1. Details of Module and its structure

Module Detail	
Subject Name	Geography
Course Name	Geography 01 (Class XI, Semester - 1)
Module Name/Title	Landforms — Glacial Landforms – Part 3
Module Id	kegy_10703
Pre-requisites	Basic knowledge about the landforms developed by the action of glacier
Objectives	After reading this lesson, learners will be able to: • Acquire the knowledge and understanding of formation and evolution of glacial landforms. • Understand the concept of glacial activity. • Understand formation of erosional and depositional landforms created by activities of the glaciers.
Keywords	Glacier, Cirque, Tarn lake, Horns and Serrated ridges, Arete, U-shaped valley, Hanging Valley, Fiords, Moraines, Eskers, Kame, Outwash plain, Drumlins.

2. Development Team

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Numerous changes have occurred to the pattern of climates on the earth during its long geological history. The scenery in parts of Europe and North America reflects period in the earth's history when large areas were buried beneath the thick sheets of ice and glaciers. Such periods is known as ice ages, and the last of these occurred in Pleistocene Period. During this period the northern parts of Eurasia and North America were buried beneath vast masses of Ice. This has now melted but regions around the North Pole, much of Greenland and Iceland, the whole of Antarctica and some high mountains are still buried beneath ice masses. At this time, most of the world's high mountains had their tops buried under ice which is extended down the valleys in enormous tongues, called glaciers. Glaciers form only on land and are distinct from the much thinner sea ice and lake ice that form on the surface of bodies of water.

The Pleistocene Ice Age began about two million years ago. During the last 20,000 years, conditions became warmer and the period in which we now live is called as inter-glacial period. From the beginning of the Pleistocene Ice Age, several climatic changes took place which resulted in the ice advancing, which produced an ice age, and then retreating to give an inter-glacial period. It has been calculated that for these changes to take place a temperature change of 5 ^{0}C was needed. In other words, a fall of 5 ^{0}C would be sufficient to cause the ice to advance again, including the glaciers in the mountain of East Africa. Snow consists of small ice crystals separated by air spaces, but as the depth of snow increases, the pressure exerted on the bottom layers causes some of the crystals to melt, and the water formed trickles down into the air spaces where it freezes. This causes the snow to be turned into a granular mass, called *neve* or *fern*. In time, all the air spaces disappear and eventually the *neve* is converted into a compact mass of ice known as glacial ice. When a continuous mass of ice covers a large land surface, it is called as ice sheet. There are ice sheets in Greenland and Antarctica. In both regions the ice sheets reach to the coasts and into the surrounding seas. Large masses break off from the ice sheets and form icebergs.

When a mass of ice occupies a valley it is called a *glacier* (Fig.1). The largest glaciers today's are in high mountain ranges such as Himalayas, Andes, Rockeies and Alps, but some mountainous highlands in Africa also have glaciers. These are Mount Kenya and Kilimanjaro and the Ruwenzori Mountains. Snow falls annually on these mountains and also on the tops of the Atlas Mountains, the Ethiopian Highlands, the Drakensberg and Cape Ranges. Glaciers form only on land and are distinct from the much thinner sea ice and lake ice that form on the surface of bodies of water. The movement of glaciers is slow unlike water flow. The movement could be a few centimetres to a few metres a day or even less or more. Glaciers move basically because of the force of gravity. The rate of movement is greatest in the middle where there is little obstruction.

Figure.1 Glaciers

https://upload.wikimedia.org/wikipedia/commons/5/5c/Perito_Moreno_Glacier_Patagonia_Argentina_Luca_Galuzzi_2005.JPG

Snow accumulates; it is gradually transformed into ice. This transformation is the result of several processes, not all of which are clearly understood. Among the processes responsible for transforming snow into ice is sublimation, recrystallization (with growth of large crystals at the expense of smaller one), regelation (melting-refreezing under pressure), and compaction (underweight). As snow piles up by actual precipitation and drifting, compaction of the lower layers takes place. The increasing pressure then causes a slight lowering of melting point. This melted water percolates through interstices of snow and refreezes (called regelation) around snow crystals to form ice granules.

