CHAPTER V

GLACIAL GEOMORPHOLOGY

GLACIAL GEOMORPHOLOGY

V. 1. INRODUCTION

Glaciers are naturally occurring dynamic body of ice which flow under the influence of gravity and its own pressure. Glaciers are also considered as living ice as they constantly change their shape and size to adjust to change in environmental conditions. Glaciers are born where accumulation of winter snow exceeds the melting of snow during the summer. The process of formation of glacier from snow follows a regular sequence. Initially, fresh snow has bulk sp. gravity less than 0.1, later on when it has survived a summer melting season it is called *Firn* or *neve* having bulk sp. gravity greater than 0.4. Then as successive annual layers accumulate the deep firn is compacted and individual grains freeze together. The firn itself undergoes further change as continued pressure forces out most of the air between the granules, reduces the space between them, and finally transforms it into glacier ice, a true solid composed of interlocking crystals having bulk sp. gravity of 0.8. (Leet and Judson, 1969).

Glaciers vary greatly in their rates of response to climatic fluctuations. The largest and most slowly moving *Ice Sheets*, lying in high altitude regions of severe climate are least sensitive. The glaciers of middle latitude with a critical mass balance where slight changes in rates of accumulation or ablation may have very profound consequences, are better indicators of climatic change. The fluctuations are obvious in terms of the retreat or advance of glacier snouts over periods of a few years or decades. In India glaciers are a valuable source of fresh water which sustain perennial Himalayan rivers even during peak summer months and provide water for drinking, irrigation and hydel power generation. For the sustainable development of these regions, systematic mapping of glacial geomorphic features and understanding of the processes are of utmost importance. In above perspective, detailed glacial geomorphic studies have been carried out for Baspa valley.

V. 2. MORPHOLOGICAL CLASSIFICATION

The morphological classification of glaciers is done following the classification given by Leet and Judson, (1969) and Sugden and John, (1976) and includes three main types (Table 5.1). The three main glacier types are distinguished by fundamental differences in the way their morphological expression reflects the interactions between glacier ice and topography. These three main types are then subdivided (where necessary) into component elements on the basis of morphology.

(Table 5. 1) Morphological classification of glaciers

Ice sheets and Ice caps (Unconstrained by topography)	Ice domes Outlet glaciers
Ice shelves	---
Glaciers (constrained by topography)	Ice fields Valley glaciers Cirque glaciers Other small glaciers

An *ice sheet* or *ice cap* is superimposed on the underlying topography which it largely submerges; the direction of flow of the ice reflects the size and shape of the glacier rather than shape of the ground. Thus, ice mass covering Antarctica, northern America or British Isles would be termed *Ice sheet*, whereas an Ice mass over Wales, The Grampian mountains of Scotland or Svalbard would be termed *Ice Cap*. The surface of an ice dome is gently sloping in the centre where ice is thickest, and steepens progressively as the ice becomes thinner towards margin (Sugden and John, 1976). *Outlet Glacier* flows down from an ice sheet, ice field or ice cap beyond its margins, has no clearly defined catchment area and usually follows local topographic depressions (Frank et.al., 2005). An Ice shelf is a floating Ice Cap or part of an ice sheet which deforms under its own weight. Floating ice sheet of considerable thickness attached to a coast nourished by glacier(s); snow accumulation on its surface or bottom freezing (Frank et.al., 2005). A glacier constrained by topography is strongly influenced both in its form and its direction of flow by the shape of the ground. An *Icefield* can be regarded as an approximately level area of ice which is distinguished from an ice cap because its surface does not achieve the characteristic domelike shape, and because flow is strongly influenced by the underlying topography. They generally occur in topographical depressions or plateaus. *Valley glaciers* are streams of ice that flows down the valleys of mountainous areas. Like streams they vary in width, depth and length. Valley glaciers that are nourished on the flanks of high mountains and that flow down the mountain sides are sometimes called *Mountain glaciers* or *Alpine glaciers*. Very small mountain glaciers are referred as *Cliff glaciers, Hanging glaciers*, or *Glacieretes* (Leet and Judson, 1969). A *cirque glacier* is a mass of small ice generally wide in relation to its length characteristically occupying armchair-shaped bedrock hollow. No tongue developed, in contrast to simple basin and catchment area is created through the process of glacial erosion (Frank et.al., 2005). Other small glaciers include *Ice aprons* which are thin irregular masses of snow and ice adhering to steep mountain slopes or ridges. *Niche glacier*s are Small glacier in V-shaped gully or depression on a mountain slope and genetically less developed in form than cirque glacier. The Himalayas largely comprises of valley type of glaciers. India's largest valley glacier is the Siachen glacier (*Black rose)* in the Karakoram Himalayas. It is the second largest glacier, outside the polar region and is about 74 km in length. Glaciers investigated in Baspa valley are mainly of alpine type and at places associated with permanent snowfields

