ANNEX 1[*]

1: GEOLOGICAL CRITERIA FOR SOIL CLASSIFICATION

1.1 THE IMPORTANCE OF GENETIC SOIL CLASSIFICATION IN HAZARD ASSESSMENT

Geological criteria for soil classification are essential for assessing potential mass movements in hazard studies and hazard mapping. Such identification provides information on the potential behaviour of the overburden versus environmental events such as storms, floods, earthquakes; or man induced activities, such as canal building, road construction, and deforestation, which are able to cause unstability.

Soil genetic classification provides the following information relating to mass movement:

- potential positions of water table and perched water tables;
- range of soil parameters; and
- potential soil thickness.

Geological classification of soil types includes:

- processes involved in the formation of the overburden such as weathering processes and gravitational processes; as well as water or ice transportation and deposition;
- morphological features specific to the geological environment of the different soil types; and
- soil features.

Table 1.1 summarizes the main features and processes of soils.

1.2 CLASSIFICATION OF RESIDUAL SOILS

1.2.1 *Residual Soils*

Residual soils are formed by the disintegration and decomposition of rocks and the consequent weathering of minerals. They are commonly found on transport-limited slopes where the rate of residual soil production is greater than the capacity of transport and sliding processes to remove it. The angle of residual soil slope cannot therefore be steep and this type of soil is found on the gentle or flat portions of hills and ridges. Residual soil slopes are consequently stable in general. Road or canal cuttings may, however, destabilize such slopes through either translational slides or rotational slides; the latter mostly when there is a flat zone above the cutting.

Due to intense weathering and trough water, in tropical or subtropical regions, residual soil may become considerably thick on flat areas where water infiltration is strong. When cutting of the residual soil takes place, the stability depends to a great extent on the presence of a water table or perched water table.

---

[*] Tables and Figures without credit lines in this Chapter are compiled by the author.

1.2.2 *Residual Soil Identification and Specific Features*

As the residual soils are normally a result of the bedrock's weathering, pieces and zones of weathered bedrock are frequently visible in cuts or pits. Residual soils are therefore easy to identify.

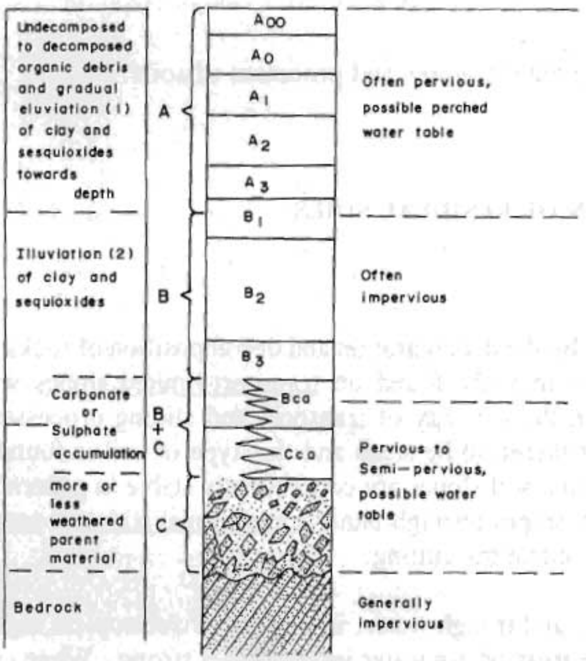
1.2.3 ***Residual Soil Profile ABC***

The presence of a well-developed soil profile not only implies the operation of the soil forming processes over a considerable period of time but also implies a protracted period of slope stability and stable environmental conditions. It is thus obvious that only gentle or horizontal materials, which are stable in principle, may produce the ABC type of soil. The original material is generally the bedrock but other stable and gently inclined material, such as ancient alluvial terrace, may produce this type of soil profile.

The impervious horizon B may be shallow or several metres deep; particularly when there is agricultural activity which implies the infiltration of humic acid.