Classification of Glacier

The moving ice mass down the slope under the impact of gravity is called glacier. It originates at high altitudes due to low temperature and high orographic precipitation. Ice-sheets, ice-caps and glaciers are considered to form to 10% (Approximately) of the world's land area at present. Continental glaciers cover nearly 13,000,000 km^2 or about 98 percent of Antarctica's 13,200,000 km^2 , with an average thickness of 2,100 m (7,000 ft). Greenland and Patagonia also have huge expanses of continental glaciers.

Glacial Processes

Erosion by glaciers is tremendous because of friction caused by sheer weight of the ice. The material plucked from the land by glaciers (usually large-sized angular blocks and fragments) get dragged along the floors or sides of the valleys and cause great damage through abrasion and plucking. Glaciers can cause significant damage to even un-weathered rocks and can reduce high mountains into low hills and plains.

Abrasion

It is accepted that one of the most important of glacial processes is the grinding away of bedrock (into and smaller particles) by ice armed with rock fragments of various sizes. The reality of ice abrasion is indicated by polished rock surfaces, deep grooves or furrows. Other evidences is afforded by the finely ground rock material washed by melt water streams from the snouts of present day glaciers. The process is accelerated by high sliding rates, soft bedrock, hard grinding rock in large fragments, melting at the base of the ice so that fresh angular debris can be carried down into contact with bed rock by efficient removal of rocks floor to leave fresh surfaces and by the ice thickness large enough to produce high contact pressures between abrading particles and the bed. It is a mechanical process which needs tool. Tools are unconsolidated rocks and when they move they lead to grooves.

Plucking

The incorporation of large rock fragments into a glacier bed by freezing on is called plucking. The process of quarrying (plucking) may be affected in one of two ways. Firstly, the glacier ice may freeze on to the solid rock and since it is moving liberally wrench away blocks defined by joints or other lines of weakness. Secondly, the percolation of water into joints, followed by freezing and expansion of that water, might lead to the wedging away of the blocks, which can then become incorporated in the following ice. It seems most probable that this is entrainment of blocks already loosened by other processes and not primarily erosional. It is a mechanical process and it get struck with parent rocks and the rock tends to pluck the ground when it was resting.

Erosional Landforms

Valley glacier produces more impressive features than ice sheets because they operate in valley. These valleys already have relief which is worked over by the glaciers. The main features of glacial erosion are overdependence valleys.

Cirque

Cirques are the most common of landforms in glaciated mountains. The cirques quite often are found at the heads of glacial valleys. The accumulated ice cuts these cirques while moving down the mountain tops. They are deep, long and wide troughs or basins with very steep concave to vertically dropping high walls at its head as well as sides. A lake of water can be seen quite often within the cirques after the glacier disappears. Such lakes are called *cirque or tarn lakes*. There are main four types of cirque, a) simple cirques; b) compound cirques; c) hanging cirques; and d) nivation cirques.

There are three main components of an open cirque:

1. Cirque head wall is almost vertical and may attain as much as 600 top 900 meter high with wall like steep slope. There is not accumulation of debris at its base. It may be noted that the absence of any debris (talus) denotes the fact that there is no role of weathering in the development of cirques and thus glacial erosion is responsible for their formation.
2. The second component of cirques their basins which represent the floors of cirques. After de-glaciations the cirque basin may form lakes if water collects in it.
3. The third component is threshold, which is the outer margin of cirque.

They are commonly found on nearly level upland tracts or in tundra areas of sub-polar regions. They are produced by solifluction and rill wash beneath snow banks. Conditions that seem to favour maximum cirque development are:

- Rather wide spacing of pre-glacial valleys, so as to permit expansion without intersection of adjacent cirques at an early stage.
- Snowfall sufficient to form large snow fields and glaciers but not heavy enough to form ice caps.
- Fairly, homogeneous rocks which permit cirque extension equally well in any direction.

