Chapter - 3 Earth's Surface : Landforms

Highlights :

- The processess that create and shape the various landforms visible on the surface of the Earth and the characteristics of such landforms are studied.
- Landforms created due to erosional and depositional processes by water, wind and ice are explained.

Introduction :

Amongst all the known planets of the Solar system, Earth is unique. It is probably the only planet whose surface is being continuously renewed. When compared to the Moon, the Earth's surface is much younger, though the two formed around the same time. This chapter lists and explores a few of the important forces that continually reshape Earth's surface, leading to the formation of varied surface landforms, many of them unique to our planet.

You have studied and understood the two key processes weathering and erosion, responsible for reshaping the Earth's surface. Most weathering processes involve running water. Wind, glaciers and biological agents also play a significant role. Weathering as a process does not give rise to magnificent landforms, it helps the process of erosion. Water, wind and ice work relentlessly to erode i.e. carve and flatten our planetary surface, resulting in erosional landforms. It was as early as 1546 when Agricola, a German physician, recognized the importance of water as the most powerful erosive agent. Water along with wind and ice also transports material to places of deposition giving rise to spectacular depositional landforms.

Do you know?

Air and water differ from ice in that they are both fluids. Viscosity is a measure of a fluid's resistance to flow. Wind has a low viscosity; while water has greater viscosity than wind. Ice "flows" but only by melting and refreezing as it moves over a surface.

Activity :

Try moving the open palm of your hand through air and then through water in a bucket. You will note the effect of density difference on your hand. Blow air on a sheet of paper several times. You can tell that the faster the air blows, more is the force exerted on the paper. Now direct a stream of water against the paper with the same velocity as the air. The force striking the paper would be 800 times as great because water is 800 times denser than air.

3.1 Erosional and depositional landforms :

Water and wind are the most important agents of erosion and deposition. The processes that shape the landscape in areas where there is little or no rain differ from those at work in moist regions. Dry landscapes, where there is rarely a covering of soil or the action of rivers to smoothen the contours, consist of mainly bare rock, sharp cliffs, and dry valleys. The most active agent of erosion as well as deposition in a dry arid environment is therefore wind.

The wind patterns of our planet are determined by :

i) **Variations in solar radiation :** The amount of solar radiation received on Earth, varies with respect to latitude because of the angle at which solar radiation strikes different latitudes. When the Sun's rays strike the Earth's surface near the equator, the incoming solar radiation is more direct i.e. it makes an almost perpendicular angle with the surface at the equator. At higher latitudes, the radiation makes a smaller angle with the surface of the Earth. This results in cooler average surface temperature at regions away from the equator and warmer average surface temperatures near the equator.

ii) **Coriolis effect :** The coriolis effect is an apparent deflection of the path of an object that moves within rotating co-ordinate system. On Earth, any object (wind, water) that moves along a north-south path (or longitudinally) will get deflected to the right in the Northern hemisphere and to the left in the Southern hemisphere. This happens because :

1) The Earth rotates eastward
2) The tangential velocity at a point on the Earth is a function of latitude.

Gravity : It is one of the most important force in transportation and deposition of the sediments. During transport it can further erode landform as seen significantly in glacial and fluvial processes.

3.2 Fluvial (Riverine) landforms :

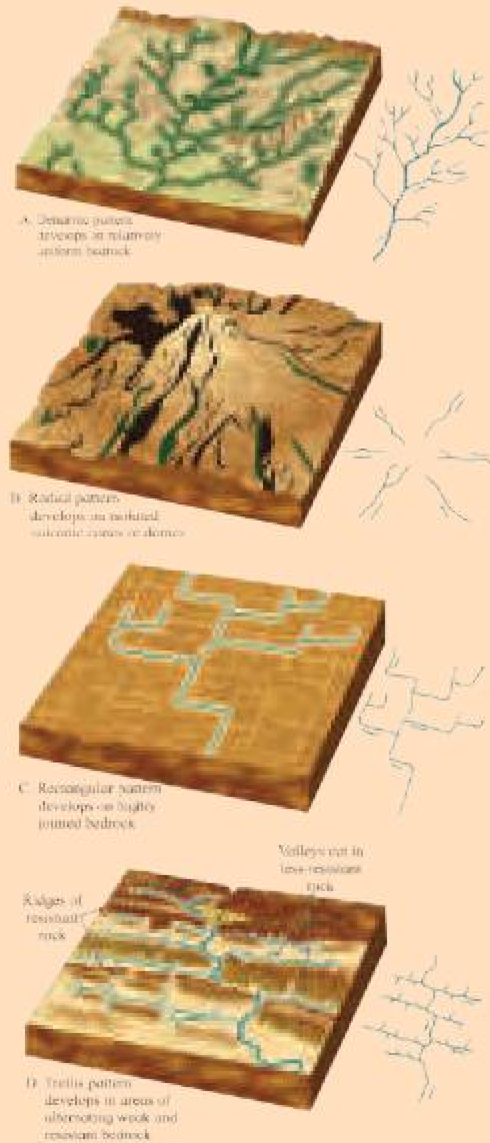
Fluvial landforms are controlled by river systems. A river system is a network of connecting channels through which water precipitated on the surface is collected and transported back to the ocean. At any given time, about 1300 cubic km of water flows in the world's rivers. Rivers are one of the most powerful agents of erosion on our planet. They also transport and deposit enormous amounts of alluvium. A river system is made up of a main channel and all of the tributaries that flow into it, and can be further divided into three subsystems :

1) **Collecting system :** It consists of the network of tributaries in the catchment area that collect water and carry it along with sediments to the main stream. The tributaries usually form a dendritic or tree like drainage pattern, with numerous branches that extend upslope.

2) **Transporting system :** It is the main trunk stream which functions as a channel through which water and sediments flow from the catchment area towards the ocean. The major process operating in this region is transportation, but deposition also takes place when the channel meanders and the river overflows its banks.

3) **Dispersing system :** It consists of a network of distributaries at the mouth of the river which disperse the sediments and water in the ocean, lake, or a dry basin.

Do you know? Drainage patterns



Drainage patterns of rivers

Do you know?

Bramhaputra and Sindhu (Indus) rivers are actually longer than Ganga, but the distances they cover in India are lesser than that of Ganga. Hence, Ganga is the longest river of our country. It is also the third largest river of the world by discharge.

3.2.1 Fluvial erosional landforms :

Erosion of land is one of the major processes associated with fluvial systems. It has occurred on this planet throughout the geological time and will continue to operate as long as the river system exists and the land is exposed above the sea level. The evidence of erosion is ubiquitous and varied. It can be observed in the thick layers of sedimentary rocks that cover a large part of continents and bear witness to the extensive erosion and deposition that took place over the ages. Erosion by rivers can be accomplished by three basic processes :

A) **Removal and transport of regolith :** Loose rock debris or regolith is washed downslope into the drainage system and is transported as sediment load in streams and rivers.

B) **Downcutting of stream channel :** It is a fundamental process of erosion in all stream channels, accomplished by the abrasion of channel floor by sand and gravel, as the channel is eroded downstream by flowing water.

C) **Headward erosion :** The tendency of rivers to erode headward (upslope) and to increase the lengths of their valley until they reach the divide.

The above processes give rise to the following fluvial erosional landforms :

1) **Valley :** A valley is a low area between hills or mountains, often with a river flowing through it (Fig.3.1). Valleys are gradually carved out by rivers with the aid of weathering and mass movement of debris (erosion).

Fig. 3.1 : Zanskar valley, Jammu and Kashmir

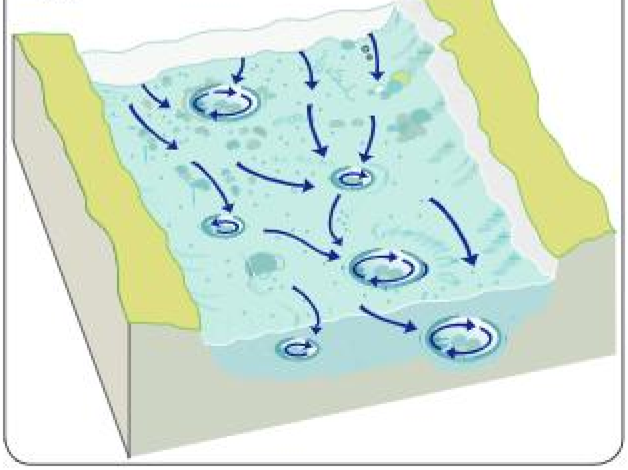
2) **Gorge :** A gorge is a narrow, deep valley with steep, rocky walls (Fig. 3.2). It is formed due to down cutting action of the river over a long period of time.

Fig. 3.2 : River Penna gorge, Gandikota, Cuddapah district, Andhra Pradesh

3) **Waterfall :** A waterfall is a feature characterised by a sudden drop in the channel profile of a stream or river. A waterfall is commonly found in areas where differential erosion of soft and hard rock has resulted in a step like feature where water flows down the step with great force.

4) **Potholes :** Potholes are deep holes (Fig. 3.3 A, B) created by drilling action of sand, gravel, pebbles and boulders trapped in a depression and swirled around by currents. It is an effective and interesting type of abrasion. As the pebbles and cobbles are worn away, new ones replace them and continue drilling the bedrock of the river channel, thus deepening the potholes.

A)



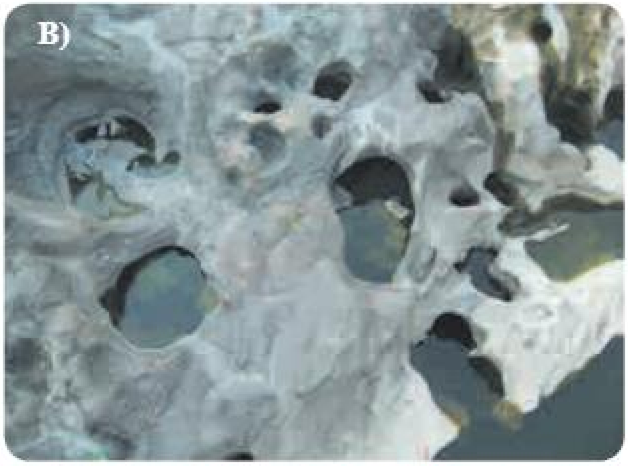


Fig. 3.3 : A) Process of pothole formation, B) potholes at Nighoj, Kukadi River, Maharashtra

5) **Meandering river channel :** All rivers have a tendency to flow in a sinuous pattern, owing to the bends in the river channel. The irregularities in the river channel deflect the flow of water to the opposite bank, where the sheer force of flowing water causes erosion and undercutting of the bedrock.(Fig. 3.4 A). With time, the bend grows larger and is accentuated, eventually growing into a large meander. Erosion takes place on the outside bend of the meander where velocity is greatest (Fig. 3.4 B, C), whereas deposition takes place on the inside of the meander, where velocity is low.

