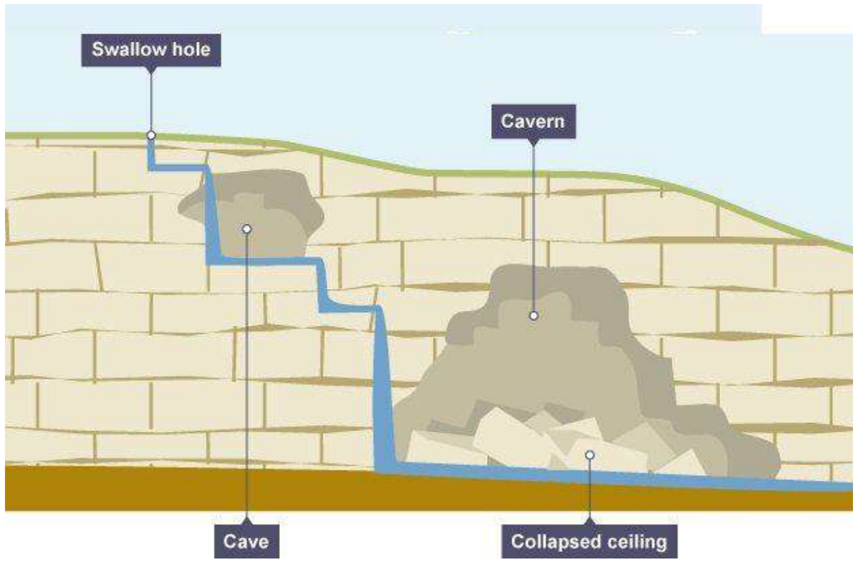
Fig. 19.5 : Sink holes, swallow holes, dolines, uvalas and poljes.

Residual hills

- In limestone areas, after a long period of solutional erosion, some residual hills and hillocks remain which resemble monadnocks. These rounded limestone hills rise from the polje surface.
- They are known as hums in Yugolsavia, pepino hills or haystack hills in Puerto Rico and mongotes in Cuba

Caves

- Cave formation is prominent in areas where there are alternating beds of rocks (sandstone, shale, quartzite) with limestone or dolomite in between or in areas where limestones are dense, massive and occurring as thick beds.
- Water percolates down either through the materials or through cracks and joints and moves horizontally along bedding planes.
- Gradually, the limestone dissolves along these bedding planes resulting in the creation of long and narrow gaps called caves.



Depositional landforms

- Depositional landforms in karst region are developed due to the deposition of calcium carbonate. The calcium carbonate dissolved during the erosional process starts to precipitate when the water evaporates or when the solution is super-saturated.
- Stalactites, Stalagmites and Pillars are the most spectacular underground features, found in the limestone caves.

Stalactites

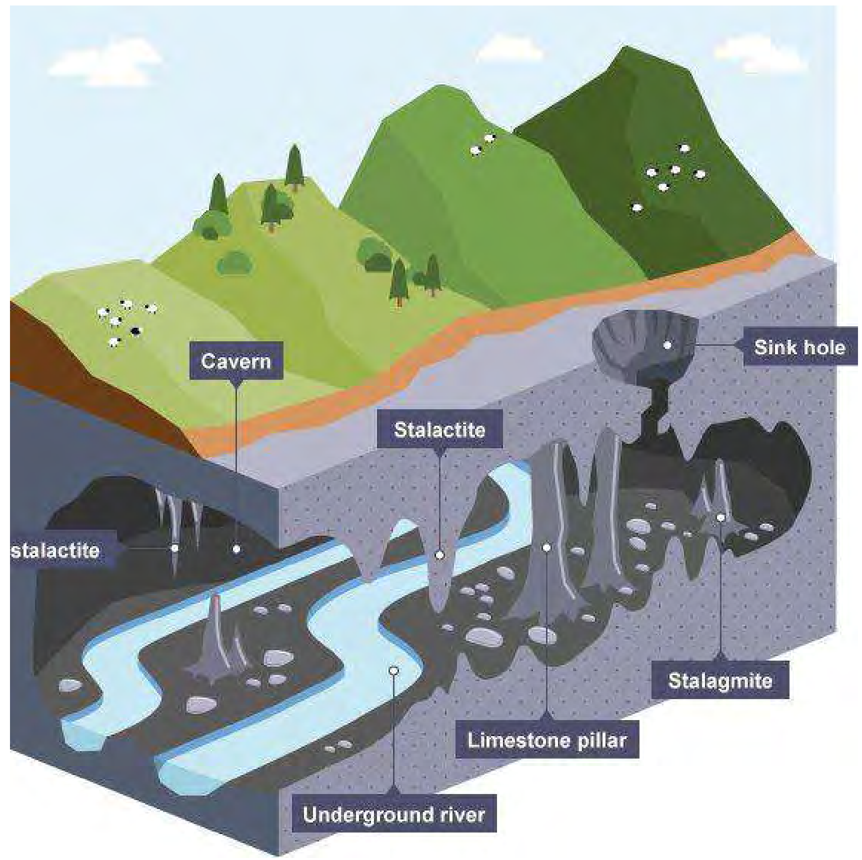
- Stalactites are the sharp, slender, downward-growing icicles of different diameters that hang from the cave roofs.
- Stalactites have a variety of forms
- Their bases are normally broad which taper towards the free ends
- The water carries calcium in solution and when this lime-charged water evaporates, it leaves behind the solidified crystalline calcium carbonate.

