GLACIERS/ LANDFORMS MADE BY MOVING ICE

The word glacier comes from French, and ultimately from Latin 'glacies' meaning ice. A glacier is a large, slow-moving river of ice, formed from compacted layers of snow that slowly deforms and flows in response to gravity. It can also be defined as

> "A large mass of ice moving slowly over some land surface or down a valley, formed over long periods from the accumulation of snow in areas where the amount of snow that falls exceeds the amount that melts."

Glacier ice is the largest reservoir of freshwater on Earth and second only to oceans as the largest reservoir of total water. Glaciers cover vast areas of Polar Regions but are restricted to the highest mountains in the tropics.

TYPES OF GLACIERS

There are three main types of glaciers: **alpine glaciers**, which are found in mountain terrains e.g. Siachin Glacier etc., and **continental glaciers**, which can cover larger areas e.g. Antarctica.

A **piedmont glacier** is valley glacier that has spilled out onto bordering flat land. For example, the Malaspina Glacier in Alaska is a piedmont glacier and is about 40 miles wide.

BRIEF FACTS

During the last ice age, glaciers covered 32% of the total land area. Presently, 10% of land area on Earth is covered with glacial ice, including glaciers, ice caps, and the ice sheets of Greenland and Antarctica. Glacierized areas cover over 15 million square kilometers (5.8 million square miles).

GLACIERS ARE SIMILAR TO RIVERS

Glaciers are also called rivers of ice. Both share following commonalities:

1. They both flow downhill, although a glacier is slower 3 to 300 metres per year.
2. A river flows into the sea while a glacier ends in a snout (dead ice) or in the sea.
3. Both have distinctive cross profiles and long profiles.
4. In both cases, upland areas have erosion features and lowlands have depositional features.

BRIEF FACTS

The fastest glacier ever moved over seven miles in three months.

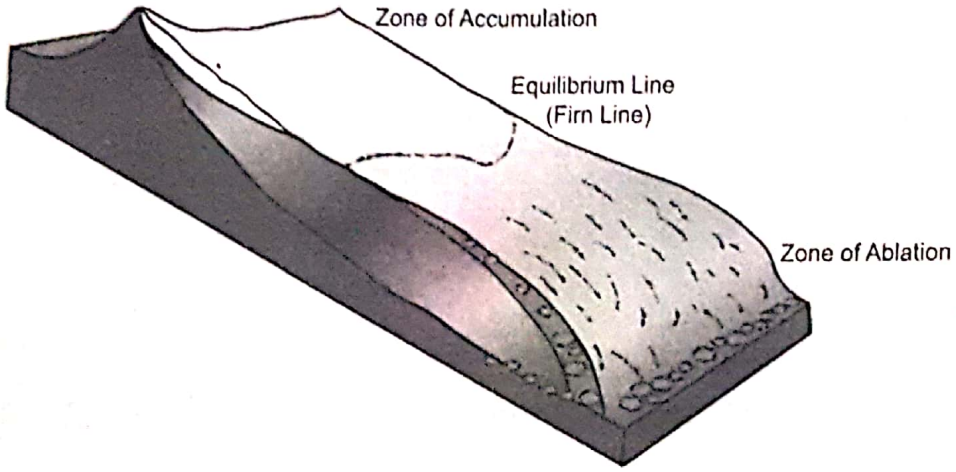
FORMATION

The temperature of the polar areas and high mountain regions remains below the freezing point. The precipitation takes place in the form of snow which with the passage of time is hardened due to pressure of the overlying snow and converted to ice. This mass of ice starts moving down the slope under the force of gravity and weight and is called as glacier.

OCCURRENCE

Glaciers occur on every continent and in approximately 47 of the world's countries. Though Australia has no glaciers, New Guinea is considered to be part of the Australian continent and small glaciers are located on its highest summit Massif of Puncak Jaya. Africa has glaciers on Mount Kilimanjaro, Mount Kenya and in the Ruwenzori Range. The process of glacier growth and establishment is called **glaciation**. Glaciers are sensitive monitors of climate conditions and are crucial to both world water resources and sea level variation.

ANATOMY OF A GLACIER



Glaciers form in the zone of accumulation; the portion of the glacier over which accumulation exceeds ablation. Ablation is the loss of ice (or snow) from the glacier. Ablation includes sublimation, wind erosion, melting and evaporation. The zone of accumulation for the large continental ice sheets resides at high latitudes. For mountain glaciers, the zone of accumulation is at a high altitude where temperatures are cold and prevent complete summertime melt. The zone of ablation is where loss of ice mass is greater than accumulation. The boundary between these two zones is the firn or equilibrium line. If accumulation exceeds ablation, the glacier will grow. If ablation exceeds accumulation, the glacier will retreat by melting in place.