1.2.4 ***Perched Water Table and Water Table in Residual Soil***

Horizon B is the main level of a residual soil where a perched water table may trigger erosion and slides after cutting. A water table at the contact of the residual soil and the sound bedrock might also be formed but, as this contact is commonly irregular, it is relatively rare that processes are triggered at this level.



(1) eluviation: movement of soil material from one place to another in solution or suspension
(2) illuviation: deposition in an underlying horizon of soil (usually B horizon)

Fig. 1.1 Diagram giving description of possible horizons in a soil profile

1.2.5 *The Specific Nature of Residual Soils and the Nature of Parent Material*

The constitution of a profile ABC (Fig. 1.1) to a large extent depends upon the nature of the residual soil. On the other hand, the nature of the residual soil and its geotechnical and geohydrological attitude depend also on the nature of the parent material. The residual soils resulting from the different types of material are described below.

1. *Residual Soils Resulting from the Weathering of Sedimentary Rocks*

The Sandstone Group consists of sand grains; commonly these quartz grains are more or less cemented by a matrix of other minerals. Characteristically, sandstones are highly porous, owing to their typically open joints, and therefore they are easily weathered. Weathering of sandstone largely causes an attack on the cement and removal of support for the quartz grains.

a. Calcite-Sandstone is frequently found in Himalayan Molasse within the southern belt of the foothills (Siwaliks). It is largely affected by solutions, and, because of initial, high joint porosity, these solutions penetrate to great depths. Calcite-sandstone produces a sandy, rather inert, and often deep, residual soil. Due to calcite precipitation, an impervious horizon may be constituted at depth.

b. Clay matrix sandstones weather through the breakdown and eluviation of clay. They may form the ABC type of soil with an impervious clay layer at depth (horizon B) due to clay illuvion. In general, clay matrix sandstones are liable to greater chemical weathering and ABC profiles are well developed.

c. Shale, mudstone, and marl group rocks consist of clay minerals with sometimes mica, and occasionally other minerals. Carbonate is present in marl. Weathering is often intense on the ground surface and decreases down the profile, although along cracks it persists to a greater depth. Thus the rock is broken into blocks which are fresh inside but weathered on their faces. In addition, this type of rock is fissile and quality increases its propensity to weather. As soon as a residual soil has been constituted from this type of parent rock, a rapid leaching of clay mineral results. Biological activity enhances this leaching which leads to an ABC soil.

   This attitude of bedding planes is important. In well-bedded horizontal rock, it is hard for water to penetrate, but, if the strata are steeply inclined, many rock edges and bedding planes are exposed. This allows water to penetrate easily. In such cases, if the slope is a dip slope, major translational slides may occur along the limit between rock and residual soil.

   Limestones form generally in thin residual soil which also may include ABC soil profiles particularly when the limestone includes clay minerals.

2. *Residual Soils Resulting from the Weathering of Granite and Coarse Grain Igneous Rocks*

Typical granite is made up of quartz, feldspars, and mica. Granite is formed at a considerable depth in the earth's crust and under great pressure. So, when exposed to the surface, the release of pressure gives rise to marked unloading joints which are subject to weathering. Chemical weathering is both marked and variable in effect. Quartz remains unaltered, but feldspars are often converted to Kaolinite and micas to clay minerals.

Deep weathering is common and residual soils of varying kinds are known. One of them results from a granular disintegration where individual mineral grains, though often little weathered themselves, become loosely attached to other grains and can be rubbed off by hand. Another one results from a type of weathering which leads to pure Kaolin with quartz grain deposits. The ABC horizon may be formed mostly in this second type of residual soil. Other coarse grain, igneous rocks weather in a similar way to granite, as long as they bear quartz grains and feldspars.