Activity : Visit a sandy sea shore during low tide. Observe how the sea water drains out of the beach sand. You will see miniature drainage channels and features like tiny meanders, braiding of stream channels etc. developing in a short duration of time. (NOTE : This activity is to be carried out under teacher/parental supervision).

6) **Oxbow lake :** As a meander bend becomes accentuated, it develops an almost complete circle. Eventually the river channel completely abandons the old meander loop, which remains as a crescent shaped lake known as and Oxbow lake (Fig. 3.4 C, D).

3.2.2 Fluvial depositional landforms :

In lower parts of a river system (i.e. the transporting and dispersing systems) the gradient of the river becomes very low, due to which the stream velocity reduces and the river deposits its sediments. Most large rivers are always muddy. In some cases, the weight of the sediment exceeds the weight of water present in the river. Deposition of sediments in the lower transporting and dispersal segments of the river

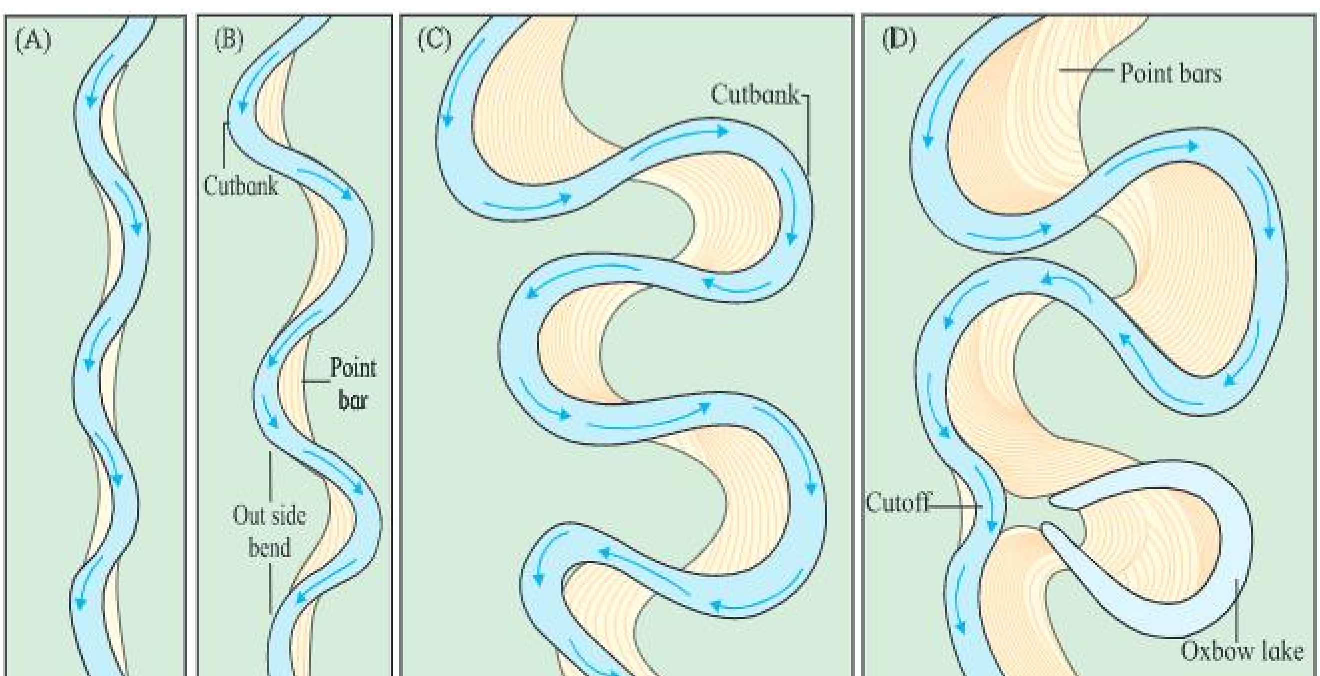


Fig. 3.4 : A, B, C, D Stages of development of meandering river and the formation of oxbow lake

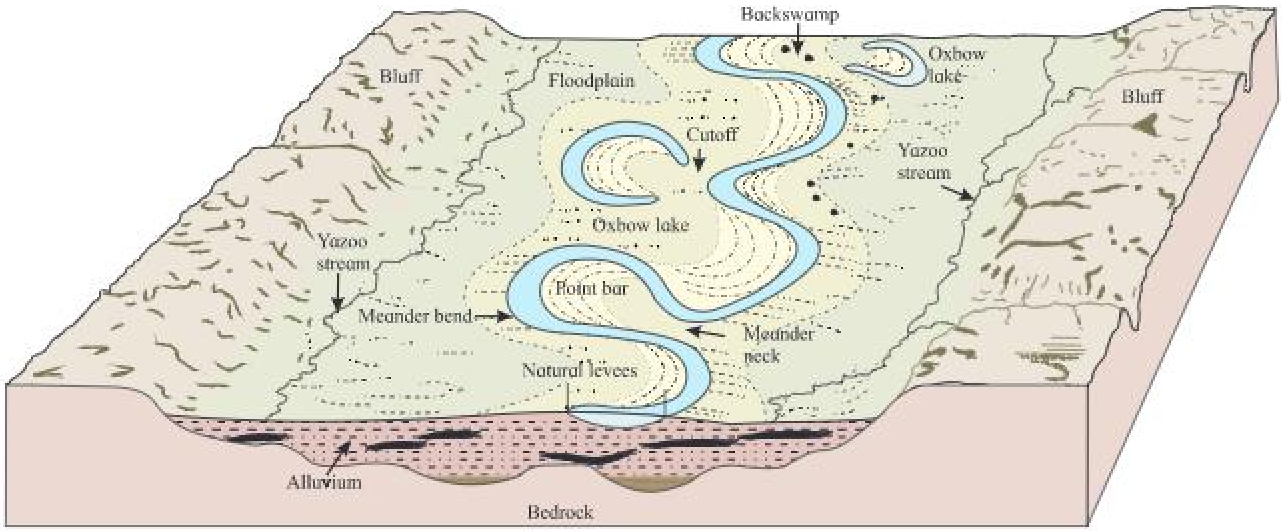


Fig. 3.5 : Major features of a floodplain

creates prominent and distinctive landforms. (Fig. 3.5). If a river carrying silt, sand and gravel loses energy, it slows down on a gentler gradient. The coarser fragments i.e. gravel will get deposited first, followed by sand and silt. The following fluvial depositional landforms are observed in nature :

1) **Floodplain :** It is a flat surface, formed due to extensive sediment deposition, over which a stream flows. The base of a floodplain can be a gently sloping surface which is covered with large quantities of sediment. During high floods, a floodplain may be completely covered with water.

2) **Natural levees :** They are high embankments on either side of a river. They form when a river overflows its banks during flood stage and the water is no longer confined to a channel, but flows over the flood plain. This unchanneled flow reduces the flow velocity significantly, and some of the suspended sediment settles down. The coarsest material deposits first, i.e. closest to the channel, followed by finer particles.

3) **Point bar :** It forms on the inside bend of the meander where deposition takes place. On the inside of the meander, the velocity is at a minimum and some of the sediment is deposited on the point of the meander inner bend.

4) **Alluvial fans :** An alluvial fan is a fan-shaped fluvial deposit, found in dry lands, which consists of coarse detrital sediment. It is usually found in areas where a steeper slope passes abruptly into a gentle slope, for example, a mountain front. The river dumps its sediments at the point where the gradient changes from steep to gentle and the sediments spread out forming a fan-shape, hence called alluvial fans (Fig. 3.6).

Fig. 3.6 : Alluvial fan

5) **Delta :** Delta is a triangular fluvial deposit formed when the river enters a lake or the sea. As the river enters the sea, it slows down and its sediment carrying capacity decreases. This leads to the river dumping its sediments in the sea, forming a huge fan of alluvial deposits. There are three types of deltas : (Fig. 3.7 A, B, C), arcuate, cuspate and bird-foot.

Fig.3.7 **A) Arcuate delta :** These deltas have an arc shaped coastline. e.g. Ganga delta, India.

Fig.3.7 **B) Cuspate delta :** These deltas have a kite like appearance because the material is deposited evenly on either side of the main channel. e.g. Ebro delta, Spain.

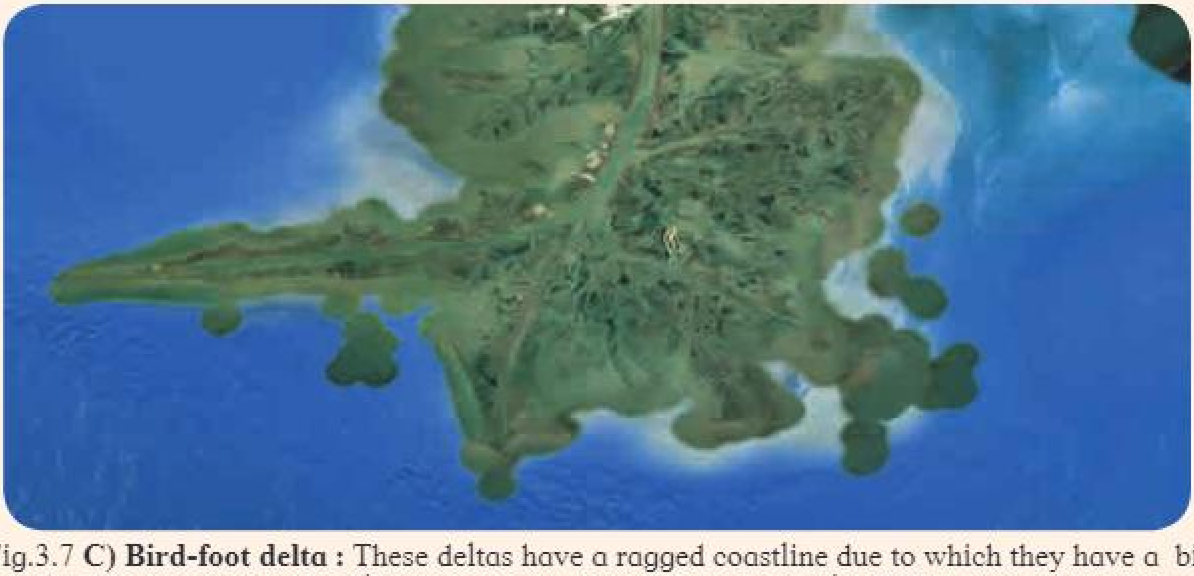


Fig.3.7 **C) Bird-foot delta :** These deltas have a ragged coastline due to which they have a bird foot like appearance. e.g. Mississippi delta, USA.