Stalagmites

- Stalagmites form due to dripping water from the surface or through the thin pipe, of the stalactite, immediately below it
- Moisture dripping from the roof trickles down the stalactite and drops to the floor where stalagmites are formed due to deposition of calcium
- Stalagmites may take the shape of a column, a disc, with either a smooth, rounded bulging end or a miniature crater-like depression.

Pillars

- Over a long period, the stalactite is eventually merged with the stalagmite
- Thus, the pillars or columns of different diameters are formed.



Limestone Pavements

- A limestone pavement is a natural karst landform consisting of a flat, incised surface of exposed limestone that resembles an artificial pavement.
- These are formed by the solvent action of underground water in the limestones, causing progressive widening and enlargement of joints and cracks in the trenches.
- The enlarged joints are called grikes and the isolated, rectangular blocks are termed as clints.

UNIT V:Applied Geomorphology: Geomorphology in Mineral Exploration – Engineering projects - Dams - Flood Management - Coastal zone management.

Applied Geomorphology

- There has been an increasing recognition of the practical applications of geomorphic principles and the findings of geomorphological research to the understanding and solution of the problems facing mankind in his use of the natural environment
- Rapid growth of population has led to increasing pressure on land resource, and large scale deforestation and extension of agriculture to hilly and marginal lands have resulted in widespread and recurring man-induced catastropies like soil erosion, landslides, floods and sedimentation.
- In many areas massive urbanization and various kinds of constructional and developmental projects have given rise to all kinds of environmental problems.
- Geomorphology can help in the identification and solution of many of these problems.

- The role of applied geomorphology relates mainly to the problem of environmental resource management and consists principally of analysing and monitoring landscape forming processes in relation to surface materials and evaluating landscape changes that may arise from human interference.
- The aims are to assist in the efficient discovery, assessment and wise management of the earth's finite resources, to prevent environmental deterioration and to avoid or prevent natural hazards.
- The capability of the geomorphologist to make a worthwhile contribution has been greatly enhanced recently by quantitative study of process-form relations at the micro-level, interpretation of remote sensing imagery and air-photo analysis and his active participation in inter-disciplinary research in land and project surveys and environmental management programmes.

- As a result, agricultural scientists, engineers, geologists, hydrologists, geographers, planners, policy decision makers and others are becoming increasingly aware of the importance of applied geomorphology.
- Though some basic studies of geomorphological processes having practical applications were carried out in the first half of the 20^{th} century, major advances really date from the 1950s.
- Terrain evaluation studies which were undertaken both in developed and developing countries after the second world war primarily for military and strategic purposes yielded valuable data about land's geomorphological characteristics for assessing land potential and for providing a basis for land use planning.

- In Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO) developed the land system approach in which an inventory of landform classification provided the framework for storing knowledge about the physical landscape.
- During the same period a comprehensive scheme for mapping land surface form, materials and processes as a basis for planning, known as geomorphological mapping was started in Poland, Russia and other countries, its main purpose being a comprehensive analysis natural resources or its physical limitations for development.
- During 1960s and 1970s geomorphology played a leading role in the resource surveys and mapping undertaken in a number of developing countries and in otherwise unknown terrain.