BRIEF FACTS

Glacial ice often appears blue when it has become very dense. Years of compression gradually make the ice denser over time, forcing out the tiny air pockets between crystals. When glacier ice becomes extremely dense, the ice absorbs all other colors in the spectrum and reflects primarily blue, which is what we see. When glacier ice is white, that usually means that there are many tiny air bubbles still in the ice.

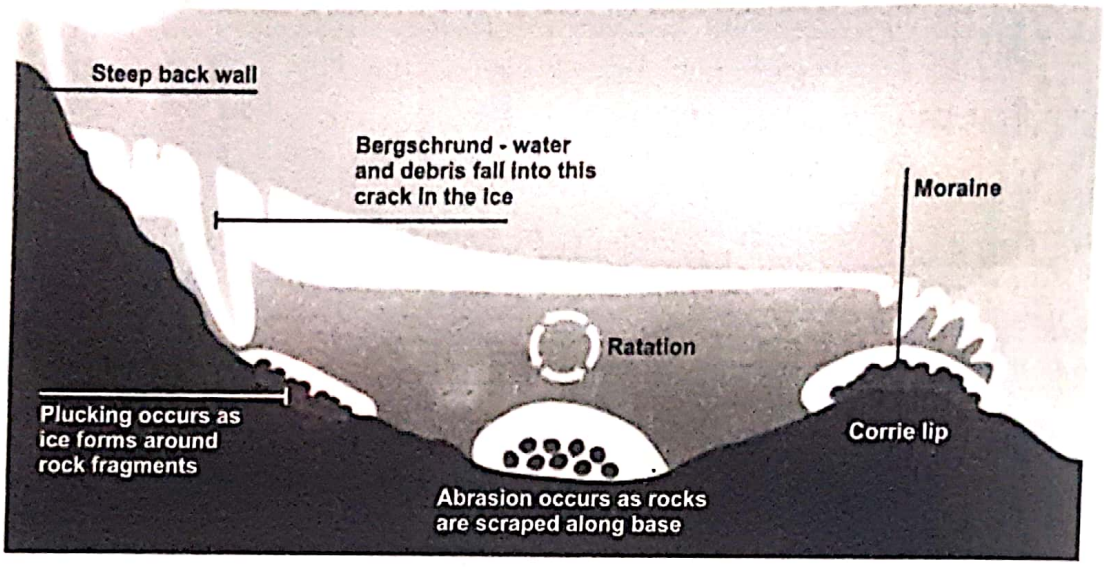
EROSIONAL LANDFORMS

1. CREVASSE

The movement of ice is different in different parts of the glacier. As a result of unequal movement of ice within a glacier, the top with least amount of friction moves much faster than the base. The cracks marked on the glacier because of the splitting up of the ice as a result of its unequal movement are known as crevasses. Most crevasses are formed across the entire glacier where the slope of its bed, i.e. the floor of the valley becomes suddenly steeper. Hence the ice cannot keep pace with its faster movement and the glacier breaks up into separate blocks on such steeper slopes.

2. BERGSCHRUND

A bergschrund (from the German for mountain cleft) is a crevasse that forms where moving glacier ice separates from the stagnant ice or firn above. It is often a serious obstacle for mountaineers, who sometimes abbreviate "bergschrund" to "schrund". Broad crevasses are known as Bergschrund.



Bergschrunds extend to the bedrock and can have a depth of well over 100 metres (330ft).In winter, a bergschrund is often filled by snow from avalanches from the mountain above it. In later summer, due to melting, it lies open and can present a very difficult obstacle to alpinists.

3. CIRQUE

Corries, also known as cirques, are often the starting point of a glacier. The diagram below shows the formation of a corrie or cirque. Snowflakes collect in a hollow. As more snow falls, the snow is compressed and the air is squeezed out to become *firn* or *neve*. With the pressure of more layers of snow, the firn will, over thousands of years, become glacier ice. Erosion and weathering by abrasion, plucking and freeze-thaw action will gradually make the hollow bigger.