3.3 Coastal landforms :

Coastal landforms are formed due to movement of water by wind generated waves, tides, tsunamis and a variety of density currents. Water in oceans and lakes is in constant motion, as it moves, it constantly modifies the shores of all the continents and islands of the world. Coastline processes can change in intensity from day to day, and from season to season, but they never cease to operate. Nearly all of the world's present shorelines were profoundly affected by the rise in sea level caused by the melting of the glaciers during late Pleistocene.

Coastal systems are complex open systems wherein the principal sources of energy are a) wind generated waves, which is the driving force behind erosion, transportation and deposition and b) gravity, as its influence is felt in tides and near shore currents.

A number of processes are responsible for shaping up coastal landforms :

Wave refraction : Concentrates energy on headlands and disperses it in the bay (Fig. 3.8).

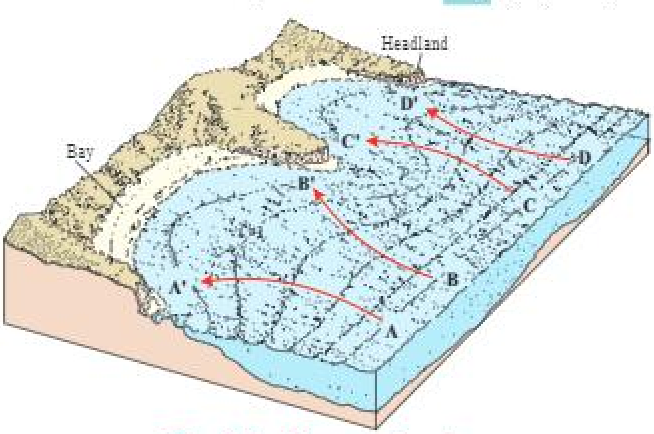


Fig. 3.8 : Wave refraction

Longshore drift : is generated when waves strike the shore obliquely. The sediments present in water move up the beach slope diagonally, but the backwash of the waves carries the particles back down on the beach-face at right angle to the shoreline. This movement results in a net transport parallel to the shore. Therefore an enormous amount of sediment constantly moves parallel to the shore (Fig. 3.9).

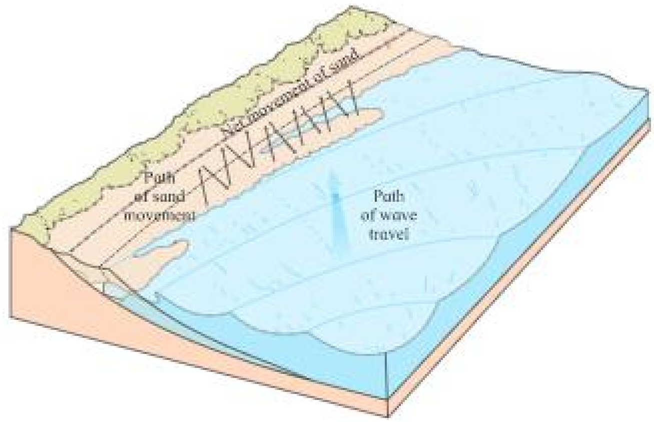


Fig. 3.9 : Longshore drift

Do you know?

Influence of longshore drift on human activities in Ratnagiri, Maharashtra :

Ratnagiri is a picturesque coastal town along the coast of Maharashtra and is the district headquarters of Ratnagiri. It is an ancient sea-port. The port being open to wave attack and sand accumulation due to the longshore drift from the Arabian sea, it was decided to construct a breakwater parallel to the coastline at some distance from the existing jetty. This was intended to help the docking of fishing boats even during rough weather and prevent the port area from clogging up with sand. This jetty is used for extensive fishing activity based near the port. The breakwater unfortunately did not serve its purpose. Today, there is continuous and extensive accumulation of sand in the Ratnagiri (Mirya Bandar) port. This is dredged out to keep this ancient port in working order, ready to berth large fishing trawlers.

3.3.1 Coastal erosional landforms :

Coastal erosion has been altering world's shorelines since the oceans were first formed. With every surging action of the waves, the movement of longshore currents, tides and pounding storms, the coastline erodes and evolves. Added to that, the sea level constantly fluctuates, which facilitates the process of reshaping the morphology of a coast. The rate at which coastlines are eroded is extremely variable. It depends on the configuration of the coast, size and strength of waves, and physical properties of the bedrock.

Coastal erosional landforms are sculpted in a variety of forms majorly due to wave action. When a wave breaks against a sea cliff, the sheer impact of water can exert a pressure exceeding 100 kg/m^2. Water enters every crack and crevice of the rock and compresses the air present within. The compressed air then acts as a wedge and widens the cracks, which in turn loosens the block.

The most effective process of erosion along the coast is abrasive action of sand and gravel moved by wave action. These tools of erosion operate by cutting the bedrock horizontally, forming wave-cut cliffs and wave cut platforms.

i) **Sea cliff** : When steeply sloping land descends beneath the water, waves act like a horizontal saw, cutting a notch into the bedrock at sea level. This undercutting produces an overhanging sea cliff or wave cut platform (Fig. 3.10).

ii) **Wave cut platform** : The fallen debris of collapsed sea cliffs is broken up and removed by wave action, and this process is repeated on the fresh surface of the new cliff face. As the sea cliff retreats, a wave cut platform is produced at it's base (Fig. 3.10).

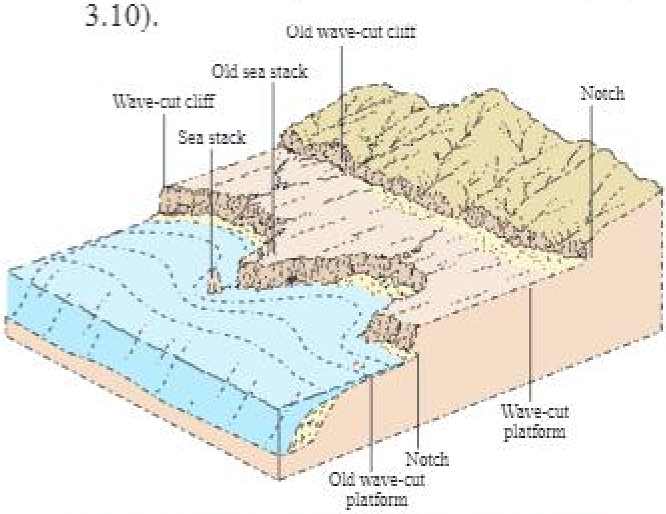


Fig. 3.10 : Wave cut platform and sea cliff

iii) **Sea cave** : Sea caves are formed when erosion takes place at a zone of weakness (for example, a joint) that extends throughout the outcrop. If a joint extends across a headland, wave action can hollow out a sea cave (Fig 3.11 A, 3.12).

iv) **Sea arch** : Sea arches form as a result of different rates of erosion of a rock which arises due to the varied resistance of bedrock. The arches may have an arcuate or rectangular shape (Fig 3.11 B).

v) **Sea stack** : Sea stack is an isolated pinnacle formed when a sea arch collapses. A new arch can develop from the remaining headland (Fig 3.11 C).

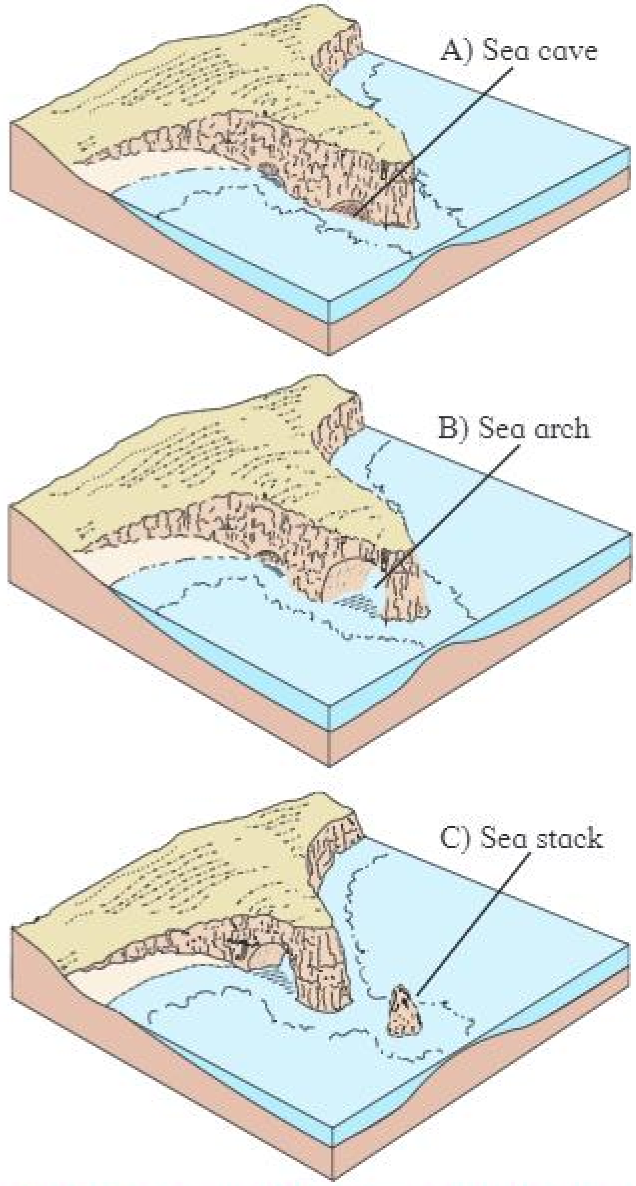


Fig. 3.11 : Sequence of development A) Sea cave, B) Sea arch, 3) Sea stack

Fig. 3.12 : Sea cave at Sarjekot, Malvan, Maharashtra

3.3.2 Coastal depositional landforms :

Coastlines receive sediment input from various sources, but majority of the sediments are derived from land and fed to the sea by rivers. The sediments are then transported by waves and currents and deposited in areas having low energy environments. The deposited sediments build a variety of landforms depending upon the geochemical environment and energy conditions present at the site of deposition.

i) **Beaches :** A beach is a shore built of unconsolidated sediments, mostly sand. Some beaches are composed of cobbles and boulders while there are others composed of fine silt and clay. The physical characteristics of a beach i.e. slope, composition and shape depend largely on the wave energy. The supply and size of available sediments also plays a huge role in formation of a beach.

ii) **Spits :** Generally, in areas where straight shorelines are indented by bays, longshore currents can extend the beach from the mainland to form a spit. A spit or sand spit is a deposition of sand or shingle, extending or jutting out into the sea from the mainland. A spit can grow far out across the bay as material is deposited at its end (Fig. 3.13).