If cirques are most significant and interesting landforms of glacial erosion their origin is also complex and still uncertain. Various geomorphologists have postulated there contrasting hypotheses to account the origin of cirques.

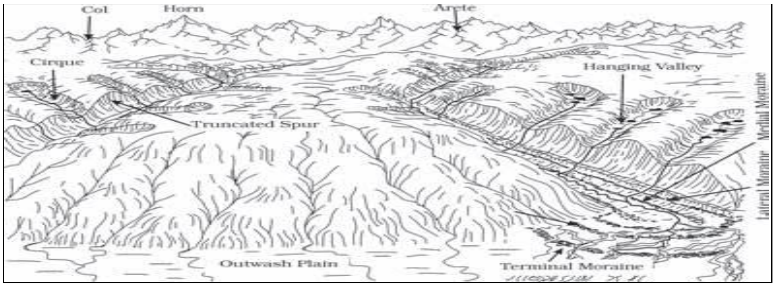

Figure 2 : Some glacial erosional and depositional forms (adapted and modified from Spencer, 1962) (NCERT Book)

Horns and Serrated Ridges

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. The divides between cirque sidewalls or head walls get narrow because of progressive erosion and turn into serrated or saw-toothed ridges sometimes referred to as *arêtes* with very sharp crest and a zigzag outline.

Glacial Valleys/Troughs

Glaciated valleys are trough-like and *U-shaped* with broad floors and relatively smooth, and steep sides. The valleys may contain littered debris or debris shaped as *moraines* with swampy appearance. There may be lakes gouged out of rocky floor or formed by debris within the valleys. There can be hanging valleys at an elevation on one or both sides of the main glacial 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. Very deep glacial troughs filled with sea water and making up shorelines (in high latitudes) are called *fjords*/*fiords*.

U- Shaped Valley

U-shaped valley is typical erosional glacial feature. U-shaped valleys are so called because of the shape such as valley has flat floor and very steep sides. The glacial on its downward journey, fed by ice from several corries like tributaries that join a river, begins to wear away the sides and the floor of the valley down which it moves. It scratches and grinds the bedrock, removing any bedrock debris and surface soil. It tends to straighten and protruding spurs on its course. The interlocking spurs and the floor of the valley are deepened. A valley which has been glaciated takes characteristics of U shape, with a wide flat floor and very steep sides, after the disappearance of the ice, the deep sections of this long, narrow glaciated trough may be filled with water forming ribbon lakes, such as Loch Ness and Lake Ullswater in Britain. They are sometimes referred to as trough lakes or Finger Lakes.

Figure 4 Avalanche Lake (Glacier National Park, Montana) sits at the mouth of a classic U-shaped, glacially-carved valley.

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On U-shaped valley glaciologist differ in their views. According to one group of glaciologist glacier do not form their own valleys but flow through pre existing fluvially originated valleys. They modify pre-existing valleys through the mechanism of abrasion and plucking and thus they transform them into U-shaped valley. On the other hand, the advocates of external glacial erosions believe that glacial dig out their own valleys through which they flow. It may be pointed out that if we look at the depth and width of the glacial valleys it became clear that such enormous valleys cannot be dug out by glaciers alone. It may be concluded that valleys are modified forms of pre-existing valleys.

Fig. 4 U-Shaped Valley at the Leh Valley

https://upload.wikimedia.org/wikipedia/commons/b/b5/U-shaped_valley_at_the_head_of_Leh_valley%2C_Ladakh_%282%29.JPG

Depositional Landforms

The unassorted coarse and fine debris dropped by the melting glaciers is called glacial till. Most of the rock fragments in till are angular to sub angular in form. Streams form by melting ice at the bottom, sides or lower ends of glaciers. Some amount of rock debris small enough to be carried by such melt-water streams is washed down and deposited. Such glacio-fluvial deposits are called outwash deposits. Unlike till deposits, the outwash deposits are roughly stratified and assorted. The rock fragments in outwash deposits are somewhat rounded at their edges. Figure 5 shows a few depositional landforms commonly found in glaciated areas.