V. 3. GLACIAL LANDFORMS

Glaciers can be divided into three major zones viz., accumulation zone, ablation zone, and deglaciated valley. These zones comprises of varied type of erosional and depositional geomorphic features as mentioned below.

V. 3. A. Accumulation zone

It is the zone where snow is collected and nourishes glacier (Plate 5. 1). In this area the total accumulation exceeds the amount of snow that melts away during summer. It gives higher reflectance and appears as white colour with fine texture on satellite data. It is generally above the snowline which at the end of snow ablation season separates from ablation zone. Valley glaciers are nourished not only in zone of accumulation, but also by great masses of snow that avalanche down the steep slopes along their course for e.g. in tectonically active area like Himalayas avalanches caused by earthquake may enable a glacier to advance in a single day equals to a normal snowfall of several years. In general the south facing glaciers show less accumulation area as compared to north facing glaciers.

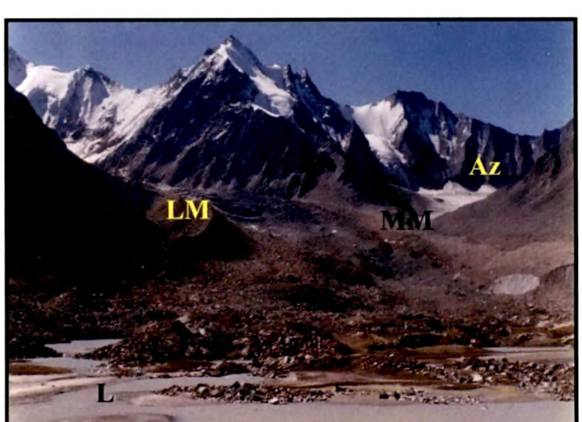

Plate 5.1. Accumulation zone (Az), Lateral moraine (LM), Medial moraine (MM), Moraine covered ablation zone (B), Lakes (L) of Shaune garang glacier

More than 50% of south facing glaciers exhibit less than 1 km^2 accumulation area. The minimum accumulation area is of 0.12 km^2 for glacier no.12 (Fig 4.9) (Table 4.13) and maximum accumulation area observed is 12.69 km^2 for glacier no.17 (Fig 4. 18, 4. 19 & 4. 20) (Table 4. 19). Majority of north facing glacier shows more than 1 km^2 area except for glacier no.20, 23, 27 & 33 (Fig 4.33, 4.36 & 4.47) (Table 4.22, 4.25, 4.29 & 4.35). The minimum accumulation area is observed for glacier no.20 and maximum is observed for glacier no.30 (Fig 4.39, 4.40) (Table 4.32), i.e., Jorya garang (Table 4.38).

V. 3. A.i. Crevasses

Glaciers are classified into two zones viz; an upper zone which acts like a brittle substance and the lower zone which behaves like a plastic substance (zone of flow). As plastic deformation takes place in the zone of flow, the brittle ice above is carried along. But as the zone of flow moves forward at different rates the rigid ice in the upper zone (Zone of fracture) is unable to adjust itself to this irregular advance. Consequently, the upper part of the glacier cracks and shatters, giving rise to series of crevasses (Leet and Judson, 1969). In Shaune Garang glacier they show surface expression of meandering pattern with bluish-white to black colour and fine-medium texture on satellite data.