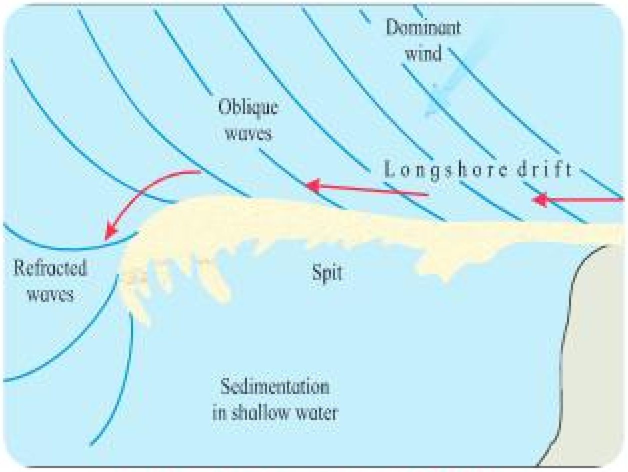


Fig. 3.13 : Formation of a Spit

iii) **Tombolos :** Tomobolos are formed when beach deposits grow outward and connect the shore with an offshore island. It forms because the island creates a wave shadow zone of extremely low energy conditions, along the coast, in which longshore drift cannot occur (Fig. 314).

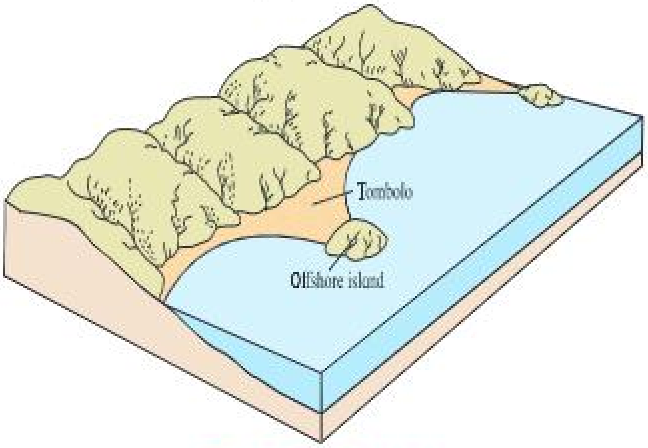


Fig. 3.14 : Tombolo

iv) **Reefs :** Reefs form a unique depositional feature as they are biological in origin. Reefs are built by coral polyps (invertebrate colonial organisms). The polyps get attached to hard substrates in shallow marine environments and secrete layers of calcium carbonate in order to form colonies to reside in. Reefs are extremely sensitive and can flourish only under specific temperature, salinity and water depth, therefore they are important indicators of past climatic, geologic and tectonic conditions.

There are four major types of reefs.They are as follows :

a) **Fringing reefs :** Fringing reefs generally range from 0.5 to 1 km in width and are attached to shores of volcanic islands or continents. The corals grow seaward in order to get food supply (Fig. 3.15 A).

b) **Barrier reefs :** Barrier reefs are roughly parallel to the shore and are separated from the mainland by a lagoon. They can be more than 20 km wide (Fig. 3.15 B).

c) **Atolls :** Atolls are roughly circular reefs that enclose a shallow lagoon in which there are no exposed central landmasses. The outer margin of an atoll is evidently the most vigorous site of coral growth

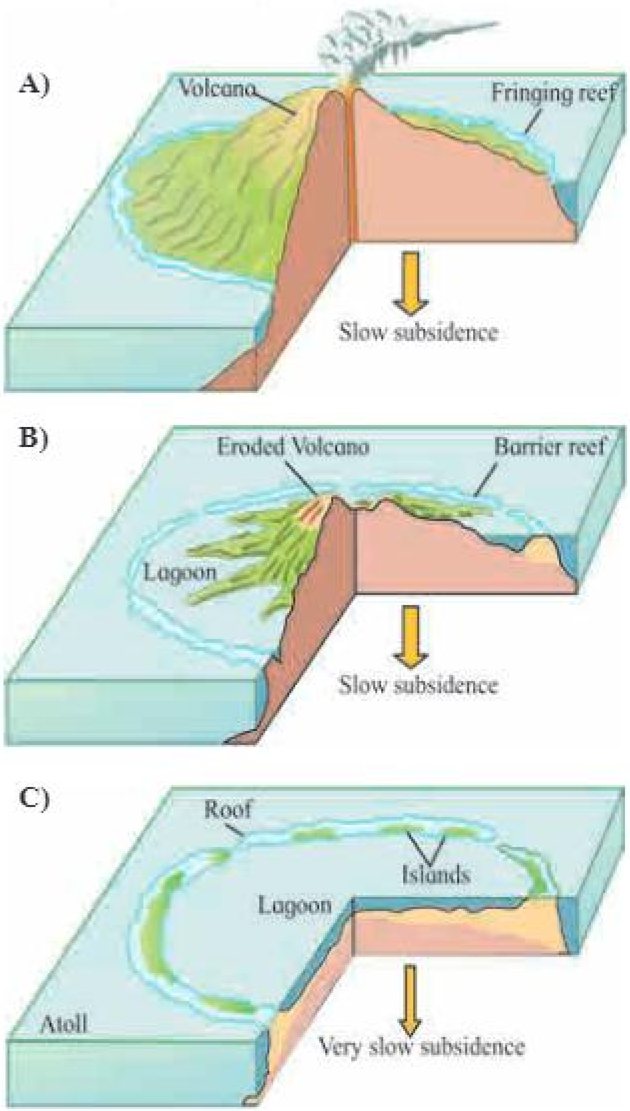


Fig. 3.15 : Formation of A) Fringing reef, B) Barrier reefs, C) Atolls

3.4 Aeolian landforms

Aeolian landforms are formed in deserts of the world where the effects of wind are most prominent. The aeolian system is a dynamic open system driven primarily by heat from the Sun, which is radiated to the Earth's surface. The uneven heating of Earth's surface makes the atmosphere a vast convecting fluid that envelop the entire planet.

A desert is a dry region usually having sandy or rocky soil and little or no vegetation. Water lost in evapo-transpiration in a desert exceeds the amount of precipitation in that region. Most deserts receive less than 25 cm annual rainfall. Vegetation cover is absent or sparse, which results in the ground surface being exposed to wind action.

3.4.1 Aeolian erosional landforms

Wind can do little to erode solid rock exposed at the surface, but it has tremendous capacity of carrying loose weathered material from one place to the other. For wind to operate as an effective agent of erosion, there are two prerequisites; presence of disintegrated rock fragments produced by chemical and mechanical weathering, and a dry climate. Dry climate is necessary because it ensures absence of vegetation, which usually covers the surface and holds the loose particles together. The major processes that operate during wind erosion are;

A) **Corrasion or abrasion :** It is the natural sandblast action of windblown sand. It is essentially the same process as artificial sandblasting used to clean building stone. Wind carries sand grains along with it, which impact rock surfaces and knock off smaller particles from the rock.

B) **Deflation :** It is the lifting and removal of loose material from Earth's surface. The grains are lifted up because of turbulent nature of wind. Deflation occurs where vegetation is absent or sparse.

C) **Attrition :** It is the wear and tear of sand particles due to mutual impact and friction as they are carried along by wind.

The above processes give rise to a number of aeolian erosional landforms.

1) **Deflation basins :** Deflation basins or hollows, as the name suggests, are broad shallow depressions formed due to deflation action of wind. They range in size from small depressions to large basins several kilometrs in diameter. These basins can also develop in areas where sand grains in sandstone are held together by calcium carbonate cement. During rainy periods, water collected in these depressions will dissolve the calcerous cement present in the sandstone. Now, since the calcareous material holding the sandstone together is no longer present, the sand grains begin to fall apart. These fallen, loose sand grains are picked up by strong winds during dry periods and transported. This process results in formation of a large depression.

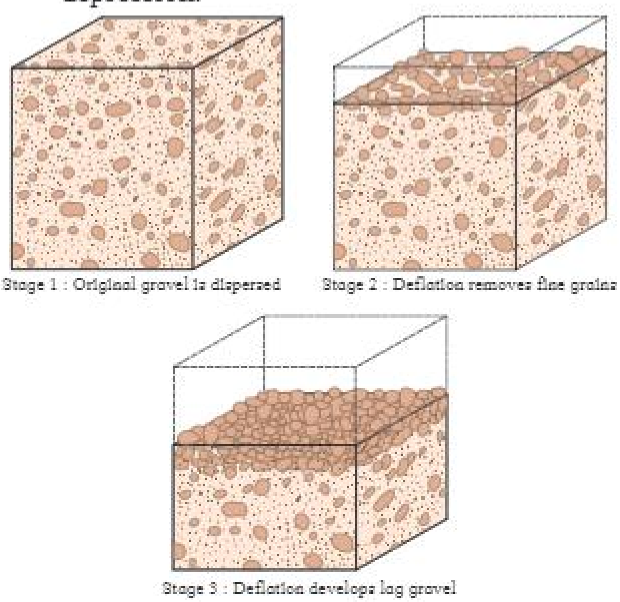


Fig. 3.16 : Formation of desert pavement / lag deposit

2) **Desert pavements :** Wind can only erode sand and dust size particles, so anything coarser than sand remains figuratively untouched by wind. Desert pavements or lag deposits are formed when wind selectively removes fine sediment and leaves behind coarser fragments (Fig. 3.16 a, b, c).

3) **Ventifact :** Ventifacts are exposed, soft, poorly consolidated rocks, shaped and polished by wind. These rocks are distinguished by two or more flat faces that meet at sharp edges and are generally well polished. The striations on ventifacts show the prevelant direction of wind during erosion (Fig. 3.17 A, B, C, D).