3. *Residual Soils Resulting from the Weathering of Metamorphic Rocks*

Schist, phyllite, and slate have marked fissility along the foliation plane and this is an important factor in weathering. Residual soils resulting from the weathering of these types of rocks are similar to those resulting from shale and marl, although the process is slower and the ratio of gravelly material is higher.

a. The Gneiss Group is a coarse-grained, foliated rock containing quartz, feldspar, micas, and other minerals. Its properties are between those of granite and schist. Minerals are segregated into bands, and bands of the most weatherable mineral affect the total rock strength. The distinct mineral orientation of the gneiss prevents an exfoliation weathering and granular disintegration is rather rare in comparison to granite. Due also to a shallower fracturation, weathering cannot be very deep. In fact, gneiss is a less weatherable material than granite, although it is mineralogically similar. Residual soils, resulting from gneiss weathering, are therefore shallower than those resulting from granite weathering although they may present the same features as, for example, ABC profiles.

b. Quartzite is a metamorphosed sandstone which consequently has lost the porosity. Therefore, it is far less weatherable. It is almost inert chemically and physical weathering is dominant. The ABC soil profiles are therefore almost non-existent and soils are thin in general.

c. Marble Group residual soils are similar to those of massive limestone and dolomite and thus they are thin in general.

4. *Residual Soils of Interbedded Rocks*

Rocks are often interbedded: shale with sandstone, gneiss with phyllite, etc. Residual soils resulting from alternating layers of two different types of rock will present features of both parent materials at the ultimate state of weathering. Alternance of sandstone and shale, schist and gneiss, phyllite and quartzite or gneiss etc may produce a residual soil where schist and other rock, producing clay horizons through weathering, may be favourable to the formation of perched water tables owing to the formation of an ABC profile.

1.3 CLASSIFICATION OF COLLUVIAL SOILS

1.3.1 *Process of Formation and Stability*

Colluvial soil usually occurs at the foot of a steep slope or in areas where a steep slope gradient levels out. The colluvial soils are materials resulting from rock and soil movements such as creeps, landslides, rockslides, rock avalanches, debris flows, and mudflows.

The composition of the colluvial soils is variable and depends upon the parent materials. For example, different rock types outcropping on to the steep slope will give rise to a mix of rock type particles and to a definite texture. Such a mix may have a wide gradation, ranging from clay or silt to boulders.

Colluvial slope stability is usually affected by the increase of moisture percolating down to the impermeable bedrock face by perched water tables or by seepage from bedrock into pervious colluvium. Mass movements such as translational and rotational debris slides or debris flow, and sometimes mudflow, may affect colluvial overburden.

Very thick and loose material covers (up to 200m thick) are often deposited within the lowermost sections of the northern Himalayan foothill valleys. This material is frequently covered with coarse colluvial deposits. The material itself is essentially silty and sometimes clayey and this can be determined through electrical soundings and drillings. The origin of such material is not well known, but its fine granulometry speaks in favour of reworked glacial deposits. The glacial deposits were possibly primarily deposited within upper parts of the valley, and then gradually washed off and redeposited down in the lowermost river sections. Such types of cover are highly unstable, mostly when bank-undercutting affects them. It is therefore crucial to identify such types of deposit which can be classified as **reworked colluvial material** or **reworked glacial deposits**.

The stability of the colluvial overburden depends, therefore, on several factors:

- permeability of the material - which greatly depends on the parent material,
- slope of the material and slope of the rock face,
- thickness of the material, and
- other external triggers such as bank undercutting (floods), earthquakes, etc.

1.3.2 *Identification of Colluvial Soils*

Morphological features accompanying colluvial deposits are normally rather easy to identify, although they may sometimes be confused with certain glacial morphological ones.

1) *Main Morphological Features of Colluvial Soil Environment*

The feeder rock slopes that are exposed above the colluvial deposits may often show a detachment type of morphology such as crowns, wedges, scarps, etc, i.e., a breaking surface (See Fig. 1.2). **Screes** (talus), however, are caused by gradual disintegration of walls and normally no detachment features are visible on them. The surface from where a mass movement started may be barren if the movement is recent or vegetated if the movement is ancient. Thus, in this case too, the identification of the detachment surface is not always easy. In the case of mass movements, such as debris flows or debris avalanches, the detachment sites may be located at some distance from the deposit and are therefore not directly visible.