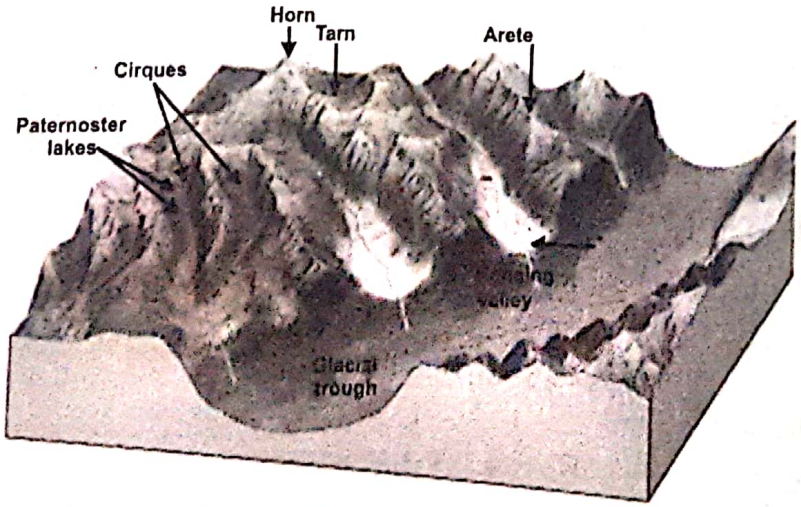


Figure: Glaciated topography

Even though the ice is trapped in a hollow and unable to move down hill, gravity will still encourage it to move. This circular motion is known as **rotational slip** and can cause the ice to

pull away from the backwall creating a crevasse or bergschrund. Plucked debris from the backwall causes further erosion through abrasion which deepens the corrie. Some of this debris is deposited at the edge of the corrie, building up the lip. These processes create a characteristic rounded, armchair shaped hollow with a steep back wall.

4. Tarn Lake

After the glacier melts, the corries are usually occupied by water and the lakes are formed called tarns.

5. Aretes and Horns (Pyramid Peak)

There may be two glacial cirques 'back-to-back' which erode deep into their backwalls until only a narrow ridge, called an arete is left. An arete is a narrow crest with a sharp edge. An arete is also formed when two glaciers erode parallel U-shaped valleys. The arete is then left separating the two valleys. The meeting of three or more aretes creates pointed pyramidal peaks also called horns. If arêtes are in chain they form a comb like structure called comb ridges.

6. Fjord

Geologically, a fjord or fiord is a long, narrow inlet with steep sides, created in a valley carved by glacial activity.Fjords are formed when a glacier cuts a U-shaped valley by abrasion of the surrounding bedrock. Many such valleys were formed during the recent ice age.

Most fjords are deeper than the adjacent sea; Sognafjord, Norway, reaches as much as 1,300m (4,265ft) below sea level. Fjords generally have a sill or rise at their mouth caused by the previous glacier's terminal moraine, these characteristics distinguish fjords from rias, which are drowned valleys flooded by the rising sea.

BRIEF FACTS

The land underneath parts of the West Antarctic Ice Sheet may be up to 2.5 kilometers (1.6 miles) below sea level, because of the weight of the ice, which is over 4.2 kilometers thick.

7. Sheepback Rock/Roche Moutonnee

Some rock formations in the path of a glacier are sculpted into small hills with a shape known as roche moutonnée or *sheepback*. It has a gentle slope on its up-glacier side and a steep to vertical face on the down-glacier side. The glacier abrades the smooth slope that it flows along, while rock is torn loose from the downstream side and carried away in ice, a process known as 'plucking'. It may have striations on it indicating the direction of glacier movement.

8. Crag and Tail

Crag and tail is the opposite of the roche moutonnee as the ice hits the steep resistant rock outcrop first. This protects the lee (far) side of the obstacle from erosion. Edinburgh castle is built on crag and tail. Hard rock is called crag and soft rock attached is called tail.

9. Staircase Lake (Paternoster Lakes)

As mountain glaciers flow down valley, they encounter exposed bedrock of varying resistance to erosion. The glacier will erode down into weaker rock but have to flow over the stronger rock. This creates a series of rock steps composed of the more resistant rocks with small depression behind them where the weaker rock is exposed. Often these depressions are occupied with water to form staircase lakes.

10. GLACIAL VALLEYS

Before glaciation, mountain valleys have a characteristic "V" shape, produced by downward erosion by water. However, during glaciation, these valleys widen and deepen, which creates a **"U-shaped glacial valley.** Besides the deepening and widening of the valley, the glacier also smooths the valley due to erosion. Many glaciers deepen their valleys more than their smaller tributaries. Therefore, when the glaciers recede from the region, the valleys of the tributary glaciers remain above the main glacier's depression, and these are called **hanging valleys.** These hanging valleys create spectacular waterfalls.

GLACIAL DEPOSITION AND DEPOSITIONAL LANDFORMS

Sediments that were deposited by melting ice or by glacial streams are called Fluvio-glacial. Debris deposited directly by the glacier, such as moraine and intra-glacial material dropped 'in situ' by retreating ice, is known as **Till.** The range of sediment sizes and processes of deposition produce a wide range of landforms:

BRIEF FACTS

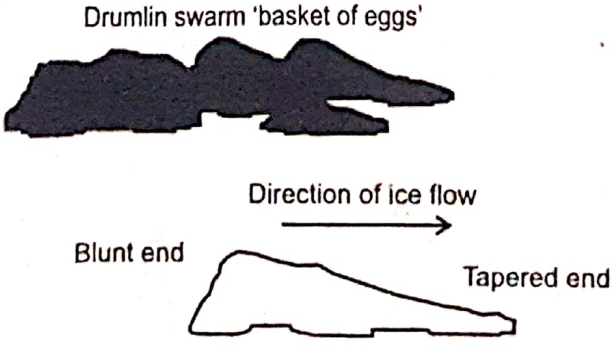
The Kutiah Glacier in Pakistan holds the record for the fastest glacial surge. In 1953, it raced more than 12 kilometers (7.5 miles) in three months, averaging about 112 meters (367 feet) per day.