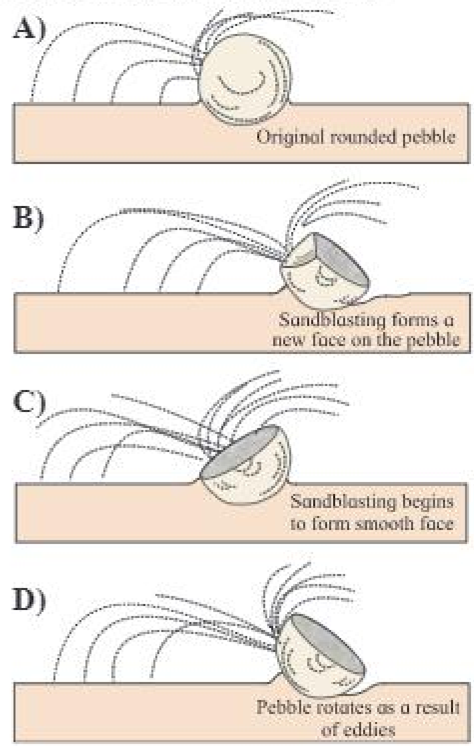


Fig. 3.17 : Formation of a typical ventifact

4) **Yardang :** Yardangs are distinctive linear ridges, generally large landforms produced by abrasion action of wind. The name is derived from the Turkistani word 'Yar', which means ridge or bank. They typically occur in clusters oriented parallel to the prevailing wind direction that formed them. (Fig. 3.18).

Fig. 3.18 : Yardang

Theoretically, they can form in any rock type, but they are best developed in soft, fine grained sediment or volcanic ash that can be easily pliable but cohesive enough to retain steep slope.

5) **Mushroom rocks / Rock pedestals :** Mushroom rock, as the name suggests, resembles a mushroom in shape. It is typically formed due to differential erosion of rock, especially at the bottom portion of the rock. (Fig. 3.19). This happens because at an average height of ~ 1m, the material carrying capacity of the wind and the speed is maximum, therefore, abrasion is maximum here. As the wind moves further up, its material carrying capacity decreases, which leaves the upper portion of the rock fairly untouched (uneroded). In some cases, mushroom rocks are also formed due to presence of soft rock layers at the base of hard rock layers.

Fig. 3.19 : Mushroom rock

6) **Mesa :** A mesa is an isolated, flat topped, steep sided desert mountain. It is formed by weathering and erosion of horizontally layered rocks (Fig. 3.20). Some rocks are more prone to weathering and erosion than others, hence they get weathered at a faster rate. This process is called differential erosion. The more resistant layers form cliffs, while the less resistant layers form the gentle slopes. Cliffs retreat and are eventually cut off from the main plateau.

7) **Butte :** A butte is an isolated hill, with a relatively flat top. Buttes are smaller landforms than mesas (Fig. 3.20). In distinguishing mesas from buttes, the rule of thumb is that a mesa has a top that is wider than its height.

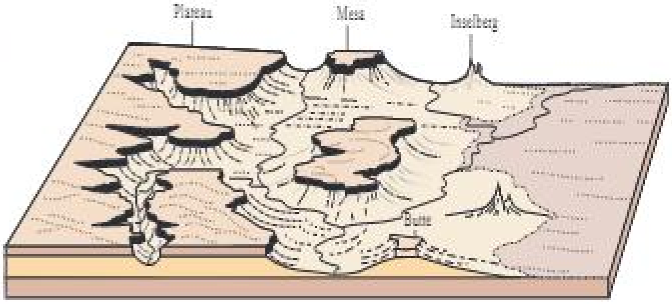


Fig. 3.20 : Mesa and butte

8) **Inselberg / Monadnock :** An inselberg or monadnock is an isolated hill, pinnacle, ridge or small mountain that rises abruptly from a relatively plain surrounding (Fig. 3.21). The word inselberg has a German origin, it literally means 'Island Mountain'. Inselbergs are mostly erosional remnants, they are composed of more resistant material.

Fig. 3.21 : Inselberg

Mesas, buttes and inselbergs are landforms which can also form due to other erosional processes, e.g. the mesas and buttes seen in deccan traps.

3.4.2 Aeolion depositional landforms :

When wind velocity decreases, it does not have enough energy to sustain the weight of the suspended sediment, as a result it gets deposited. Wind blown sand accumulates, upon deposition, to give rise to sand sheets, ripples and dunes. The structure formed will be a function of sand supply, wind direction and velocity. About 40%

of wind deposits are gently undulating, almost flat sand sheets. The following landforms are formed due to aeolian deposition :

Dune :

Dune is a hill of loose sand built by deposition of aeolian and fluvial sediments, but they occur more widely in aeolian environments. Dunes migrate downwind and modify the landscape rapidly, damaging or obliterating almost anything that comes in their path. Forests have been entombed by advancing dunes, streams diverted, and villages completely covered. Dunes march on, leaving behind devastated countrysides and damaged properties.

Formation of dunes : Many dunes originate where an obstacle such as a large rock outcrop, vegetation or any human made structure, essentially anything that creates a zone of quieter, calmer air behind it. As wind blows up or around the obstruction, its velocity is reduced and deposition occurs (Fig. 3.22). Once a small dune is formed, it itself acts as a barrier, disrupting the flow of air and causing continuous deposition downwind. Dunes range in size from 30 cm to 500 m high and about a kilometer wide.

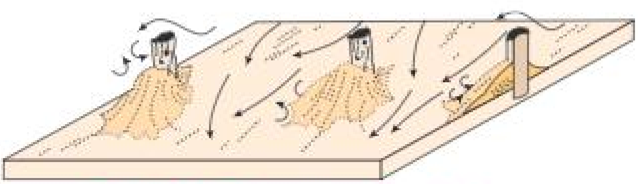


Fig. 3.22 : Formation of sand dunes

Migration of dunes : A sand dune is typically asymmetrical with a gently inclined windward slope and a steeper downwind slope i.e. lee side or slip face. The lee or slip face of a dune shows direction of prevailing wind. The wind picks up sand particles from the windward slope and drops it beyond the crest of the dune, this accumulates on the slip face. When the sand grains exceed the 'angle of repose', they spill down the slip face causing small landslides or 'avalanches' (Fig. 3.23 A, B).

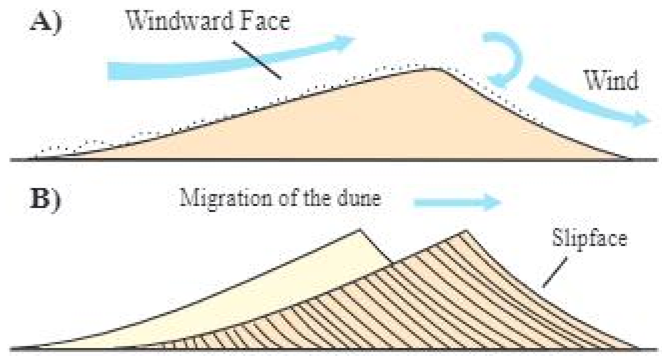


Fig. 3.23 : Migration of dunes

Types of dunes :

1) **Transverse dunes :** Transverse dunes typically develop where there is high supply of sand and constant wind direction. These dunes develop wavelike forms, with sinuous ridges and troughs perpendicular to the prevailing wind direction (Fig. 3.24). Transverse dunes generally form in deserts where exposed ancient sandstone formations provide ample supply of sand.

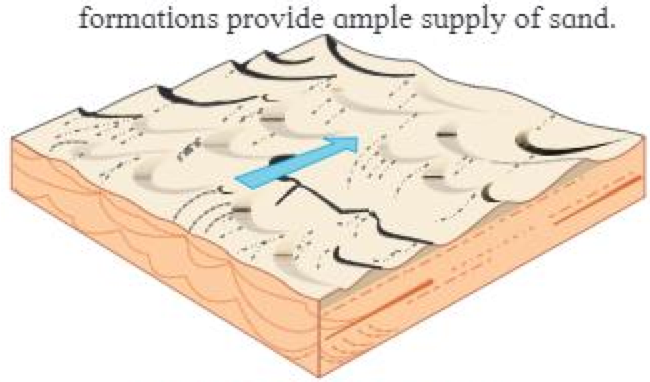


Fig. 3.24 : Transverse dunes

2) **Barchan dunes :** Barchan dunes form in areas with limited supply of sand, and where wind blows at moderate velocity in a constant direction. Barchan dunes are crescent shaped, small and isolated. The tip of a barchan dune points downwind (Fig. 3.25). Constant wind direction gives rise to beautiful symmetric barchan dunes.

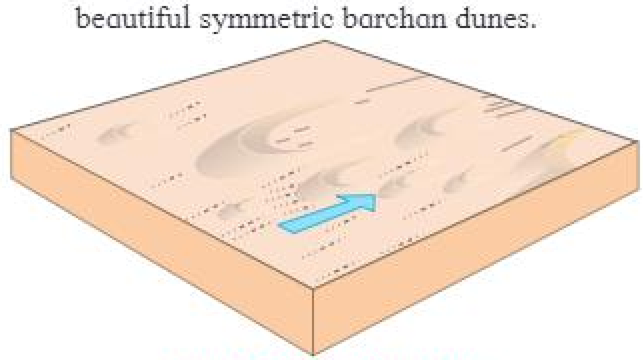


Fig. 3.25 : Barchan dunes

3) **Linear or Seif dunes :** 'Seif' (Arabic word for sword) dunes are long, parallel ridges of sand, elongate in a direction parallel to the vector resulting from two slightly different wind directions. These develop when strong prevailing winds converge and blow in constant direction over an area with limited sand supply (Fig. 3.26). These dunes do not attain great heights but they can extend downwind for several kilometers.

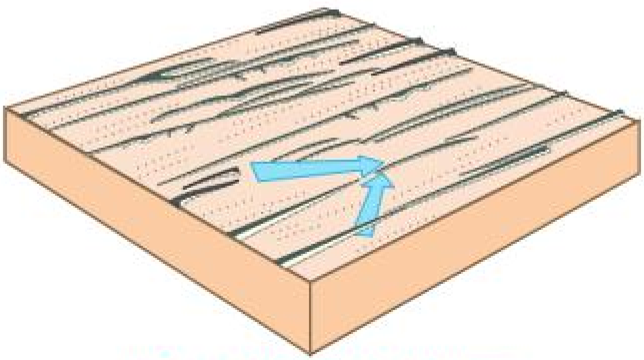


Fig. 3.26 : Linear or Seif dunes

4) **Star dunes :** Star dunes are mounds of sand with a high central point from which three or four arms radiate. The internal structure of star dunes suggests that they are formed due to winds blowing in three or more directions (Fig. 3.27).