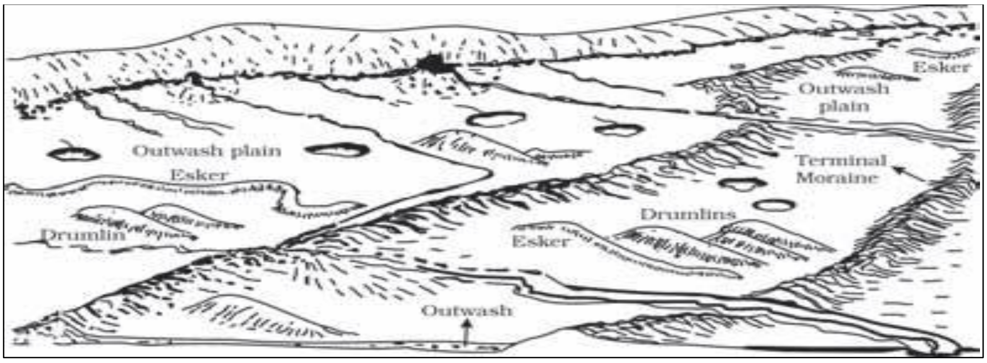

Figure: 5 A panoramic diagram of glacial landscape with various depositional (Adapted and modified from Spencer, 1962)

Moraines

The term moraine as originally used by the French peasants was applied to ridge-like embankments of glacial deposits in alpine valleys. They are long but narrow ridges with height more than 30 meters. Moraine is a general term applied to the rock fragments, gravel, sand etc. carried by a glacier. Moraines are generally divided in 4 parts on the basis of locational aspects of glacial deposits.

Ground Moraines

Ground Moraines are formed when glacial sediments (till) are deposited at the floor of glacial valleys. Ground moraines may consist of both basal and superglacial till. The sediments are not sorted because coarse and fine sediments are deposited together. If thick, its typical topographic expression is a till pain. In Ohio, Indiana, Illinois, and Iowa its average thickness probably exceeds over 100 ft and locally over periglacial valleys it may be several hundred feet thick.

Lateral Moraines

Lateral moraines are parallel ridges of till on either side of a glacier. They are formed due to deposition of sediments along the margins of a glacier when it contracts in size due to melting of ice. Lateral moraines are generally, long, narrow and steep sided ridges parallel to the glacial valleys. They are several hundred of metros of height.

Figure: 6 lateral moraine

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Medial Moraines

Medial moraines are formed due to deposition glacial sediments along the interval margins of two glaciers at their confluence. They project above the surface of glacial valley. In other words when two glaciers joins their lateral moraines also join near their confluence are called medial moraines.

Figure: 6 Medial moraines -

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End Moraines

This moraine is a known as terminal moraines. They are formed due to the deposition of glacial till across the moving ice sheets at the snouts glaciers after ablation of ice. Terminal moraines are horse shoe shaped or crescentic ridges having concave slopes facing glacial valleys. They stretch for hundreds of kilometers in length and more than 100 meters in height. The recession of glaciers or ice sheets results in the deposition of several irregular ridges, mounds separated by basins. Such landscape is called 'Knob and basin topography'. The materials in end moraines may be deposited in three ways, by lodgement, pushing or dumping. They are deposited of clay till. End moraines are seldom continuous for great distances but usually are segmented.

Figure: 7 Terminal_Moraine

https://upload.wikimedia.org/wikipedia/commons/a/a1/Penny_Ice_Cap_Terminal_Moraine.jpg

Eskers

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 (not in a valley cut in the ground) with ice forming its banks. Very coarse materials like boulders and blocks along with some minor fractions of rock debris carried into this stream settle in the valley of ice beneath the glacier and after the ice melts can be found as a sinuous ridge called *esker*.