1. BRAIDED STREAMS

When glacial ice melts, the water moves away from the glacial snout in fast-flowing streams and rivers. The water transports vast quantities of sediments and larger debris. If the sediment load is very large in relation to the velocity of the stream, the more coarse material may start to block the stream, choking it and forcing it to constantly change its course. The stream starts to diverge, splitting into numerous segments which split and join repeatedly. The small islands formed within the stream are called eyots.

2. DRUMLINS

Drumlins are formed of till. They are elongated features that can reach a kilometre 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 used to face into the ice flow. 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.



3. ERRATICS

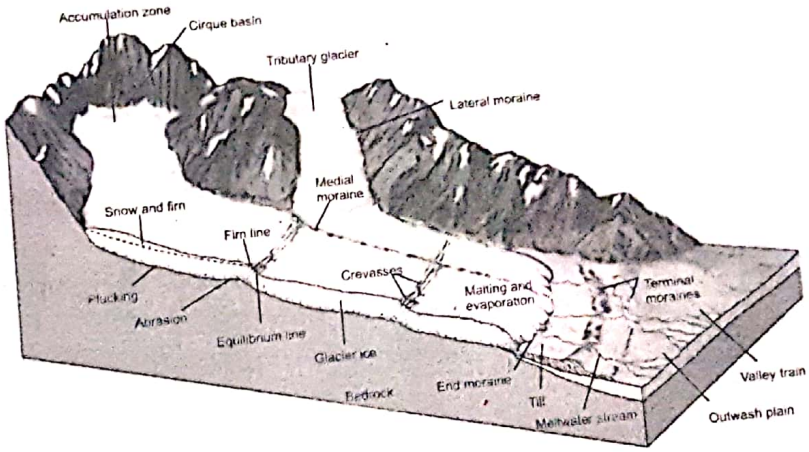
Erratics are large boulders that have been transported by glaciers, and often deposited a considerable distance from their origin. For example, there are erratics in the county of Norfolk, in the United Kingdom, that originated in Norway. By establishing the origins of the erratic, by comparing its lithology with possible originating areas, it is possible to determine the direction of ice flow that brought it to its present location. This helps glaciologists monitor and plot past ice movements across large areas.

4. GLACIAL MORAINE

Moraine is material transported by a glacier and then deposited. There are seven types of moraine, five of which form recognisable landforms, and two of which exist only whilst the glacier exists.

a. Ground Moraine

Ground moraine is till deposited over the valley floor. It has no obvious features and is to be found where the glacier ice meets the rock underneath the glacier. It may be washed out from under the glacier by meltwater streams, or left in situ when the glacier melts and retreats.



b. Lateral Moraine

Lateral moraine forms along the edges of the glacier. Material from the valley walls is broken up by frost shattering and falls onto the ice surface. It is then carried along the sides of the glacier. When the ice melts, it forms a ridge of material along the valley side.

c. Medial Moraine

Medial moraine is formed from two lateral moraines. When two glaciers merge, the two edges that meet form the centre line of the new glacier. In consequence, two lateral moraines find themselves in the middle of the glacier forming a line of material on the glacier surface. The existence of a medial moraine is evidence that the glacier has more than one source. When the ice melts, it forms a ridge of material along the valley centre.

TIP OF THE ICEBERG
Almost 90% of an iceberg is below water—only about 10% shows above water.

d. Recessional Moraine

Recessional moraines form at the end of the glacier so they are found across the valley, not along it. They form where a retreating glacier remained stationary for sufficient time to produce a

mound of material. The process of formation is the same as for a terminal moraine, but they occur where the retreating ice paused rather than at the farthest extent of the ice.

e. Terminal Moraine

The terminal moraine forms at the snout of the glacier. It marks the furthest extent of the ice, and forms across the valley floor. It resembles a large mound of debris, and is usually the feature that marks the end of unsorted deposits and the start of fluvially-sorted material.