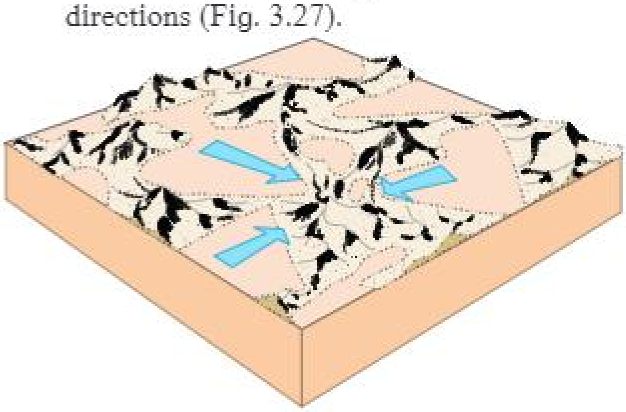


Fig. 3.27 : Star dunes

5) **Parabolic dunes :** Parabolic dunes develop along coastlines where vegetation partly covers a ridge of wind- blown sand, which is transported landward from the beach. In map view, a parabolic dune is similar to a barchan, but the tips of a parabolic dune point upwind and are fixed in place by vegetation (Fig. 3.28). Such dunes are also present in Thar desert.

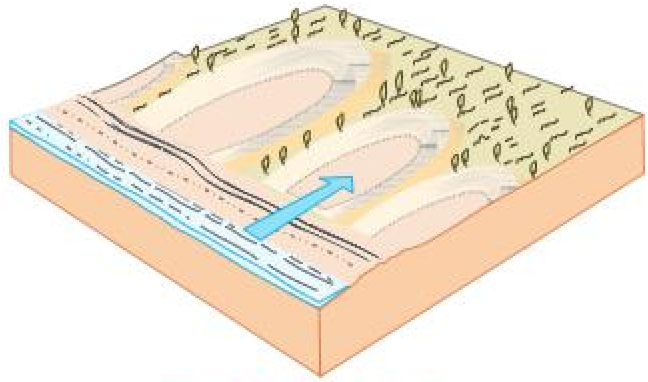


Fig. 3.28 : Parabolic dunes

3.5. Glaciated landforms :

Glaciers constitute an important part of the cryosphere, the portion on our Earth where the temperatures are so low that water is in a frozen state. Snow, perennially frozen ground, and sea, lake and river ice are other components of the cryosphere.

A glacier is a permanent body of ice, consisting largely of recrystallized snow, that moves downslope due to gravitational pull. The process of modification of land surface by the action of glacier ice, is called glaciation and it involves erosion, transport, and deposition of sediment.

3.5.1 Glacial erosion :

A glacier changes the land surface over which it moves. A glacier acts as :

1) an abrasive 'file' – whereby it rubs or rasps away hard rock.
2) a plow – it scrapes up weathered rock and soil and plucks out blocks of bedrock.
3) a sled – it carries away the load of sediment acquired by plowing and filing.

Small-scale erosional features :

a) Glacial striations : These are long sub parallel scratches engraved on bedrock. Due to the ploughing action of rock fragments which are studded along the base of a glacier that is slowly but steadily moving down a valley (Fig. 3.29).

Fig.3.29 : Glacial Striations (the deep grooves on the surface almost perpendicular to the strata)

Do you know?

Principal types of glaciers, classified according to form.

Glacier type	Characteristics
Cirque type	Occupies bowl shaped depression on the side of a mountain.
Valley glacier	Flows from cirques on to and along floor of valley.
Fjord glacier	Occupies submerged coastal valley and base lies below sea level.
Piedmont glacier	Terminates on open slopes beyond confining mountain valleys and is fed by one or more large valley glaciers.
Ice cap	Dome shaped body of ice and snow that covers mountain highland, or lower-lying lands at high latitudes and displays generally radial outward flow.
Ice field	Extensive area of ice in a mountainous region that consists of many interconnected Alpine glaciers. Lacks domal shape of ice cap. Its flow is strongly controlled by underlying topography.
Ice sheet	Continent size masses of ice that overwhelm nearly all land within their margins.
Ice shelf	Thick glacier ice that floats on sea and commonly is located on coastal embayments.

b) Glacial chatter marks : They are rows of small crescent-shaped cracks, similar to the marks made when a chisel slips across a wood or stone surface. The horns of the crescent point in the direction of ice movement. The stick-slip motion of stones across the glacier bed gives rise to sets of small curved fractures on brittle rock surfaces (Fig. 3.30).

Fig. 3.30 : Glacial chatter marks

Landforms of glaciated mountains :

a) Cirques : They are bowl-shaped hollows on a mountainside, open downstream and bounded upstream by a steep slope (Fig. 3.31). Cirques are excavated mainly by frost wedging, glacial plucking and abrasion. The floors of many cirques are rock basins, which may contain small lakes, called tarns, ponded behind a bedrock threshold at the edge of the cirque. Headward growth of cirques on opposite sides of a mountain crest can produce a narrow serrated ridge called an arête (French for 'fishbone,' 'ridge,' or 'sharp edge') (Fig. 3.32).

b) Horn : Where three or more cirques have sculpted a mountain mass, the result can be a high sharp-pointed peak or horn, the classic example of which is the peak – Ama Dablam in the Himalayas.

Do you know?

Ama Dablam 6,812 m (22,349 ft) is a popular Himalayan peak for climbing expeditions and is a prominent peak that is frequently visible on the trek up to Everest Base Camp. Ama Dablam means 'Mothers

Necklace' in Nepali and is in reference to the hanging glaciers that fall off the peak's, icy ledges. It has also been referred to as a 'Matterhorn' of the Himalayas.

c) Col : A col (from the Latin collum, 'neck'),or pass, is when two cirques erode headward into a ridge from opposite sides. When their headwalls meet, they cut a sharp-edged gap in the ridge (Fig. 3.33 B).

Fig. 3.31 : Glacial cirque and horn, Rohtang pass, Himachal Pradesh, India

d) Glacial valleys : Instead of fashioning their own valleys, glaciers probably follow the course of preexisting valleys, modifying them in a variety of ways. The chief characteristic of a glacial valley includes a cross profile that is trough like (U-shaped) and a floor that lies below the floors of smaller tributary valleys. From such hanging valleys, streams often descend as waterfalls. Because the tongue of an advancing glacier is relatively broad, it tends to broaden and deepen the V-shaped stream valleys into broad U-shaped troughs (Fig 3.33 A, B).

e) Truncated spurs : As a moving river of ice has difficulty in negotiating the curves of a stream valley, it tends to straighten and simplify its course. In this process of straightening, the ice cuts or shears-off any spurs of land that come across its flow. The cliffs thus formed, are shaped like large triangles or flatirons, with their apex upwards and are called truncated spurs (Fig 3.33 A, B).

f) Fjords : A segment of a deep glaciated valley, partly filled by an arm of the sea is called a fjord. Fjords are common features along the mountainous west facing coast of Norway.

Fig. 3.32 : Arête bordering a glacier in Karakoram range, Ladakh, India

3.5.2 Glacial deposits and resulting landforms

As a glacier moves, it plucks, collects and encompasses a host of Earth materials within its ice. As and when this ice melts, the material is deposited on the glacial valley floor. The general term 'drift' is applied to all deposits that are laid down directly by glaciers or that, as a result of glacial activity, are laid down in lakes, oceans, or streams. Drift can be divided into two general categories: unstratified and stratified.

i) Unstratified Drift : As the term conveys, is the material deposited from a melting glacier without any sorting and is called 'till'. It is composed of rock fragments ranging in size from boulders weighing several tonnes to tiny clay and colloid particles. The type of till varies from one glacier to another. If clay size particles predominate, it is called clay till. If larger size

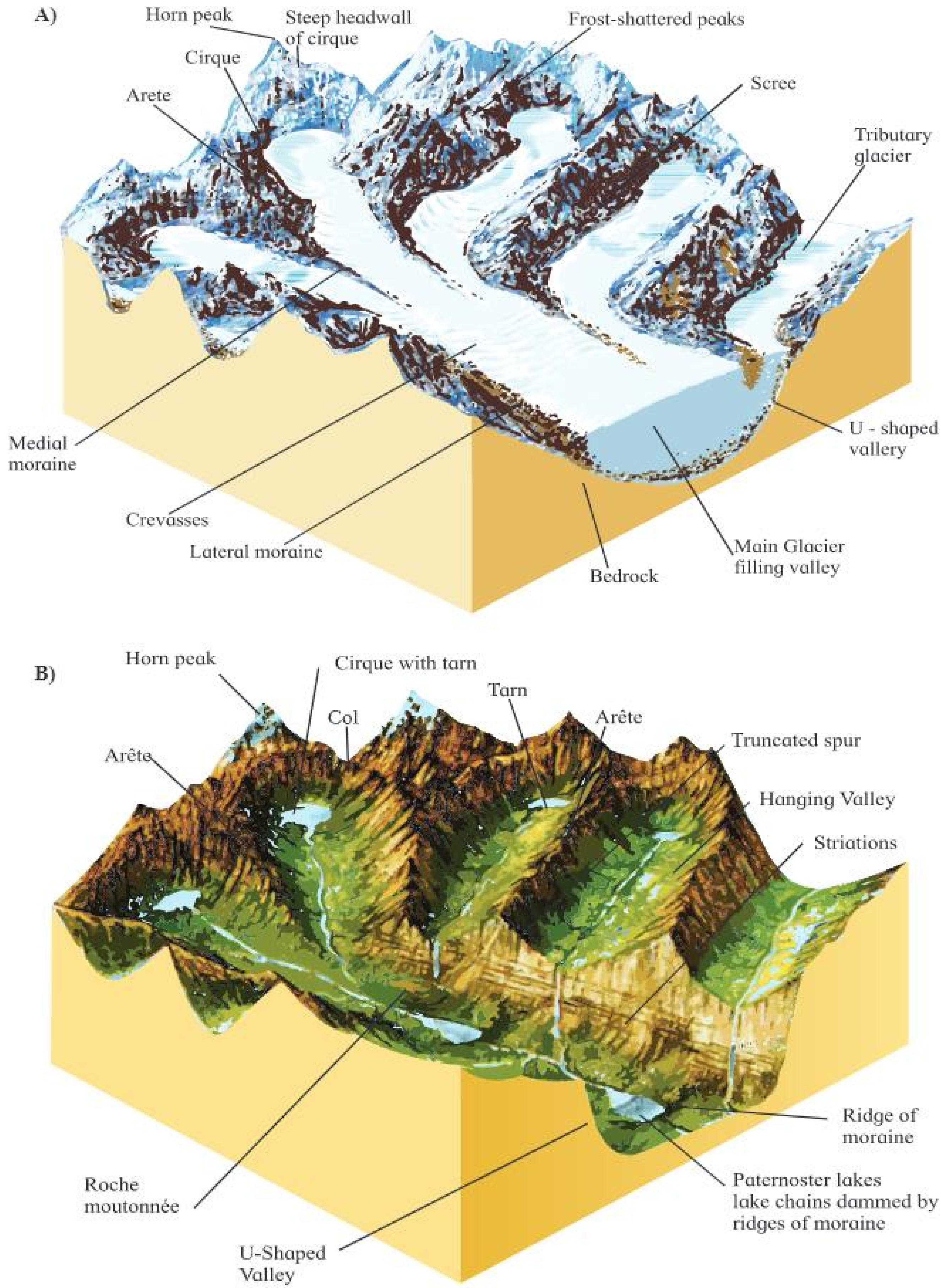


Fig. 3.33 : Glaciated terrain A) with glaciers, B) post glacier melting

rock fragments and boulders predominate, then the deposits are called as boulder tills or stony tills.