The environmental morphology of reworked colluvial or reworked glacial deposits, as described above (Fig. 1.3) is typical and may be easily identified. Therefore, colluvial identification criteria should be drawn also from the composition, the morphology, and other features of the deposits themselves.

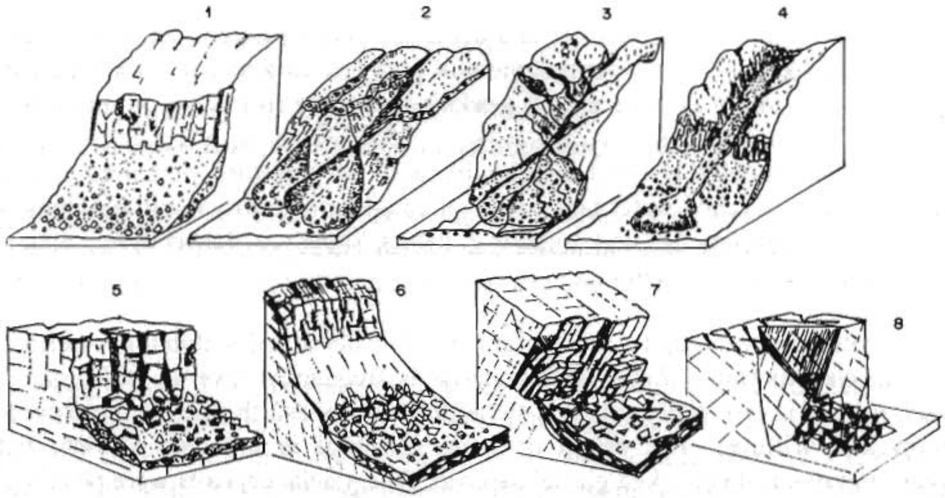


Fig. 1.2. Features of rock feeder slopes and morphology of colluvial deposits

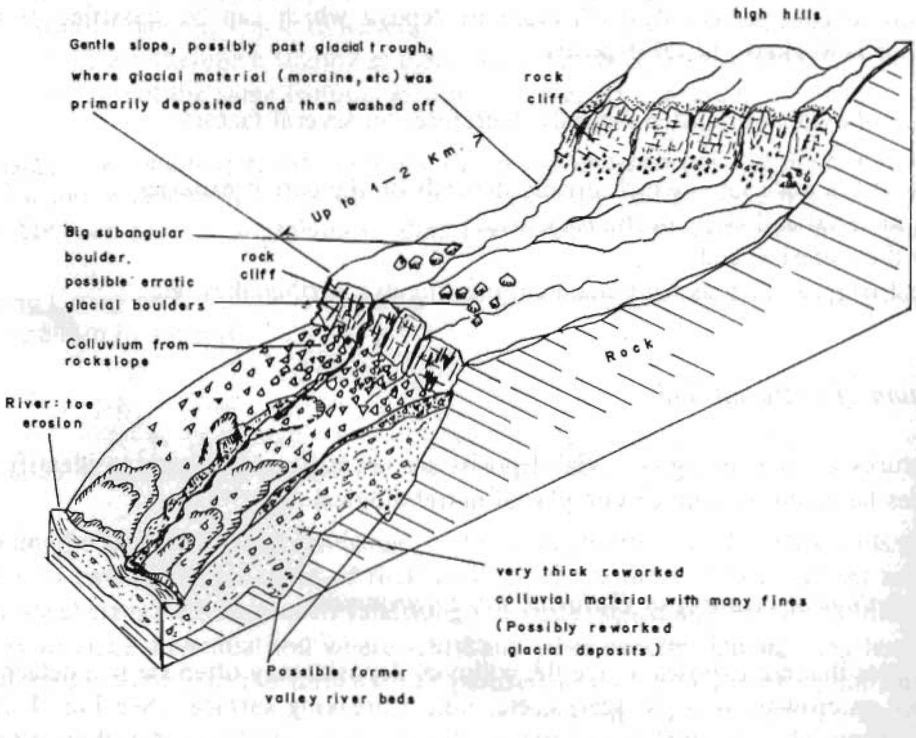


Fig. 1.3 Features of reworked colluvial or reworked glacial deposits and their environmental morphology