MELTWATER /STREAMS LEFT DEPOSITS / GLACIO–FLUVIAL DEPOSITS

Meltwater deposits came from streams in, on and under the ice. These streams increased in discharge due to the large-scale melting of the ice. They also had large loads which made new features when they were deposited:

1. OUTWASH PLAINS

These are large areas of glacial sediment deposited by meltwater streams furthest away from the glacial snout. They are formed from gravels, sands and clays, the clays being furthest away from the snout because the smaller particles are carried furthest

2. ESKERS

Eskers are produced as a result of running water in, on or under the glacier. They are linear mounds of sand and gravel that commonly snake their way across the landscape. They are the deposits of rivers and streams that flowed on, in or under a glacier.

An esker is a long winding ridge of stratified sand and gravel, examples of which occur in glaciated and formerly glaciated regions of Europe and North America. Eskers are frequently several miles long and, because of their peculiar uniform shape, are somewhat like railroad embankments.

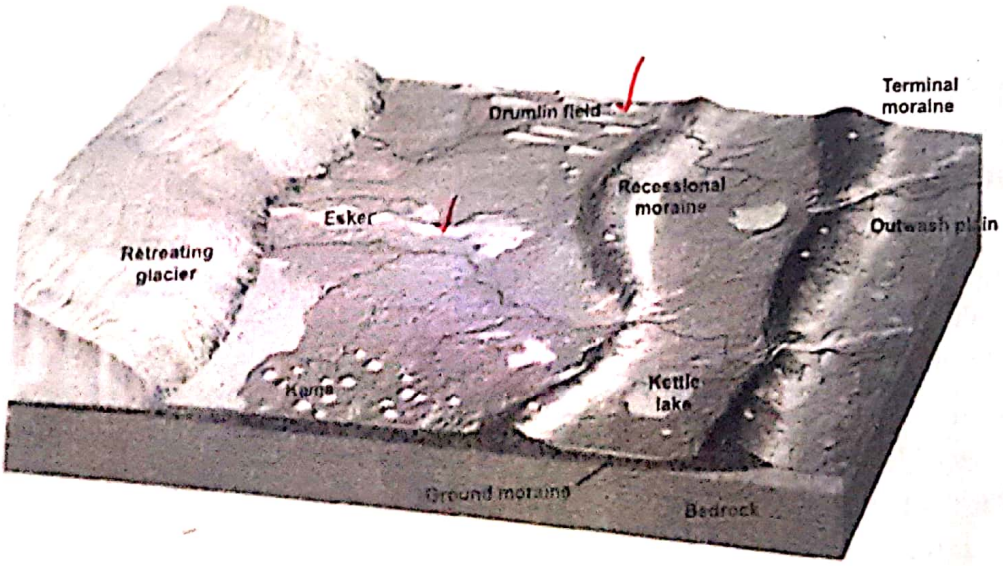


Figure: Glacio-fluvial deposits

3. KAMES

Kames are small mounds of deposits formed when meltwater streams flow over the snout of the glacier to flatter ground below. Kames are mounds of sediment which are deposited along the front of a slowly melting or stationary glacier/ice sheet. The sediment consists of sands and

gravels, and builds up into mounds as the ice melts and more sediment is deposited on top of old debris. Often, a kame will collapse when the ice melts back and leaves the mound unsupported.

4. Kettle Lakes

Kettle Lakes are found where blocks of ice broke off from the glacier as it retreated and were buried in the old deposits. When the ice melted, the overlying material collapsed to form a small depression a kettle hole. When the ice blocks eventually melt, they leave behind holes or depressions that fill with water to become Kettle Hole Lakes.

Expected Questions

1. Briefly discuss the landforms that are typically associated with the glaciated region.
2. What is a glacier? Discuss the action of glacier as an agent of erosion and deposition.
3. Describe the landforms developed by glacial erosion and deposition.
4. What is a glacier? Discuss the formation of landforms resulting from glacial erosions. Illustrate your answer.
5. Write short note on glacial topography.
6. Define glacier? How would you categorize them according to the mode of formation? Explain with the help of diagrams the characteristic features of a glaciated region?
7. What is glaciation? Describe the landforms associated with glaciation in the highland areas.
8. Discuss the origin and characteristics of the landforms produced by glaciers.
9. What is a "Glacier"? Discuss the formation of landforms resulting from the "Glacial Erosion".
10. Describe landforms and evolution of landscapes of glaciation in the mid and high latitudes.
11. Present glaciated morphology through various stages.
12. What is a glacier? Discuss the action of glacier as an agent of erosion and deposition and the resulting landforms.
13. Write a note on major types of glaciers and what features are produced by glacier deposition?

THE WORK OF WIND/ AEOLIAN PROCESS/ LANDFORMS OF ARID REGION

Although wind is a less important geologic agent than water, it does exert an appreciable influence on the topography of arid regions. Wind action is referred to as an eolian process, and all topographic features created by such a process are referred to as eolian landforms. Eolian landforms are typically depositional in nature; however, several types of erosional landforms exist as well.