Unstratified drift or till is further named based on the topographic form, and location, it is deposited at with respect to the flow channel of the glacier, and includes moraines, drumlins, erratics, and boulder trains.

a) **Moraine :** Moraine is a general term used to describe many of the glacial deposits composed largely of till (Fig. 3.34).

A terminal moraine, or end moraine, is a ridge of till that marks the utmost limit of a glacier's advance. A terminal moraine can vary in size from hundreds of meters to very low, interrupted walls of debris. It forms when a glacier reaches the critical point of equilibrium the point where the glacier melt rate is matched by the rate of ice nourishment. So, as the ice melts in the zone of wastage, the debris is released and the terminal moraine grows.

Behind the terminal moraine, and at varying distances from it, a series of smaller ridges known as recessional moraines may build up. These ridges mark the position where the glacier front was stabilised temporarily during the retreat of the glacier.

'Till' is laid down across the length and width of a glacial valley. It forms gently rolling plains across the valley floor, appearing at times as a thin veneer or may be tens of meters thick and is called ground moraine.

Valley glaciers also produce two special types of moraine :

- **Lateral moraine :** Seen as a ridge along each side of the valley. It is formed due to rubble that kept tumbling down from the valley walls and collected along the side of the glacier. When the glacier melts, this debris is stranded as a ridge (Fig. 3.34).
- **Medial moraine :** Created when two valley glaciers join to form a single stream of ice. The material formerly carried along the edges of the separate glaciers is combined in a single moraine near the centre of the enlarged glacier (Fig. 3.33 A).

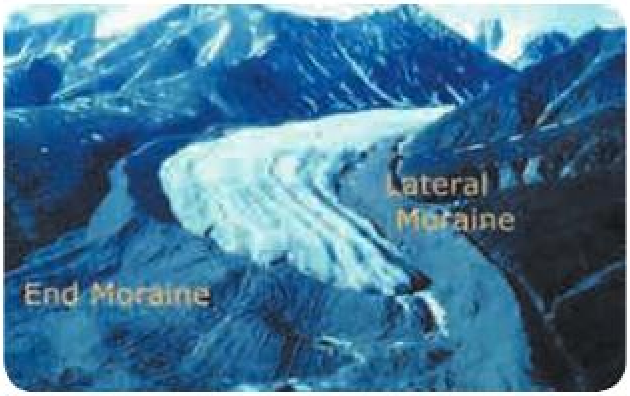


Fig. 3.34 : Glacial moraines

b) **Drumlins :** Drumilns are formed of till. They are elongated features that can reach a kilometer or more in length, 500m or so in width and over 50m in height. One end is quite steep, whilst the other end tapers away to ground level. The stoss end is the steeper of the two ends and faces the ice flow (Fig. 3.35).

The lee slope is the more gentle slope and becomes lower as you move away from the source of the ice. This means that the highest point will always be at the stoss end of the drumlin and the lowest point will be the end of the lee slope. It is common to find several drumlins grouped together. The collection of drumlins is called a 'swarm'. Areas with swarms of drumlins are sometimes referred to as 'basket of eggs' topography because of the rounded bumps that remind people of a box containing eggs.

There is still some debate about how drumlins are formed, but the most widely accepted idea is that they were formed when the ice became overloaded with sediment. When the competence of the glacier was reduced, material was deposited in the same way that a river overloaded with sediment deposits the excess material. The glacier may have experienced a reduction in its competence for several reasons, including melting of the ice and changes in velocity. If there is a small obstacle on the ground, it may act as a trigger point and 'till' will build up around it.

Fig. 3.35 : Drumlin field, Northern Ireland

Do you know?

It is difficult to understand how the material could have been directly deposited in the characteristic shape of a drumlin unless the ice was still moving at the time, but it may also have been reshaped by further ice movements after it was deposited.

c) **Erratics and boulder trains :** A stone or a boulder that has been carried from its place of origin by a glacier and left stranded on bedrock of different composition is called an erratic. The term is used whether the stone is embedded in a till deposit or rests directly on the bedrock. An erratic can weigh several tonnes (Fig. 3.36). Some could have travelled a limited distance of a few hundred meters or also hundreds of kilometers. Boulder trains consist of a series of erratics that have come from the same source and appear as a line of erratics stretching down-valley from their source or in a fan shaped pattern with the apex near the place of origin. They are good indicators of the direction of flow of the glacier.

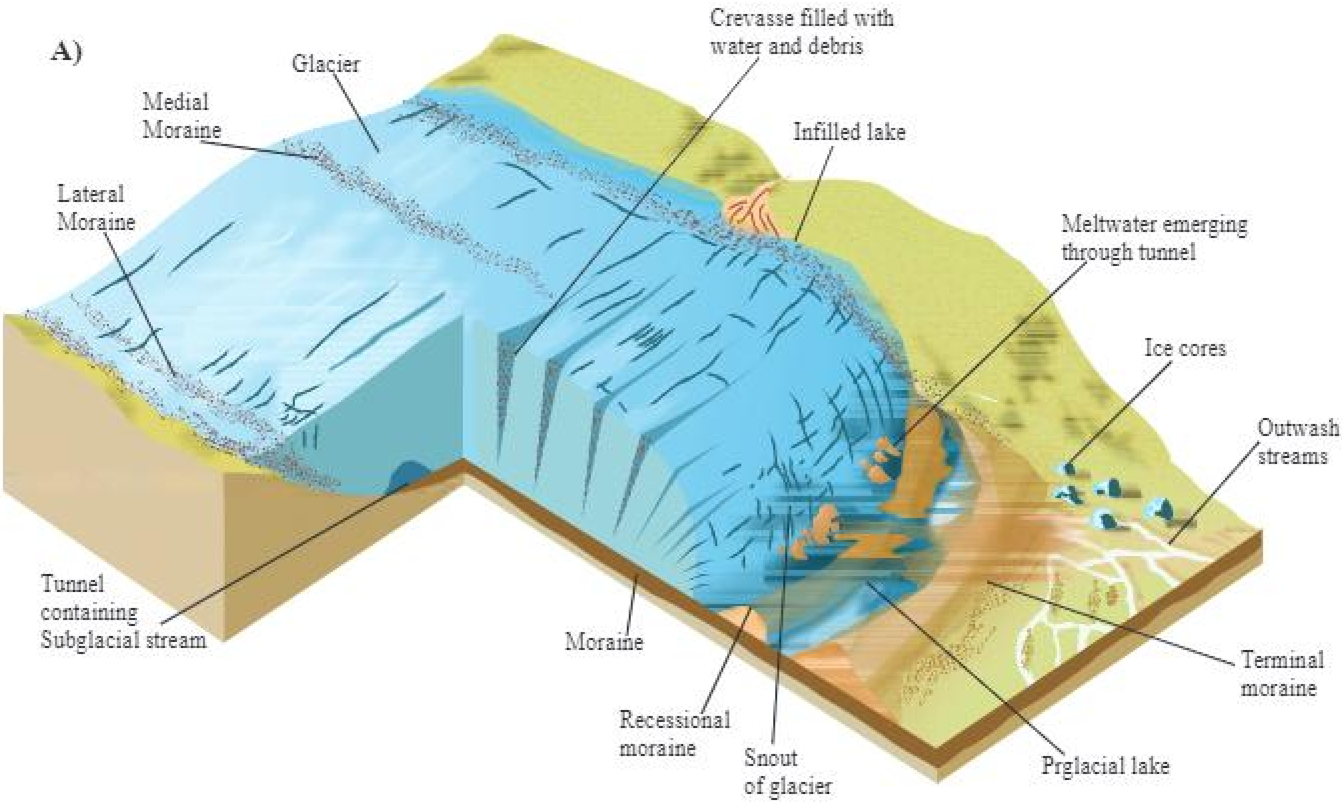
Fig. 3.36: Glacial erratics

ii) **Stratified drift :** It is ice-transported sediment that has been washed and sorted by glacial meltwaters according to particle size. Since water is a much more selective sorting agent than ice, deposits of stratified drift are laid down in recognisable layers, unlike the random arrangement of particles typical of till. Stratified drift occurs in outwash plains, kettles, eskers, kames and varves.

a) **Outwash sand and gravel :** The sand and gravel that are carried outward by meltwater from the front of a glacier are referred to as outwash. When continental ice sheets melt, the outwash deposits stretch for kilometers, forming what is called an outwash plain or 'Sandar' (Fig. 3.37 A).

b) **Kettles or Kettle holes :** These are small depressions in glacial debris. When an ice sheet retreats it may leave behind small 'lenses' of ice that get buried in glacial till or outwash before it finally melts. When these lenses finally melt, they leave behind a small pit or depression or kettle in the drift. These depressions range from a few meters to several hundred meters in diameter and a few meters to over 30 m in depth. Many outwash plains are pockmarked with kettles and are referred to as pitted outwash plains (Fig. 3.37 B).