V. 3. B. Ablation Zone

It is the zone in which snow and ice are lost from glacier by the processes of melting, evaporation and wind erosion. The ablation zone can be classified into exposed ablation zone and moraine covered ablation zone. The exposed ablation zone appears as grayish white colour with fine texture while moraine covered ablation zone appears as brownish colour with medium texture on satellite data. In general the exposed ablation zone exhibit faster melting, while the area which is covered by debris shows slow melting. The ablation zone with debris cover also shows variation in the rate of melting. Thin debris cover absorbs the heat and on account of conductivity the glacier melts faster (Jansson and Fredin, 2002). In case of thick debris cover the absorbed heat does not reach up to the glacier and hence slow down the process of melting (Konrad and Humphries, 2000). This is also supported by Kulkarni and Bahuguna, (2001) stating that, many small low altitude glaciers are well protected due to extensive debris cover. Shaune and Jorya Garang also show majority of glacier under moraine cover (Plate 5.1 & 5.2) (Fig 4.50) (Table 4.36). In case of Baspa valley majority of glaciers show more moraine covered area as compared to south facing glaciers (Table 4.38).

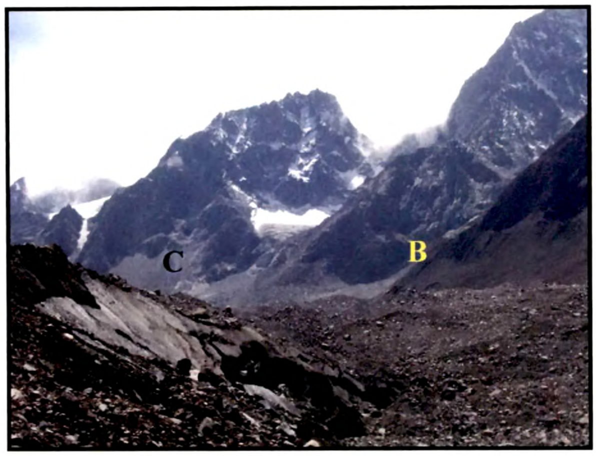

Plate 5.2. Moraine covered ablation zone (B) and Ice wall (C) of Jorya garang glacier

V. 3. B.i. Snout

Snout is known as the terminus of a present glacier where glacier system ends and fluvial system begins. In satellite image it appears as a black colour on account of shadow of the ice wall and shows linear to curvilinear shape. It is normally difficult to identify the snout on the imagery if the glaciers are debris covered. Certain geomorphic features can be used to identify the snout. Often moraine dammed lakes are formed downstream of a snout. Sometimes snout is characterized by steep ice wall. Depending upon relative positions of the sun and wall, it can form shadow in downstream which can be used as marker for identification of snout (Kulkarni et al. 2007). In case of Shaune Garang (Fig 4.50, 4.51) (Plate 5.1) and Jorya garang (Fig 4.39, 4.41) the snout is marked, where the stream originates from the Ice wall (Plate 5.3 and 5.4).

(Lat- 31°16'40" N, **Lon-** 78°29'03" E, **Elev-** 4208 m**)**

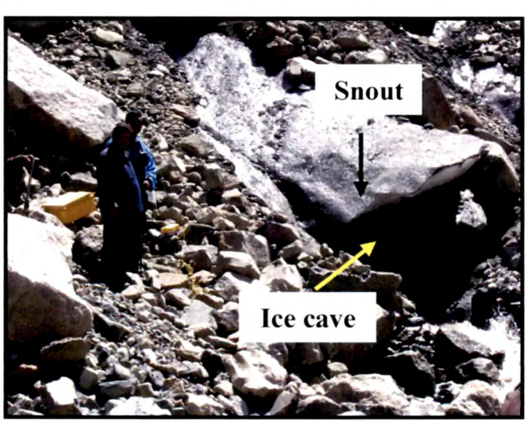

Plate 5.3. Snout & Ice cave, Jorya garang glacier

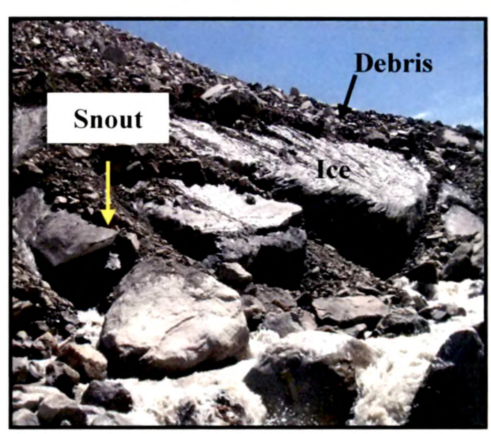

Plate 5.4. Snout, Jorya garang glacier

Average elevation of snout for south facing glacier is 4980 m and for north facing glacier is 4570 m (Table 4.38). This indicates south facing glacier is retreating faster than north facing glacier.