FACTORS AFFECTING WIND EROSION

The ability of the wind to erode the surface is determined by two factors, air density and wind velocity. The erosive power of the wind (E) is given as:

$$E = V^3\rho$$

Where V = wind velocity, and ρ = air density. Density has relatively little impact on the power of the wind. The erosive force of the wind is primarily related to its velocity. Its importance is seen as erosive power and varies with the third power of velocity. For instance, a doubling of the wind velocity increases the erosive power by 8 times while a tripling of velocity produces a 27 fold increase.

WAYS IN WHICH EROSION TAKES PLACE

1. Deflation

This involves the lifting and blowing away of loose materials from the ground. Such unconsolidated sand and pebbles may be carried in the air or rolled along the ground depending on the grain size. The finer dust and sand may be removed kilometres away from their place of origin, and be deposited even outside the desert margins. Deflation results in the lowering of the land surface to form large depressions called deflation hollows. The Qattara Depression of the Sahara Desert lies almost 135m below sea level.

2. Abrasion/Sand Blasting

The sandblasting of rock surfaces by winds, when they hurl sand particles against them, is called abrasion. The impact of such blasting results in rock surfaces being scratched, polished and worn away. Abrasion is most effective at or near the base of rocks, where the amount of material, the wind is able to carry, is greatest. This explains why telegraph poles in the deserts are protected by a covering of metal, a metre or two above the ground. A great variety of desert features are produced by abrasion.

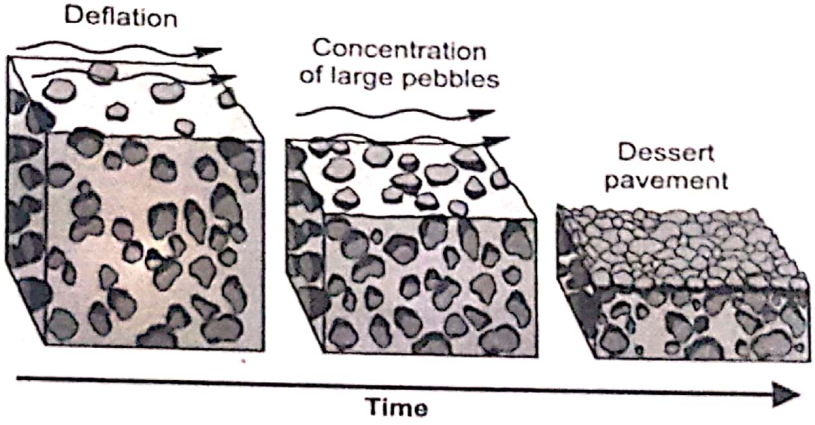
3. Attrition

When wind-borne particles role against one another in collision, they wear each other away so that their sizes are greatly reduced and grains are rounded into millet seed sand. This process is called attrition.

EROSIONAL FEATURES CREATED BY WIND ACTION

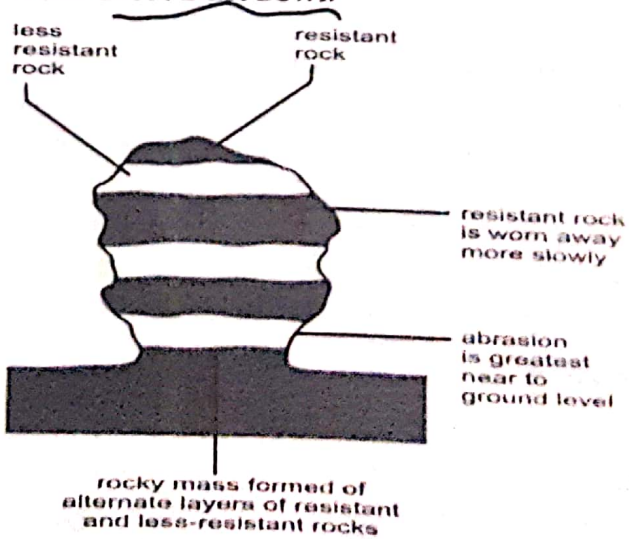
1. Desert Pavement / Desert Lag

When heterogeneous surficial mixtures of gravel, sand and silt undergo erosion by deflation, the finer particle are removed, leaving behind only the particles that are too large to be transported. Eventually, a continuous remnant layer of gravel is left to protect the underlying heterogeneous material from further erosion. The gravel layer is referred to as a desert pavement due to its resemblance to cobblestone mosaics.