A)



B)

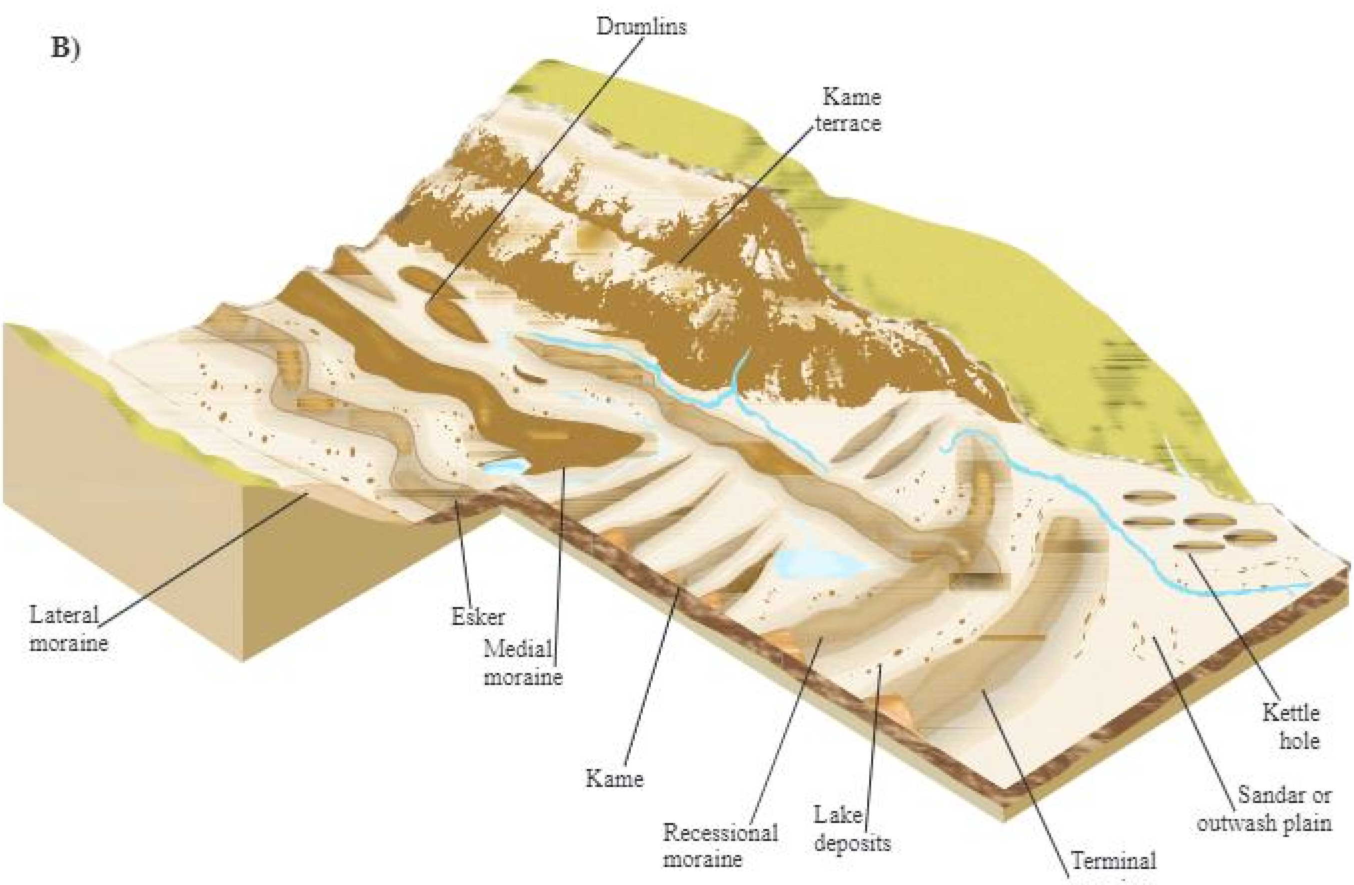


Fig. 3.37: Glacial valley A) During glaciation, B) After glaciation

c) **Eskers and crevasse fillings :** Winding or snaking, steep walled ridges of stratified sand and gravel, sometimes branching and often discontinuous are called eskers. They are now believed to be deposits left by englacial streams of water flowing beneath the ice (Fig. 3.37 B).

Crevasse fillings or Kames are similar to eskers in height, but they form crescentic ridges. They are formed from the material that was caught-up in cracks and crevasses on the glacier surface, and later the material gets deposited as the glacier melts.

A kame terrace on the other hand is a deposit of stratified sand and gravel that has been laid down between a wasting glacier and an adjacent valley wall. When the glacier melts, the deposit stands as a terrace along the side of the valley (Fig. 3.37 B).

d) **Varves :** A varve is a pair of thin sedimentary beds, one of coarse and the other fine sediment. This couplet of beds is usually interpreted as representing the deposits of a single year and is thought to be formed as a result of the alternate freezing and thawing of glacial lakes. During thaw, large amount of coarse particles settle to the bottom of lakes (giving rise to the thin coarse bed). During the following winter, when the water freezes, and the waters of lakes are not disturbed by winds, then the finer clay and silt sink to the bottom and form a thin layer of fine sediment. Varve pairs are used for counting the freeze-thaw cycles and hence dating specific glacial events.

3.5.3 Glacial mass budget :

Glaciers grow by accumulation the building up and compaction of new snow. At the same time ice is lost by ablation that is, melting and evaporation. The difference between accumulation and ablation is the glacial mass budget. If the budget is positive (accumulation exceeds ablation) the glacier advances. If it is negative (ablation exceeds accumulation) the glacier retreats. Usually, glaciers have a negative budget at the foot (the ablation zone) and a positive budget at the top (the accumulation zone).

3.6 Connecting to life/Job skills

Understanding the processes of landform formation gives an insight into the material properties and the internal structure of the said landforms. Constructing roads, buildings, dams, canals, ports, jetties and other man-made structures need an understanding of the landforms. Portions of our Konkan railway periodically experience landslides. If a house is constructed on a wrong spot, say on a sea cliff, it may slide into the sea due to wave attack at the base of the cliff. It is important, then, to study and research the landform on which a railway track, or your house and all valuable infrastructure is to be constructed, or you plan to purchase. No location can be certified as completely safe, but a little research on understanding the landform can help prove some sites to be relatively safer.

Activity :

Prepare a list of all the landforms mentioned in this chapter.

i) Classify them based on their mode of formation.

a) Erosional b) depositional.

ii) Classify them based on location giving Indian examples.

Summary :

- The Earth's surface is unique because of the methodical and constant sculpting by 'erosive agents', viz. water, wind and ice. The heat from the sun and the activity of organisms on the surface materials also plays an important role in development and evolution of various landforms.

- The combined effects of the erosive power of water, wind and ice along with the variations in climate through the Earth's past have resulted in a unique set of landforms. A systematic study of these landforms helps a geologist interpret the processes that could have created them. Hill, valley, plateau and beach are colloquial terms which are used to depict landforms, but when these very common and simple appearing features are studied in detail, the intrinsic differences in various kinds of each of these features is evident.
- Topographic differences are further accentuated or enhanced by the underlying differences in geological structure and rock type. The systematic study of landforms is what a Geomorphologist does and hence contributes to a better understanding of our planet.

EXERCISE

Q. 1. Choose the right alternative :

1) Barchan dunes are formed under .... conditions
   a) High wind velocity and higher supply of sand.
   b) Winds blowing in multiple directions.
   c) High wind high moisture content.
   d) Limited supply of sand and moderate wind velocity.
2) The most active agent of erosion and deposition in dry and arid environment is ....
   a) Temperature   b) Wind
   c) Heat   d) Water
3) Earth's experinces higher average temperature at the equator because
   a) Suns rays strike perpendicular at the equator
   b) Suns rays strike oblique at the equator
   c) Equatorial area is closer to the sun
   d) Magma is generated along the equator.

Q. 2. Choose the correct sequence of development of desert pavement :

a) Finer fraction removal - deflation - gravel dispersal
b) Dispersed gravels - finer fraction removed - lag gravels
c) Lag gravels - dispersal of gravels - removal of gravels
d) Lag gravels - dispersal of gravels - filling up of finer material

Q. 3. Find odd one out :

1) i) Ventifact   ii) Yardang
iii) Oxbow lake   iv) Mesa
a) i   b) ii   c) iii   d) iv

2) i) Sea cave   ii) Sea horse
iii) Sea arch   iv) Sea stack
a) i   b) ii   c) iii   d) iv

Q. 4. Sort out the following into erosional and depositional landforms :

i) Desert pavement
ii) Potholes
iii) Star dunes
iv) River meander
v) Cirque
vi) Moraines

a) Erosional : i - iii - vi
   Depositonal : ii - iv, v
b) Erosional : i - ii - iv - v
   Depositonal : iii - vi

c) Erosional : i - iii - ii
   Depositonal : iv - v - vi

d) Erosional : iv - v - vi
   Depositonal : i - ii - iii

Q. 5. In case of sea level rise which of the following landforms would submerge first :

a) Sea cliff　　b) Drumlins

c) Tombolos　　d) Eskers

Q. 6. Answer in brief :

1) What makes the surface of the Earth and that of the Moon to differ?
2) What are the forces and agents that drive the material on the surface of the Earth?
3) State the relationship between variation in solar radiation with latitudes
4) Distinguish between an alluvial fan and delta
5) State the use of glacial mass balance and budget
6) What kind of landforms changes can occur as a result of glacial melting due to global warming

Q. 7. Read the following passage and answer the questions :

The 250–800 m high Siwalik Ranges form the southern front of the Himalaya. These are made up of sediments deposited by ancient Himalayan rivers in their channels and floodplains in the last 16 to 1.5 Ma. The rugged Siwalik ranges are commonly broken by south-facing scarps, while on their steepened northern slopes, rush down streams through unending cascades and waterfalls as can be seen in the central sector. Then, there are long flat stretches within the otherwise rugged Siwalik terrain called the duns. The duns represent gravelly deposits within depressions or fillings of now vanished lakes that were formed in the synclinal valleys owing to ponding of rivers and streams or to slackening of current velocity as a result of decrease in gradient following tilting of the ground.

Ref: K. S. Valdiya, The Making of India., (2016).

1) When did the sediments deposited by rivers and flood plains on the southern front of Himalaya stop?
2) Differentiate between northern and southern slopes of the Siwalik hills.
3) What kind of -sedimentation is represented by the duns as compared to the Siwaliks?
4) Explain why lakes within the valleys to disappear?