- At the international level the International Geographical Union appointed a commission on Applied Geomorphology in 1956, followed in 1968 by the commission on (i) Man and Environment, (ii) Geomorphological Survey and Mapping, (iii) Present-day geomorphological processes, and in 1976 by the Commission on Environmental problems and Field experiments in Geomorphology.
- According to Verstappen (1983), (the Netherland Geomorphologist) geomorphology has diverse applications over a large area of human activity. These include;
- 1. applications in the field of earth sciences, including topographic and thematic mapping of natural resources

- 2.applications in the field of environmental studies, especially in the survey of natural hazards, landslides, avalanches, earthquakes, volcanism, land subsidence, flooding and drought
- 3.applications in the field of rural development and planning emphasizing land utilization, erosion control, conservation and river basin development
- 4.applications in the field of urbanization for urban extension, site selection or mining
- 5.applications in engineering including assessments for communication networks, river and coastal engineering

- According to D.K.C. Jones, applied geomorphology could be defined as “the application of geomorphic understanding to the analysis and solution of problems concerning land occupancy, resource exploitation, and environmental management and planning”.

  The application of geomorphology, according to Charley, Schumn and Sugden

- (i) Geomorphology can be an aid to resource evaluation, engineering construction and planning.
- In this category we may put resource inventories, environmental management, soil and land evaluation, production of maps for hydrological, erosional and stability control, geomorphic mapping, mapping for land systems and evaluating terrain, classification and retrieval of information on terrain and other matters of use to earth scientists, engineers and planners.

- Applied geomorphology in this aspect can be of use in urban planning in different geomorphic environments and in preparation of natural hazard maps, morpho-agricultural regionalisation, land use planning, construction and management of roads.
- (ii) Applied geomorphology is also concerned with human beings as geomorphic agents, in terms of their planned or inadvertent effects on geomorphic processes and forms.
- Human beings have over time tried to tame and modify geomorphic/environmental processes to suit their economic needs.
- Embankments have been built to check flooding of rivers; meandering courses of rivers have been straightened and channels diverted; coastal areas have been sought to be protected against wave erosion by building walls; there have been attempts to stabilise sandy areas through plantation, and check soil erosion through afforestation. These are some examples of planned activities by human beings that have an impact on geomorphic forms and processes.

- The inadvertent effects of human activities on geomorphic forms and processes are many:
  - ➢ forests are cleared and grasslands burnt for cultivating crops or for building settlements;
  - ➢ mining activities and water extraction cause subsidence of land; building and mining activities result in modification of terrain;
  - ➢ excessive, unplanned deforestation causes accelerated soil erosion and increase in sediment load leading, in turn, to recurrent floods and riparian decay.
  - ➢ Pollution has been a major inadvertent effect of human economic activity.
  - ➢ Dams cause changes in river load and accelerated erosion. High altitude construction has modified permafrost.

Geomorphology and Hydrology

- Water used by human beings is available from different sources—streams, lakes and rivers on the surface of the earth or groundwater. Different stratigraphic and lithological zones present different conditions of surface and groundwater.
- Limestone terrains vary widely and the ability to yield water depends on the type of rock. Permeability in limestones may be primary or secondary. Primary permeability depends upon the presence of initial interconnecting voids in the calcerous sediments from which the rock was formed. Secondary (or acquired) permeability occurs because of earth movements such as faulting, folding, warping, and due to solution or corrosion mechanism.
- This secondary permeability varies notably with respect to the topography of a region, being greatest beneath and adjacent to topographic lows or valleys. Much of the groundwater in karst terrain is confined to solution channels.

- In early stages of karst evolution conditions are not too different from those of other types of landscapes with similar relief. But as the cycle advances, a large proportion of water is diverted to solutionally opened passageways, and surface water gets diminished.
- The main source of water in such regions then are karst springs. Such springs may supply water to meet moderate demands, but the quality of water may be affected by pollutants and bacteria.
- The sources of the spring water should be determined in such a case of pollution. The swallow holes and sinkholes feeding water to the underground drainage systems emerging as springs may be located.
- This can be done by putting some colouring material, such as fluorescein, into the water entering nearby swallow holes (or sinkholes) and testing the various spring waters to find out their source.
- A knowledge of the structural geology of the region is of use in this context, as groundwater moves down rather than up the regional dip.