V. 3. C. Deglaciated valley

Deglaciated valley lies below the ablation zone and are formed due to retreat of glacier from its maximum extent. They appear as brown colour and medium texture on satellite data. Glacial erosion was most intense when thick, well-nourished temperate glaciers were flowing rapidly down steep slopes towards a free outlet usually following valleys prepared for them by pre-glacial rivers, and enlarging them into spectacular troughs. When the snowline fell glaciers extended out from cirques and flowed through this valleys. The present glaciers are only very small remnants of their much larger Pleistocene predecessors, whose effects are now clearly revealed in the parts of valleys from which the glaciers have retreated.

One of the most striking characteristic of a well developed glaciated valley is the U-shape of its cross profile. The side walls are considerably oversteepened, approaching the vertical in places (Plate 5.5). The valley floor is flatter than in river. Widening and deepening may depend upon the ability of the glacier to erode valley walls and cut into the rock of its bed. This also depends upon the lithology of its bedrock. Another likely cause that much of the overdeepening must have been achieved by glacial plucking of previously loosened blocks.

Plate 5.5. Deglaciated valley of Jorya garang glacier

Plate 5.6. Outwash sediments and braided pattern of Shaune garang river

Apart from the U-shaped cross-profile, other significant features of deglaciated valley are presence of number of sets of arcuate shaped ridges of Terminal moraines, linear to curvilinear Lateral moraines and scattered Ground moraines indicative of stages of deglaciation. The valley floors are filled with reworked outwash sediments and broad braided stream channels (Plate 5.6). Deglaciated valley is also marked by series of rock basins, formed probably by plucking in areas of bedrocks which were shattered or closely jointed. As time passes, these rock basins fill up with water forming lakes (Plate 5.1). Length of deglaciated valley varies for different glaciers. Almost all the glaciers of Baspa valley shows deglaciated valley of varying nature. (Table 4.38)

V. 4. EROSIONAL LANDFORMS

Glaciers have special ways of eroding, transporting and depositing earth materials. Plucking, quarrying, nivation, frost shattering (Plate 5.9 and 5.10), and abrasion [striations (Plate 5.7) and polishing (Plate 5.8) of rocks] are five basic processes involved in shaping the various erosional landforms of glacial origin and the resulting features are explained here.

Plate 5.7. Striations on boulder of granitoid

Plate 5.8. Polished surface of granitoid

Plate 5.9. Frost shattering of rocks, Shailpya garang glacier

Plate 5.10. Frost shattering Jorya garang glacier

V. 4. A. Cirques

The term cirque is the oldest established and was introduced in 1823 by Jean de Charpentier. The cirques have long been recognised as one of the most characteristic forms of glacial erosion. In its fully developed form, it consists of a rounded basin partially enclosed by steep cliffs from which mountain glacier flows and is focal point for the glacier nourishment. The cliffs at the back of the basin may rise to great heights and culminate in jagged peaks or aretes (Plate 5.11). Cirques are worldwide in their occurrence, but confined to areas of present or former glacierization.

The actual process involved in the formation of cirque is nivation, a term that refers to erosion beneath and around the edges of snow bank. When seasonal thaws melt some of the snow, the meltwater seeps down to the bedrock and trickles along the margin of snowbank. Some of the water works its way to cracks and bedrock where it freezes again, producing pressures that loosen and pry out fragments of the rock (Plate 5.10). These fragments are moved off by solifluction, by rill wash, and perhaps by mass wasting forming a shallow basin. As this basin grows deeper, a cirque eventually develops. When no accumulation takes place in the cirques and all ice is lost away then the cirque becomes isolated and no longer feeds the trunk glacier but is stranded with the mouth enclosed by a bar of rock debris. This is observed in case of Shailpya Garang glacier of Baspa valley which is near the village Chhitkul (Plate 5.12).