2. Blowouts Depressions or Deflation Hollows

The most noticeable result of the deflation in some places is shallow depressions called blowouts or Deflation Hollows. In some places, layers and layers of loose dry sediments are removed by deflation. The result is a blowout. In the Great Plains Region, from Texas north to Montana, thousands of blowouts can be seen. The Faiyum Depression in Egypt lies 40m below sea level. Large areas in western USA, stripped-off their natural vegetation for farming were completely deflated when strong winds moved materials as dust storms, laying waste crops and creating what is now known as the Great Dust Bowl.



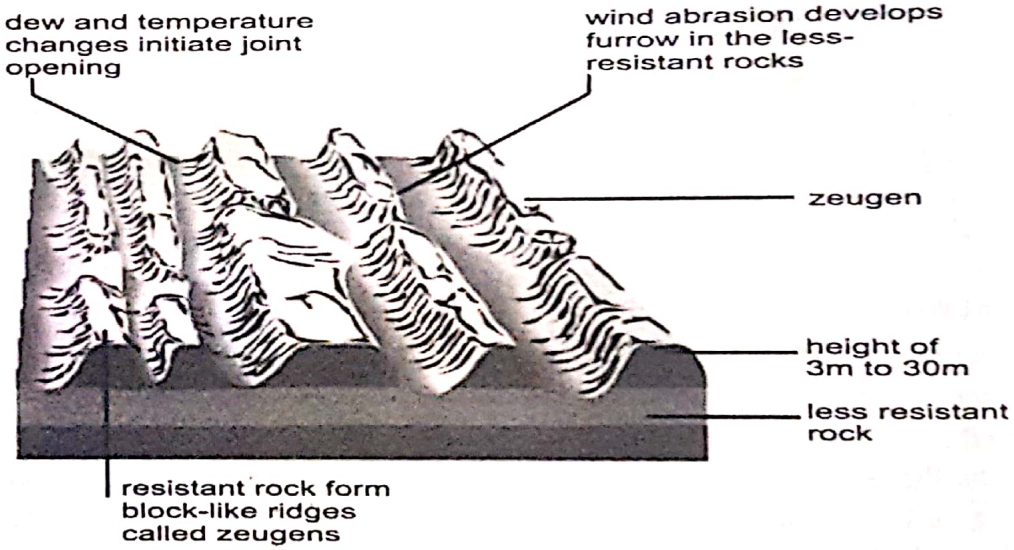
3. MUSHROOM TOPOGRAPHY/PEDESTAL ROCKS

The sandblasting effects of winds against any projecting rock masses wear back the softer layers so that an irregular edge is formed on the alternate bands of hard and soft rocks.

Grooves and hollows are cut in the rock surfaces, carving them into fantastic and grotesque-looking pillars called Rock Pedestals. Such rock pillars will be further eroded, due to abrasion, near their bases where the friction is greatest. This process of undercutting produces rock of mushroom shape called mushroom rock or gour as in the Sahara.

4. 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. Mechanical weathering initiates their formation by opening up joints of the surface rocks. Wind abrasion further eats into the underlying softer layer so that deep furrows are developed. The hard rocks then stand above the furrows as ridges or zeugen, and many even overhang. Such tabular blocks of zeugen may stand 3 to 30 meters above the sunken furrows. Continuous abrasion by wind gradually lowers the zeugen and widens the furrows.

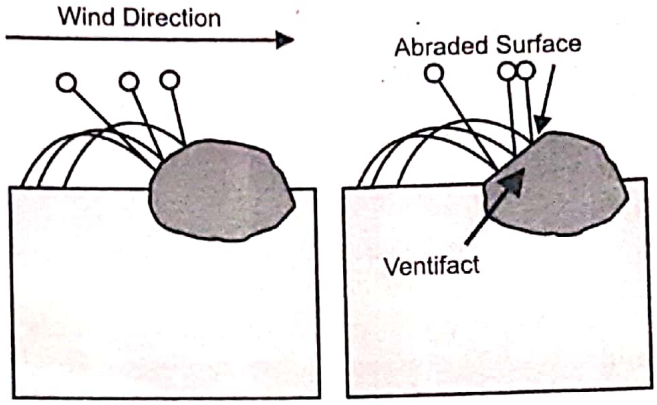


5. HAMADA

In desert areas, the exposed bedrock surfaces become the sides of the attack by sandblast and as the matter is moved to and fro, the less resistant parts gradually reduce to sand and conveyed beyond the limits of the region. Ultimately what remains behind is the rock pavement made of resistant rock stuff over which are spread dreikanter-shaped pebbles. Such a rock flow represents the base level of erosion in deserts – the last stage of works in the cycle of dessert erosion. This flat, bare rock floor is called Hamada. The best known rocky deserts are those of the Sahara Desert, e.g., the Hamada el Homra, in Libya, which covers an area of almost 52,000 km².