- The ease with which water may be obtained in a limestone region depends on the geomorphology of the area. If the limestones have enough permeability and are capped by sandstone layer, there may be no difficulty in obtaining wells of large yields. Moreover, the water would get naturally filtered as it passes through the sandstone beds.
- If, however, the limestone is dense and compact, with little mass permeability, movement of groundwater will be largely through secondary openings. In such circumstances, the yield of water may be low or, even if adequate, subject to contamination.
- Karst plains lack a filtering cover and sinkholes, swallow holes or karst valleys within an area of clastic rocks (rock fragments or clasts) should cast doubt on the purity of the water from springs nearby.

- Groundwater potential in glaciated regions can be determined on the basis of understanding the geomorphic history of the area, characteristics of glacial deposits and landform.
- Outwash plains, valley trains (glacial deposits) and inter-till gravels are likely to yield large volumes of water. Most tills (unsorted glacial sediments) are poor sources of water because of the clay in them, but they contain local strata of sand and gravel which may hold and supply enough water for domestic needs.
- Buried preglacial and interglacial valleys could be good sources of groundwater. Their presence (or absence) may be detected by studying the preglacial topography and geomorphic history of the area. Buried valleys are located by constructing bedrock topography maps of glaciated areas.

Mineral Exploration

- Geomorphological knowledge can be used as an exploratory tool in the search for minerals.
- Geomorphic features may be helpful in locating mineral deposits in three ways.
- 1. some mineral and ore bodies have direct surface expression as landforms
- 2. the relief features of an area may provide a clue to the geological structure which has favoured the deposition of particular minerals
- 3. the geomorphic history of an area may provide an insight into the physical conditions under which the minerals were deposited or enriched

Surface expression of minerals

- Some ore bodies have direct surface expression either as relief features or as structural features or as outcrops of ore or residual minerals.
- Aerial photographs may help in the recognition of sites worthy of detailed field examination
- The lead-zinc lode at Broken Hill, Australia is marked by a conspicuous ridge. Massive outcrops of hematite and magnetite ores occur as whole hills in the rocks of the Dharwar system in the Indian Peninsula.
- The iron bearing hematite-quartzite of iron ore series in the Singhbum-Mayurbhanj region of Jharkhand and Orissa, stand out as sharply inclined hills about three thousand feet high.
- The pre-Cambrian iron ore deposits of the Lake Superior region in U.S.A. are so much associated with hills and ridges that they are commonly referred to as the Iron Ore Range.

- The rich deposit of high grade iron ore at Cerro Bolivar, Venezuela was discovered by field investigation of two small mountains showing on the aerial photograph.
- Bauxite carrying flat topped isolated table lands known as ‘pats’ in western Chota Nagpur, where the basalt capping the plateau has been weathered to laterites.
- In the Chinhuahua region of Mexico as well as in part of Arizona and California, quartz veins stand out as hills and ridges because of their greater resistance to weathering and erosion than the surrounding rocks.
- In some areas the mineralized areas may be found associated with depression or subsidence features.

- The coal bearing Gondwana rocks of India are found in association with river valleys or down faulted basins, e.g., the Damodar basin, the Mahanadi basin and the Wardha valley etc.
- Calcite veins in parts of Arizona and British Columbia coincide with surface depressions.
- After reduction in bulk of the ore body due to oxidation, the roof may collapse, resulting in what has been called oxidation subsidence or mineralization slump.

Weathering and economic deposits

- Several economic mineral deposits, such as iron ore, bauxite, the clay minerals and some manganese and nickel ores are essentially weathering residues, the more mobile elements being leached away in solution.
- Weathering and erosion are constantly at work on the earth's surface leave behind certain products which may form economic deposits.
- The distinctive banded iron formation of Pre-cambrian age which supply much of the world's iron ore are residual iron deposits resulting from long periods of weathering which has leached the silica, leaving an enriched iron bearing deposit

- On limestones, where solution can remove most parts of the rock, insoluble residues accumulate. They consist of clay and iron oxides and give rise to the red soil known as terra rosa.
- Bauxite, the ore of aluminium, is a weatherin residue which forms primarily through intense leaching in tropical or subtropical regions and removal of all other materials including silica and iron oxides.
- Weathering processes may also lead to the formation of enriched ore deposits. The valuable minerals are transported down the weathering profile where they may be redeposited.
- In this way rich ores may be made richer, lean ores (low grade) more valuable and non-commercial primary material may be improved to commercial grade. This process is called ‘supergene enrichment’.