Fig. 1.2 (1) Talus slope: no specific detachment features are visible on the rock slope which sheds scree. A grading from the top to the toe of the colluvial deposit is visible.

Fig. 1.2 (2) Debris cone with its detachment zone above: the slope of the debris cone is steep; usually 30°-38°. A gradation is visible from top to toe. If a stream is the agent of debris transportation, particles may have sub-angular shapes. Due to high permeability of many debris cones, streams do not usually flow on them.

Fig. 1.2 (3) Alluvial fan: this figure is shown for comparison with a colluvial debris fan. Alluvial fans show similar features to debris cones but their slopes are gentle, usually 10°-15°, and the particles are rounded or subrounded. Normally, a gradation of material from top to toe is not present. Generally streams flow on alluvial fans.

Fig. 1.2 (4) Rock avalanche tongue: this is characterized by a colluvial debris tongue and a debris cone. The cone is formed at some distance from the main slope. Detachment features of the feeder rock slope are not observed because they are away from the deposition area.

Fig. 1.2 (5)(6)(7)(8) Rockfall, rockslide and rock avalanche head, slab and topple failures, and wedge failures: these usually have visible detachment surfaces and coarse material deposits with rough gradation from top to toe.

1.3.3. *Features of Colluvial Deposits (See Fig. 1.2)*

Colluvial deposits may form any combination of slope and cone forms. This depends upon the nature and distribution of sliding processes along rock slopes, and upon whether and to what extent the joint pattern permits the development of rockslides and rockfalls. Because streams also may be active on mountain slopes, there are no simple distinctions between cones formed by rockslides, landslides, and rockfalls; or debris flows and alluvial fans produced respectively by stream deposition or debris flow processes respectively.

a. Slope: A continuum may exist from steep angle rock debris cones to lower angle alluvial fans. Colluvial fans, however, normally have an angle between 28° and 46° (generally close to 35°, whereas the slope angle of an alluvial fan rarely surpasses 110. Talus deposits have angles between 30° and 38°. Large rockslides or rockfalls have steeper upper slope angles, especially where the debris has a slope-like shape and cannot roll down the slope.

b. Aspect, gradation, and fabric of colluvial deposits (Fig. 1.2) Rockfalls and rockslides produced by the failure of material, including hard rock, show rugged and very irregular deposits, whereas some failures, having occurred in softer rock, are smoother and more regular. Irregular lobes, small slide scarps, and hollows are common features of these types of deposit. Debris flows have small lobes or cones and levees. They carry fine and coarse materials to positions on the slope and this is controlled by the energy of the flow and its water content. For this reason, they may come to rest at any point on a slope. Levees at lobes are formed when water drains away and the flowing mass of the debris flow comes to rest. Cones are rather regular and typical in shape and their identification is easy.

The upper part of the colluvial slopes are normally made up of smaller-sized debris than the lower ones. This gradation is due to gravity and also to the trend of smaller-sized debris to be trapped into small hollows, whereas the bigger ones can only be trapped in the bigger cavities that are in the lower sections of the colluvial slope.

In section, colluvial deposits display a variety of fabrics and sometimes a rough bedding of the material. Many of the bedding forms can be associated with particular processes and are good indicators of the significance of those processes. Four main types of fabric are usually recognised (Fig. 1.4).