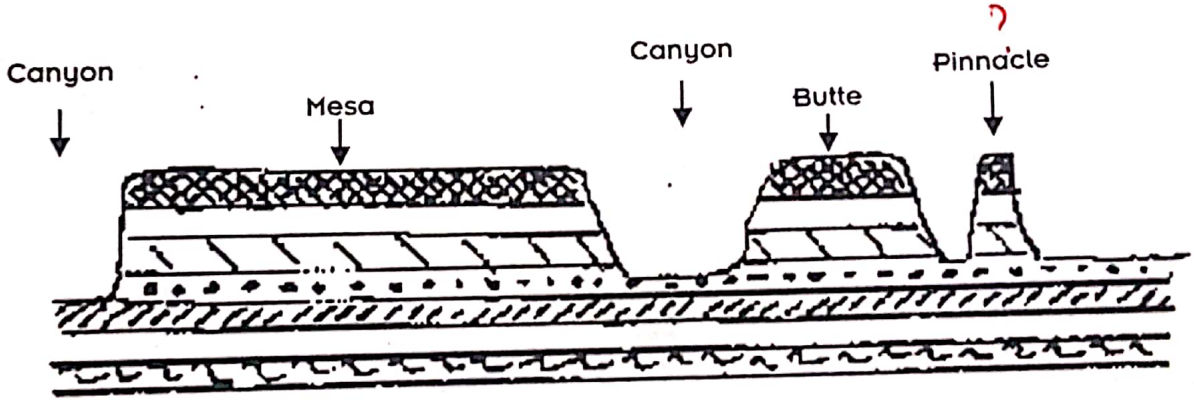
6. VENTIFACTS/ DREIKANTER

In windswept areas, where abrasion is a predominant form of eolian erosion, sandblasting may result in the formation of smoothly-polished face on exposed rock surfaces. If the wind direction or the position of the rock changes, additional facets may develop. A multifaceted rock shaped by wind abrasion is called a ventifact.



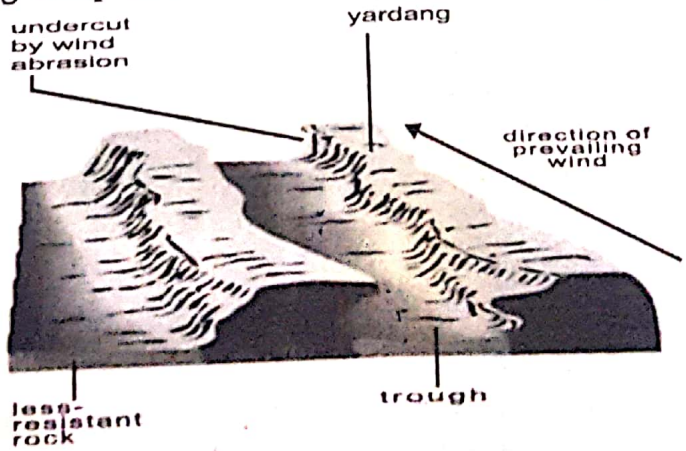
7. MESA AND BUTTES

Mesa is Spanish word meaning table. It is a flat, table like-land mass with a very resistant horizontal top layer, and very steep sides. The hard stratum on the surface resists denotation by both wind and water, and thus protects the underlying layers of rocks from being eroded away. Mesas may be formed in canyon regions, e.g. Arizona. Continued denotation through the ages may reduce mesa in area so that they become isolated flat-topped hills called buttes. Many of them in arid countries are separated by deep gorge or canyon.



8. YARDANG

A yardang is a wind-abraded ridge formed in cohesive material. The word itself is of Turkish origin, meaning 'steep bank'. Some are found in dried-up riverbeds.



Yardangs may also be found in deserts and may form very unusual shapes and some resemble various objects.Yardangs are elongate features typically three or more times longer than they are wide, and when viewed from above, resemble the hull of a boat. Facing the wind is a

steep, blunt face that gradually gets lower and narrower toward the lee end. They come in a large range of sizes, and are divided into three different categories: **mega-yardangs** can be several kilometres long and hundreds of metres high, **meso-yardangs** are generally a few metres high and 10 to 15 metres long, and **micro-yardangs** are only a few centimetres high.

9. INSELBERGS

This is a German word meaning "island-mountain". They are isolated residual hills rising abruptly from the level ground. They are characterized by their very steep slopes and rather rounded tops. They are often composed of granite and are probably relics of an original plateau which has been almost entirely eroded away. These represent an island like emergence from a rock plain.

10. OTHER EROSIONAL EOLIAN FEATURES

Several types of exotic erosional features may result from wind abrasion. For example, isolated rock masses have been carved into mushroom-shaped pedestals and bridge-like arches. In addition, holes, called windows, have been cut completely through rock walls.

SEDIMENT TRANSPORTATION BY WIND