Epigenetic minerals

- Minerals which are younger than the rocks containing them are called epigenetic minerals.
- They have been ound to be associated with ancient erosion surfaces which now occur as unconformities covered by later deposits.
- It is found in U.S.A., and Canaada where the age of the minerals ranging from Pre-cambrian to Tertiary

Placer deposits

- Placer deposits are mechanically deposited minerals which accumulate where the speed of the medium carrying the minerals falls.
- Placer mineral concentrations result from specific geomorphological processes and ae found in specific topographic positions.
- Nine types of placer deposits are recognised.
- 1. residual, 2. colluvial, 3. alluvial, 4. aeolian, 5. bajada, 6. glacial, 7. beach, 8. buried and 9. ancient placers

- Residual placers are residues from the weathering of quartz veins and are usually of limited amount
- Colluvial placers are produced by downslope creep of residual materials and are transitional between residual and alluvial placers.
- Alluvial placers are the product of fluvial activity and are the most important. Gold, tin, platinum and diamond are among the minerals obtained from alluvial placers. In India alluvial gold placers are found in the Subarnerekha valley in Chota Nagpur.
- About 1/3 of the world's platinum is derived from alluvial placers, particularly in Russia and Colombia. About 1/5th of the world's diamond comes from alluvial placers deposts, including the Vaal and Orange river districts of South Africa, Congo Republic and Minas Geraes in Brazil
- Aeolian placers are a source of gold in Australia and Mexico.
- Bajada placers form in the gravel deposits of a pediment and in the alluvial fans near the mountain base.

- Beach placers have yielded diamonds in Namaqualand, South Africa, gold in California, ilmenite and monazite from the Keala coast in India, and zircon in India, Brazil and Australia.
- Glacial placers are not important but gold has been found in the sand and gravels of valley trains and moraines in pars of Colorado.
- Ancient placers are of Tertiary age. Some of these have been submerged beneath the sea, as a result of post-glacial rise of sea level and large quantities of ancient tin placers lie submerged in the drowned river valleys of Malaysia.
- Among the buried placers, those of the Eocene valleys of Sierra, Neveda, U.S.A., are famous.

Geomorphology and Engineering Projects

- Most engineering projects, large or small, require knowledge of terrain characteristics, surficial materials and bed-rock conditions
- Understanding of geomorphic principles and history is needed for construction of

  (i) highways, railways and airports that maintain the flow of goods and services,

  (ii) multipurpose dams and reservoirs for water supply, irrigation, power and flood-control

  (iii) levees, dykes, sea-walls built to protect home sites, industrial structures, harbours and navigation
- Different types of terrain pose different kinds of problems

Mountain Regions: like the Himalayas the gradient is so steep that roads have to be aligned along contours to reduce road gradient, making the roads extremely winding.

- The study of the drainage systems and the valley slopes is essential for planning the alignment of roads.
- The road connecting Hardwar with Badrinath (over 7000m) clings to the precipitous valley side slope of the Alaknanda river.
- The Srinagar Leh highway makes full use of the physiographic corridor provided by the valleys of the Jhelum, the Dras and the Indus rivers
- There are may cuts and fills and many bridges have to be built in areas of considerable relief.
- There is also the danger of landslides, earth flows and slumping
- By carefully analysing the state of relief, drainage, bedrock and regolith, the incidence of earthquakes, evidence of previous mass movements and man made features, it is possible to identify landslide prone areas and sites.

- This knowledge can be used at the planning stage of an engineering project.
- Route alignment can be decided so as to avoid these slopes, or, if they must be crossed, then remedial or controlling stage of a project, field sampling and laboratory analysis can concentrate on the potentially unstable slopes.
- Sites which are unstable should be avoided for highway or rail construction, dams, hydro-electric projects or other structures

Karst terrain: is marked by near-waterless surface with sink holes and underground caverns.

- The sink holes are liable to flooding during heavy rains
- A route over a karst plain requires repeated cut and fill
- Small cavern create problems in the process of road construction
- The local instability of the ground surface and the enlargement of solution caverns have to be kept in mind in the location and design of bridge abutments.

Glaciated terrain: A till plain is topographically most suitable for settlement or highway construction.