The size to which a cirque will grow depends on many factors. Among them competence of the rock to withstand failure will clearly be important in limiting the heights of the side and headwalls. Most of the best developed cirques in Baspa valley are associated with Igneous or metamorphic rocks (Plate 5.11 and 5.13) and this is generally true for large cirques elsewhere in the world. In areas of sedimentary rocks, cirques are often only poorly developed as in the southern and central Wales. The size of the mountain mass in which cirques are forming will also obviously affect the size to which any one cirque can grow, and the duration of glaciation will be another factor. As the cirques enlarge, the intervening ridges will be gradually cut away and the cirques themselves will eventually loose their outlines and identities.

Cirques are known to occur in almost all type of rocks. But the outlines of cirques may cut across well marked lithological boundaries. L. H. Mc Cabey (1939), in Spitsbrgen also observed that cirques were intimately related rock structure. Structures such as foliation, joints, faults, shatter plains, dialatation or pressure release joints seem to be relatively more important than lithology in cirque development.

W.M. Davis (1909), E. de Martonne (1910-11) and Storm (1945), contended that pre glacial valley heads or valley sides would provide suitable locations for the initial collection of snow and its transformation into moving ice.

Another major factor influencing cirque development is the duration of glaciation. The cirques that we now see are mostly the products of not one but several glaciations of differing magnitude. In the middle latitudes of the northern hemisphere it is well known that the majority of well developed cirques face in the directions between north and east and it is true for Baspa valley. The valley is more deepened for north and east facing glaciers as compared to short and steep south facing glaciers. If observed carefully, the accumulation is more on the north facing wall of valley as compared to south facing valley wall. F.Enquist (1917) in the Alps showed that the largest cirques and the largest glaciers lie on the lee side of the mountains with respect to the prevailing snow- bearing winds and is also observed incase of Baspa valley. Shade and wind direction are therefore the most powerful controls affecting snow accumulation, and in turn, cirque orientation. As the cirques enlarge and recede, a series of aretes and horns are created.