Outwash Plains

The plains at the foot of the glacial mountains or beyond the limits of continental ice sheets are covered with glacio-fluvial deposits in the form of broad flat alluvial fans which may join to form outwash plains of gravel, silt, sand and clay. An outwash fan is a fan-shaped body of sediments deposited by braided streams from a melting glacier. Sediment locked within the ice of the glacier, gets transported by the streams of melt water, and deposits on the outwash plain, at the terminus of the glacier. The outwash, the sediment transported and deposited by the melt water and that makes up the fan, is usually poorly sorted due to the short distance travelled before being deposited.

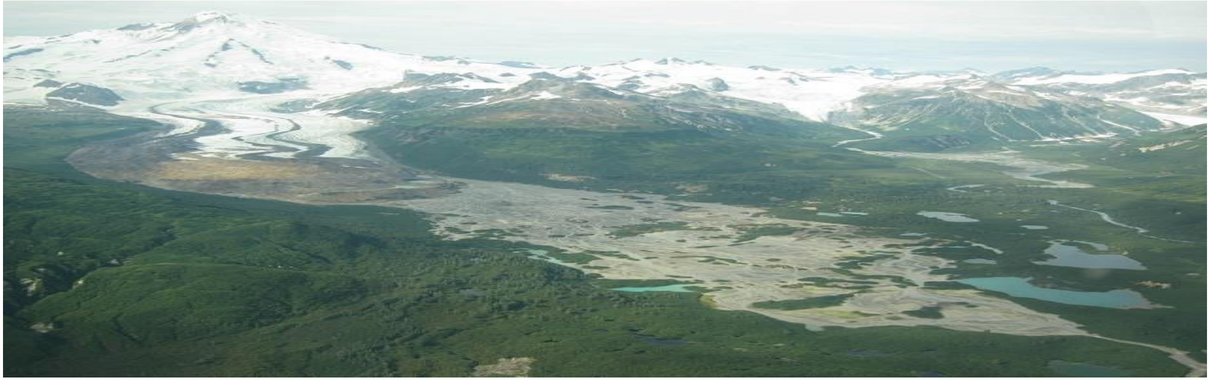

Figure: 7 Outwash plain

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Drumlins

Drumlins are smooth oval shaped ridge-like features composed mainly of glacial till with some masses of gravel and sand. The long axes of drumlins are parallel to the direction of ice movement. They may measure up to 1 km in length and 30 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 *tail*. The drumlins form due to dumping of rock debris beneath heavily loaded ice through fissures in the glacier. The *stoss* end gets blunted due to pushing by moving ice. Drumlins give an indication of direction of glacier movement.

Drumlins and drumlin clusters are glacial landforms, composed primarily of glacial till, which have been extensively studied. Geologists have proposed several theories about their origin. They can form both near the margin of glacial systems and within zones of fast flow deep within the ice sheet. They record the direction of ice movement at the time of formation. Drumlins occur in symmetric, spindle, parabolic, and transverse asymmetrical forms. However it is increasingly being recognised that there is no true 'drumlin' shape, and that rather subglacial bed forms can take on a wide range of shapes and sizes. Drumlins are commonly found with other major glacially-formed features and are related on a regional scale to these landforms. The large-scale patterns of these features exhibit spatial organization of the drumlin-forming flows with related tunnel valleys, eskers, scours, and exposed bedrock erosion.

Figure: 8 Drumlins

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Summary

- Glaciers are masses of flowing ice under the effect of gravity.
- The steady accumulation of snow produces granular ice called neve or fern. As more snow accumulates the neve compacts to give glacier ice.
- Continental glaciers are huge and may spread out over much of a continent. Valley glaciers are long and narrow and form in mountains and flow through mountain river valleys.
- Ice masses are classified into glaciers. e.g., cirque, valley, piedmont and ice caps.
- Rock debris that accumulates on and in the ice is called moraines. Types of moraine are lateral, medial, terminal etc.
- Glaciers cause erosion by plucking and abrasion. Valley glaciers form several unique features through erosion, including cirques, arêtes, and horns.Glaciers deposit their sediment when they melt and create landforms such as boulder clay, moraines, drumlins, kettle lakes, and eskers

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