- Terminal morains, eskers, kames or drumlins may present many topographic irregularities, and highway construction may necessitate cut and fill to avoid circuitous routes.
- Areas formerly occupied by lakes and now covered with lacustrine deposits are unsuitable for heavy traffic roads, as the ground is likely to sink under the weight of heavy traffic.
- On highways which are designed to carry heavy traffic the nature of the soil beneath the road surface (subgrade) is important because of its influence on the sub-surface drainage
- Poor drainage in silty clay subgrades with high water table causes cracks in the roads
- Granular materials with a low water table result in longer life and better performance
- ‘pumping’ of water from beneath the road slab through joints and cracks is necessary

- Till plains, morains, lacustrine plains, outwash plains, eskers, kames, drumlins, wind-blown sand and loess not only present different types of topography but also different types of subgrade materials – should be taken care of.

Periglacial landscape: poses engineering problems because of the presence of permafrost, strong frost action and solifluction, and an unstable mantle of poorly drained and saturated sediment mixed with gravels and boulders moving downslope

- Most of Alaska, Canada and Russia are underlain by permafrost.
- In these areas, reconnaissance surveys are undertaken using remote sensing images to determine the nature of terrain, material and ground-ice condition.
- The engineering responses to permafrost may be (a) active or (b) passive.
- Removing of frozen ground in areas of thin, sporadic permafrost and filling with materials not susceptible to frost action – active method

- In the regions of continuous permafrost, efforts may be made to preserve the permafrost by insulating the surface with vegetation or gravel cover, ventilating the undersides of heat generating structures – passive method

Dams, Reservoirs and River regulation

- A good dam and reservoir site requires (i) a water-tight river basin of adequate size for storage with suitable bedrock,
- (ii) a narrow outlet of the basin with a foundation that will allow economical dam construction, (iii) facilities for building spillways to carry surplus water, (iv) availability of materials needed for dam construction, (v) assurance that the nature of the terrain and ecology of the catchment will not make the life of the reservoir too short as a result to excessive silting
- Dam construction in a limestone terrain is likely to result in leakages and water is likely to seep into solution channels and emerge as seepages below the dam.

- Impervious bed-rock will provide a dependable and adequate reservoir
- A construction in a valley is most economical but it may not necessarily be a suitable dam site.
- Example: in glaciated areas the surface topography may not give a correct picture of subsurface conditions, as buried bed rock valleys containing sand and gravel are common.
- In such cases, the dam is likely to leak and suitable bed rock foundation for the dam may be found at much greater depths.
- Dam construction in the upstream reduces the quantity of bed material load and decreases the peak discharge of water moved through the channel
- Realignment and channelization of rivers is practised to flood damage and to drain flood plain areas
- Drainage basins form natural geomorphological units.

- A major application of geomorphology lies in the prediction of flood-peaks and run off and sediment yield characteristics of a region
- Restrict the activities permitted on flood plains by developing flood plain zoning laws.
- Any plan for utilization of flood plains should include the possibility of frequent flooding, as overbank flooding will occur every 1 to 2 years.
- Schumn states that there are 3 ways in which a geomorphologis’s knowledge of rivers and their behaviour can be applied to practical problems

  1. evaluation of existing conditions, e.g., with the help of aerial photos, difference in drainage density and drainage patterns may be used to delineate specific rock types and to locate geologic structures.

- 2. to predict what will happen in future, e.g., what will happen to the river as flood peaks are increased by urbanization or deforestation.
- 3. to interpret the past, post-diction.

Coastal Zone Management

- The coastal zone is defined as ‘an area of variable width, which extends seaward to the edge of the continental shelf, but which has no distinct landward demarcation.
- Coastal zone should be viewed as dynamic region at the interface of land and water, limited in space but subjected to growing human pressure resulting from increasing concentration of industrial, commercial, recreational, fishing and agricultural activities.
- The rapid deterioration of the coastal environment through increasing shoreline erosion, loss of valuable areas of natural beauty, pollution and extinction of species and serious disturbance of the fragile coastal eco-system and natural processes have alarmed nations throughout the world.

- Coastal zone management requires an integrated and multi-disciplinary approach.
- The geomorphologist can provide a systematic framework for the collection and evaluation of accurate and relevant data of the coastal processes
- An understanding of erosional-depositional processes and their interaction with materials in the coastal system in different environmental settings is absolutely basic to an understanding of the nature and character of the coastal zone
- The role of applied geomorphology is to provide vital data of land-sea interface for developers, engineers, planners and decision makers.