(1) An open-work fabric, in which the particles are supported at the point contacts. This fabric usually results from the fall of individual grains (scree) or from small rockfalls. It may show an imbricate structure in which elongated particles pack against each other and dip back into the slope, or it may show a majority of particles dipping down the slope.

(2) A partly open-work fabric in which some voids are filled with fine materials.

(3) A closed, particle-supported fabric in which all of the voids are filled with fine materials, resulting from the falling and washing off of fine materials into an originally open-work fabric. This fabric is indicative of water washing activity on the talus surface.

(4) A matrix-supported fabric in which the coarse fragments are totally enclosed within a fine matrix, resulting from deposition by a debris flow rich in mud and other fines or weathering of colluvial deposits rich in mudstone, slate, phyllite, or schist particles.

Fabric type (1) may result from processes and failures that have occurred in hard rock. Types (2),(3), and (4) may result from processes and failures that have taken place in soft and hard rocks such as sandstone and shale, phyllite and quartzite, schist and quartzite, schist and gneiss, etc.

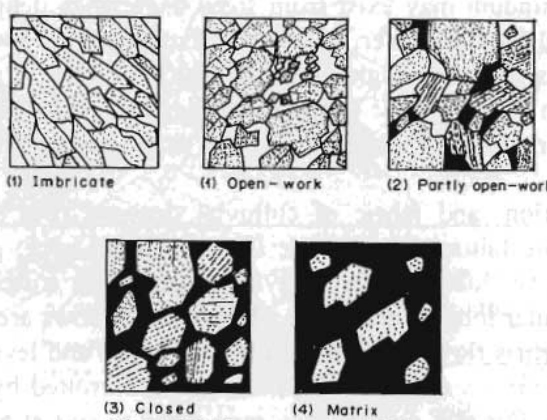


Fig. 1.4 Fabric of colluvial materials

c. Water and Stability of Colluvial Slopes: As fine-grained particles accumulate in the void space of the colluvium they add frictional strength to it. The presence of fines, however, and the movement of water within the slope permit pore-water pressures to develop, especially where drainage is impeded by lenses of matrix-supported material. Thus the fabric types (2) to (4) (Fig. 1.4) may be prone to sliding processes, whereas type (1), which is well drained, may be far more stable. This implies that the source of the colluvial material should be carefully identified if its stability has to be assessed. The degree of colluvial materials weathering increases with age and therefore, because of pore-water pressure, there is a possibility of landslides in many cases. Thus, because they are older, vegetated colluvial slopes may be subject to landslides.

d. Thickness of Colluvial Deposits: A hypothetical model, the Richter Slope, seems to fit many observations and tends to show that, apart from the reworked colluvial or reworked glacial deposits discussed above, colluvial deposits are relatively thin and cannot attain significant thickness. Figure 1.5 shows how this model process may develop.

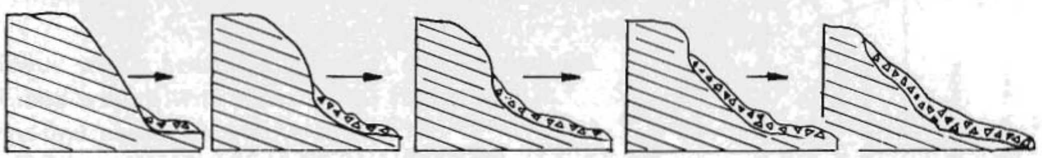


Fig 1.5 **Richter Slope: A hypothetical rock slope angle lowering process with formation of a colluvial deposit**

e. The nine-unit surface model: The hypothetical nine-unit land surface model (Fig. 1.6) provides details on the Richter slope model and shows the relationships between surface and groundwater movements on one hand and soil slope/rock slope processes on the other. It also summarizes the processes ruling the constitution of residual, colluvial, and alluvial soils.

1.4 CLASSIFICATION OF GLACIAL DEPOSITS

1.4.1 *Process of Formation and Stability*

There are converging features indicating that glacial deposits may be present within the northern belt of the Himalayan Foothills. As they are very prone to certain processes, some of their classifying features will be described below.