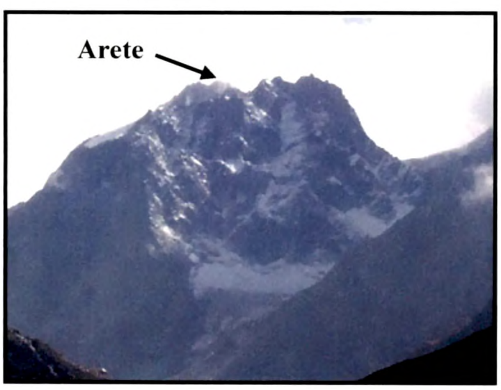

Plate 5.11. Cirque with accumulation, Jorya garang glacier

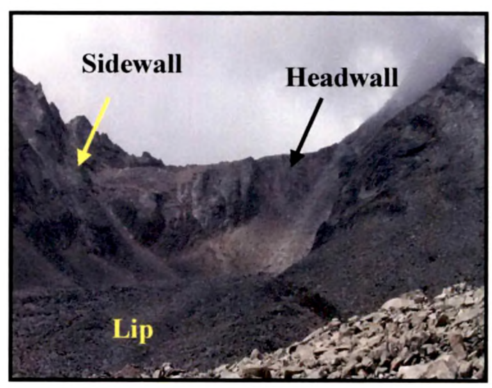

Plate 5.12. Empty cirque, Shailpya garang glacier

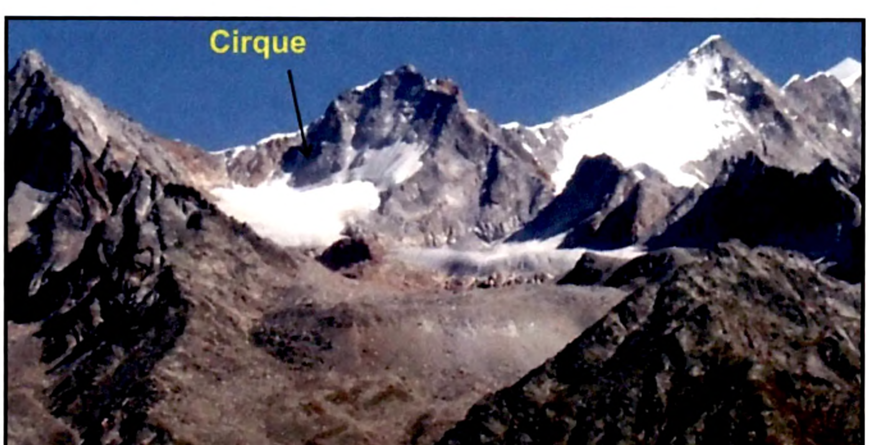

Plate 5.13. Cirque of South facing glacier

V. 4. B. Horn

Horns may rise from the intersection of three principal aretes or of four; examples of more than four principal aretes converging to a horn are fewer. It is clear that horns tend to survive long after the aretes linking them have been destroyed. It is a spire of rock formed by the headward erosion of a ring of cirques around a single mountain. In the study area at many places horns were observed with a typical pyramidal shape and pointed apex. The walls of the mountain heads were showing intensive frost shattering pattern indicative of the process of frost action within the rocks. When the glaciers originating in these cirques finally disappear, they leave a steep, pyramidal mountain outlined by the headwalls of the cirques. They are seen in the field for e.g. Jorya garang glacier (Plate 5.14).

Plate 4.14. Horn, Jorya garang glacier

IV. 4. C. Arete

They are formed when a number of cirques enlarge and gnaw into a ridge from opposite sides. At an advanced stage of cirque recession, mountain divides may be nearly

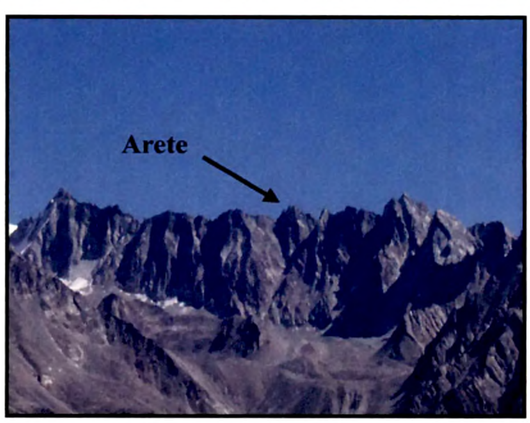

Plate 4.15. Arete, Gor garang glacier

consumed. The ridge becomes knife-edged, jagged, serrated and sharp saw-tooth which is known as arête. In the field well developed arête is seen incase of Gor garang glacier (Plate 5.15 and 5.11).

V. 4. D. Hanging valley

Hanging valleys are another characteristic features of mountainous areas that have undergone glaciation. These are tributaries to main valley glacier and has been deeply scoured by glacial ice. When the glacier disappears the tributary valleys are left hanging above the main valley glacier (Plate 5.16).

Plate 5.16. Hanging valley, Mangsa garang

The features of cirque, horn and aretes are not clearly identified from the satellite data but it is possible to demarcate by overlay analysis of SRTM DEM and satellite data as mentioned in chapter III, hence tone and texture for above feature has not been mentioned here.

V. 5. DEPOSITIONAL LANDFORMS

Depositional landform forms in a way such that, the glacial debris that the glacier has carried along either because the ice that holds it melts or less commonly because the ice smears the debris across the land surface. The general term drift is applied to all deposits that are laid down directly by glaciers or as a result of glacial activity. They are divided into two general categories stratified and unstratified drift type. The depositional landforms in the study area belong to generally unstratified drift. The unstratified drift directly laid down by glacier ice is known as till. It is composed of rock fragments of all sizes mixed together in random fashion, ranging all the way from boulders weighing several tons to tiny clay and colloid particles. The type of till varies from one glacier to another. In case of Baspa valley the tills are composed for the most part of large rock fragments of quartzite, phyllites as well as boulders of granitoids and gneisses. Deposits of this sort are known as Boulder tills or Stony tills (Plate 5.17, 5.18 and 5.19). Tills are deposited by receding glaciers in a great variety of topographic forms. Moraine is a general term to describe many of the landforms that are largely composed of till (Leet and Judson, 1969).