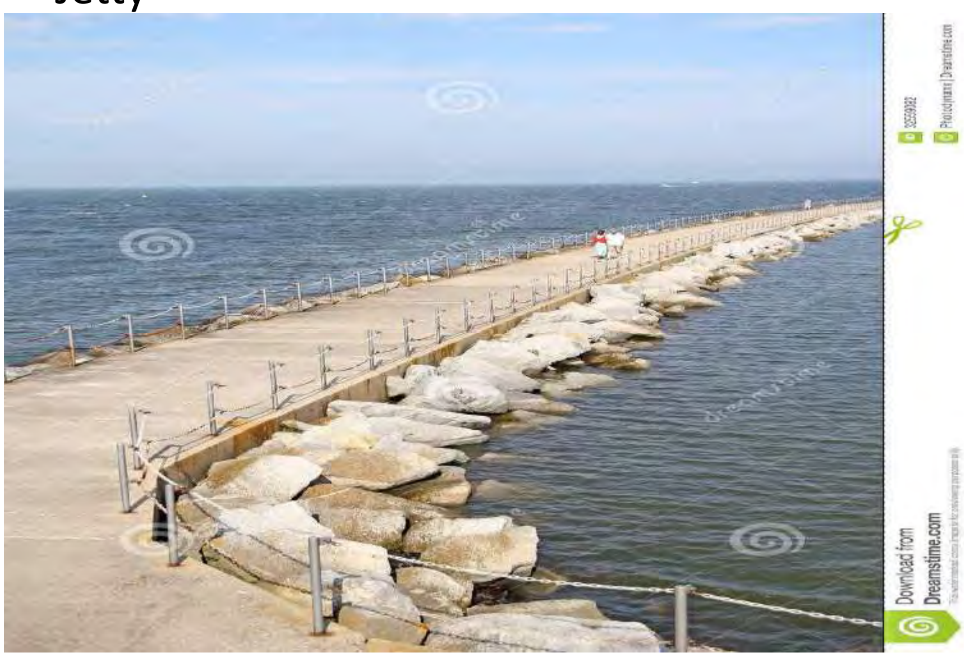
- As the coastal processes are extremely variable and have high level of activity, the forms and materials within the coastal zone are likely to change rapidly both in time and space with the possible exception of the hard-rock cliffed coasts where the changes may be slow and imperceptible.
- Waves are the most important process element on most coasts.
- The direction of wave is also important as it controls the longshore transport of beach material
- Storm waves will act differently according to the material on which they operate. Steep storm waves breaking on solid rock may lead to disintegration of rocks by shock pressure
- Similar waves breaking on shingle will throw some of it to the backshore zone to create a backshore ridge far above the high tide level.
- On sand beaches such waves are entirely destructive, and create steep beach scarp and carry much sand offshore where they create a submarine bar

- Sand and gravel available on the beach have been widely used for construction purposes
- Measures designed for coast protection include sea-defence structures such as seawalls, breakwaters, jetties and groynes.
- Sea walls are designed to protect the backshore zone from direct erosion but since they impermeable they increase the backwash and produce a destructive wave effect
- Groynes are built normal to the beach and are designed to trap beach material moving along shore.
- Breakwaters can be built with either normal or parallel to the coast to prevent silting of tidal inlets or estuaries or to provide shelter for shipping on an open coast.

Groynes

Shingle beach

Jetty



Breakwaters

Sea Wall

- The role of geomorphologist in aplied coatal studies is to measure and explain the overall sediment input/output changes along a coastline.
- These generally reflect natural or man induced variations in the flow and sediment regime of rivers, cliff retreat, offshore sediment budget and erosion of up-drift beaches.
- Such information will assist engineers to resolve local erosion problems and to build more suitable sea defences.
- It is imperative that littoral processes are fully understood before beach restoration schemes are implemented.

- According to J.A. Hails applied geomorphology must be concerned with quantitative and not descriptive research in order to obtain relevant and accurate data on
- (1) rates of natural erosion and deposition
- (2) rates and amount of sediment transport from river catchments to the nearshore zone
- (3) variation in sediment composition and distribution offshore
- (4) sources of sand supply and shoreline equilibrium
- (5) the rate of sand interchange between beaches and dune systems
- (6) the effects of constructing sea defences
- (7) sediment dispersal offshore and the effects of dredging on seabed morphology, sediments transport and wave refraction, and
- (8) landform analysis including topography of the near-shore zone, the form of the continental shelf and of relict coast lines, particularly in terms of rock outcrops.