There are three main types of glacial deposit: the **lateral** and **end moraines**, the **ground moraines** and the **glacio-fluviatile sediments**. Lateral moraines were initially colluvial deposits which were deposited at the toes of slopes on the glacier and gradually incorporated into it. These materials are subject to a certain amount of friction and grinding action by the ice that smoothens the edge angles of the material and produces a finer matrix. After the glacier melts, they are deposited as lateral moraine containing a high ratio of silty or silty-clay matrix in which subangular to subrounded particles and boulders are included. **Front** or **end moraine** result from deposition of the same type of material at the front of the glacier which normally is not subject to so much action from the ice. Therefore, they may contain more angular particles and less matrix. Ground moraine (or **lodgement moraine**) is formed from the complete incorporation of surface material and the scraping action of the glacier on the bedrock. This action results in the formation of a highly clayey material which remains, when not eroded by streams, after the glacier has melted. Below the glacier (and sometimes on the glacier), within an outwash area produced by melted ice water, **glacio-fluviatile** and **lacustrine** sediments are deposited. They show similar features to the alluvial material, although they present very specific features of their own as well as a higher ratio of fines.

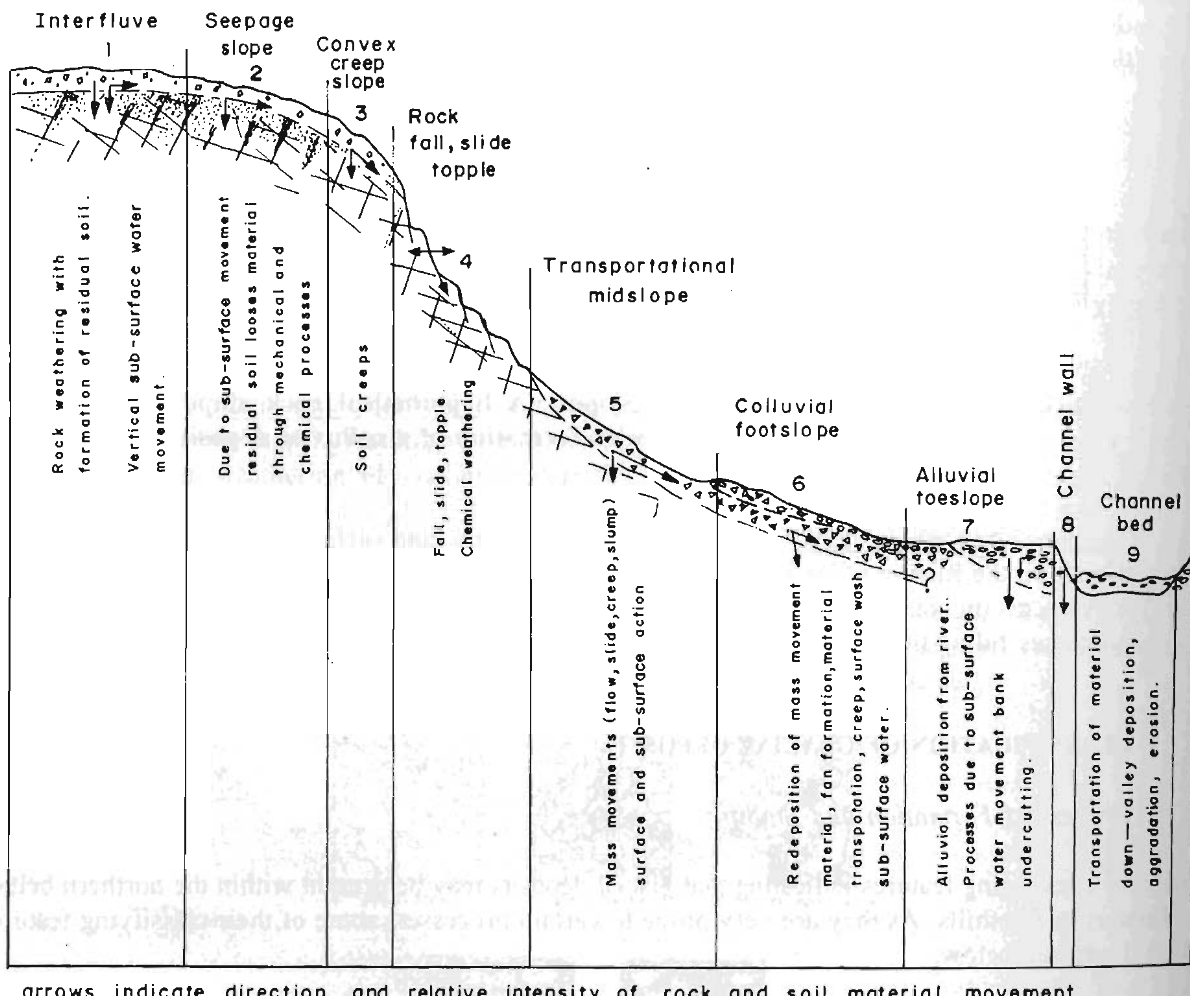


Fig. 1.6 The hypothetical nine-unit land surface model

Glacial deposits are therefore parents in some way to colluvial and alluvial deposits, and, for this reason, may sometimes be confused with them. As the behaviour of the glacial deposits is very specific and different from the behaviour of colluvial and alluvial deposits, it is important to be able to identify them properly. This is made possible by the specific, glacial morphology caused by the strong action of glaciers on bedrock as well as by specific features of the glacial deposits.