Plate 5.17. Mixed Boulder till
Shaune garang glacier

Plate 5.18. Granite Boulder till
Jorya garang glacier

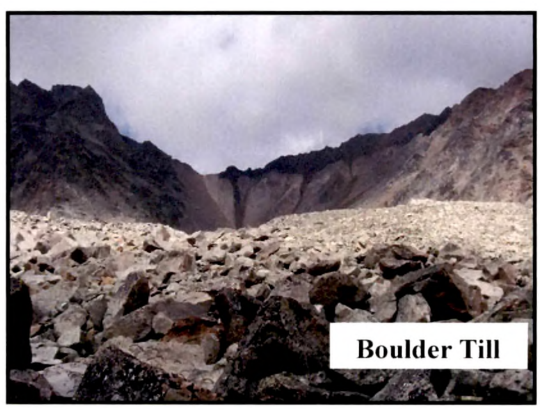

Plate 5.19. Boulder till Shailpya garang glacier

Moraines can be classified in several ways, according to their position, their state of activity, and their method of formation. In the first classification, moraines are divided into terminal, lateral and medial moraine according to their position with the glacier. Terminal or Lateral moraines are of great interest to the geomorphologist, as they indicate halt or re-advance positions, at which the ice margin lay for a considerable time during deglaciation.

In second classification they may be termed active moraines in contact with ice or inactive moraines which have lost all contact with ice forming them as a result of glacial retreat or decay. It is these moraines that provide evidence for stages of glacier retreat, glacial chronology and correlation.

The third classification subdivides moraines according to their method of formation. Moraines may be sub divided into ablation moraine (moraine covered ablation zone) and ground moraine. Ablation moraine (Plate 5.20) is the material that has accumulated on the surface of the glacier by gradual down-wasting of surface ice. They can be differentiated by coarse nature as fine material has usually been washed out by melt water. This surface debris usually increases in amount towards the snout of the glacier. However, it is concentrated both by deceleration of the ice and by increased ablation near the snout, where glacier caves are available. This layer of ablation moraine is only a surface layer and the ice beneath is normally very clean. A layer of ablation moraine is most likely to be present on a glacier that is moving slowly and which is slowly shrinking downward while its snout remains more or less static. Ground moraine is deposited sub-glacially and can accumulate once the main body of glacier melts, to form gently rolling plains across the valley floor.

Plate 5.20. Ablation moraine, Jorya garang glacier

V. 5. A. Lateral moraines

These till deposits are derived by dumping of material brought from up valley side or on account of erosion along valley walls by the glaciers.

The material is also added from frost action (Plate 5.24), snow slides and avalanches. When the ice melts, all this debris is stranded as a ridge along each side of valley forming a lateral moraine (Plate 5.23). It can be assumed that debris must have accumulated between the valley wall and higher ice surface. As ice slowly melted away, the moraine has maintained its slope away from ice. The steeper side facing the glacier has developed as the ice surface has gradually been lowered. The valley side slope often lies at the angle of rest of the material, but the glacier side is often much steeper approaching the vertical in places.

The ridges of lateral moraines are not found on both sides of valley. Majority of them are well preserved on left side of the valley Glacier. Lateral moraines found in the study area are not always straight but also occur as curvilinear shape. Maximum three stages of lateral moraine have been mapped incase of Shaune garang glacier and Jorya garang glacier Stage-1 lateral moraines occur at higher elevations, more vegetated and overlapped by debris fans and rock falls (Plate 5.21). Stage-2 moraines comprise of fresh angular boulders and are not vegetated (Plate 5.22). Lateral moraines appear as linear-curvilinear ridges with brown-gray color for non-vegetated, red color for vegetated and medium to coarse texture along the sides of valley glacier on satellite data.

Plate 5.21. Stage 1 Lateral moraine Jorya garang glacier

Plate 5.22. Stage 2 Lateral moraine Jorya garang glacier

Plate 5.23. Lateral moraine (LM), Billare bange glacier

Plate 5.24. Frost shattering Shailpya garang glacier

V. 5. B. Medial moraines

These are the morainic ridges found in the centre of the glaciers. They are formed when two separate valley glaciers/tributary glaciers carry lateral moraines and are joined together. The medial moraine is usually entirely superficial feature of coarse stony debris lying on the ice. It consists of angular and unsorted material and usually stands out as a conspicuous and curvi-linear elevated ridge on the glacier surface (Plate 5.1). Medial moraines are characteristic of living glaciers and are seldom preserved after the disappearance of the ice.

V. 5. C. Terminal moraines

It is a ridge of till that marks the maximum limit of glacier advance. The series of terminal moraines which mark the recession of glacier are called recessional moraines (Leet and Judson, 1969). It is a crescent shape with convex side extending down valley and appears as arcuate ridges. They generally comprise angular shaped boulders of granitoid-gneisses and quartzites (Plate 5.28 and 5.29).

Plate 5.25. Stage-1 Terminal moraine
Jorya garang glacier
Lat: 31°18'11" N
Lon: 78°29'50" E
Elev: 3925 m

Plate 5.26. Stage-2 Terminal moraine
Jorya garang glacier
Lat: 31°17'52" N
Lon: 78°29'39" E
Elev: 4003 m

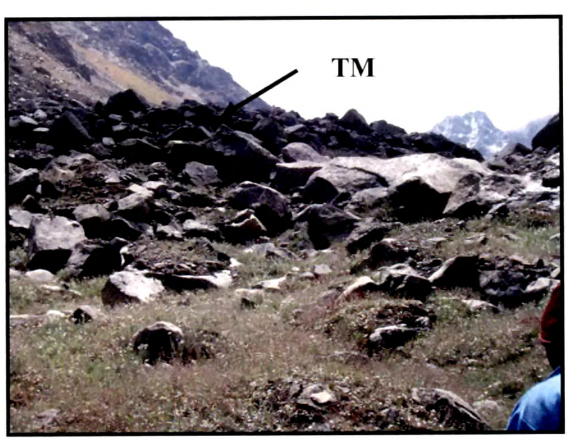

Plate 5.27. Stage-3 Terminal moraine
Jorya garang glacier
Lat: 31°17'31" N
Lon: 78°29'31" E
Elev: 4068 m

Stage-2 and Stage-3 moraines are found to be associated with formation of lakes of differing shapes ranging semicircular to rectangle shapes in Shaune garang glacier (Plate 5.1). Overall three stages of terminal moraines are identified across the valley (Plate 5.25, 5.26, and 5.27). The boulders of younger stages are fresh, angular, non-vegetated and less obliterated compared to older stage moraines which are nearly /completely destroyed and show a patchy appearance on the surface of valley floors. Stage-1 moraines are older and vegetated and dull in colour with formation of huge lichens over the surface of boulders of granitoid as compared to fresh surfaces of Stage-3 moraines. Terminal moraines appear as linear-curvilinear ridges with brown-gray colour for non-vegetated, red color for vegetated and medium to coarse texture along the terminus of a valley glacier on satellite data.

Plate 5.28. TM of Shaune garang glacier

Plate 5.29. TM of Shailpya garang glacier

V. 5. D. Debris fans

Glacio fluvial fan is also one of the common feature observed in the deglaciated valley. In the study area, these till deposits are laid down by the glacier near the foot of the valley and is later on reworked by the meltwater from glaciers and spread in the form of fan known as *debris fans* (Plate 5.30, 5.31). The coalesce of these fans (Plate 5.32 and 5.33) give rise to terraces which are covered by vegetation. They appear as light blue to grey colour with fine to medium texture on satellite data. Medium texture is obtained on account of presence of coarser rock fragments along with fine sediments.

Plate 5.30. Debris fans (DF), Jorya garang glacier

Plate 5.31. Debris fans (DF) Jorya garang glacier

Plate 5.32. Development of thatch over Debris Fan, Jorya garang glacier

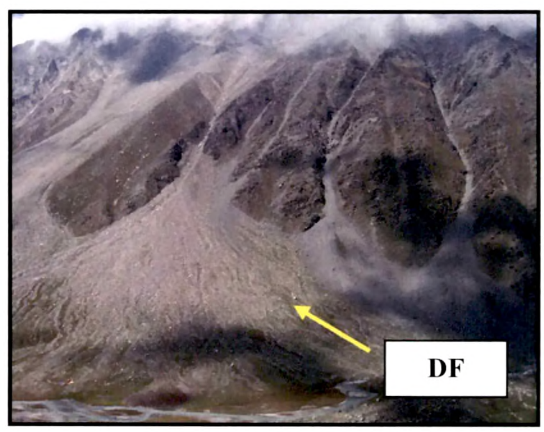

Plate 5.33. Coalesce of Debris fans, Shaune garang glacier