In the Himalayan Foothills, the soils hypothetically identified as glacial deposits are extremely silty and therefore semi-pervious, although they sometimes have impervious horizons. Due to this fact, they have a high water storage capacity with important water tables or perched water tables. As their cohesion is generally low, they are potentially extremely unstable. Translational slides, rotational slides, and gully erosions are common, therefore, within glacial (or derived from them) deposits.

1.4.2 *Morphological Features Caused by the Erosive Actions of Glaciers*

The erosive action of a glacier will leave typical morphological features after its recession and complete melting. These features are as follows:

- a **cirque** with a **headwall**, a **basin**, and a **threshold**,
- a **glacial trough** with **stairs** in the floor,
- **horns** and **passes** above the cirque, and
- a **hanging valley** and **truncated spurs** in the trough.
  (See Figs. 1.7 and Fig. 1.8)

Due to the glacial deposit's cover, these features are often not visible apart from the horns, headwalls, and truncated spurs. The buried form's position can only be identified through drilling or electrical sounding.

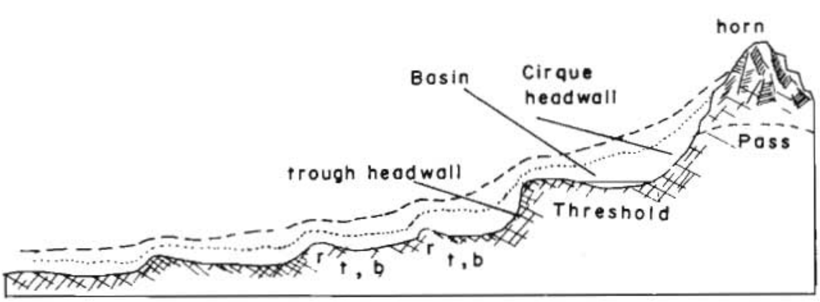


Fig. 1.7 Long section of part of glaciated valley
Showing basins (b) thread (t), riegels (r) and other features
Surfaces smoothed by abrasion alternate with slopes steeped by quarrying, imparting to the valley a steplike profile. The profile before glaciation is suggested by the dashed line. The dotted line suggests a profile made early on in the process of glacial erosion.

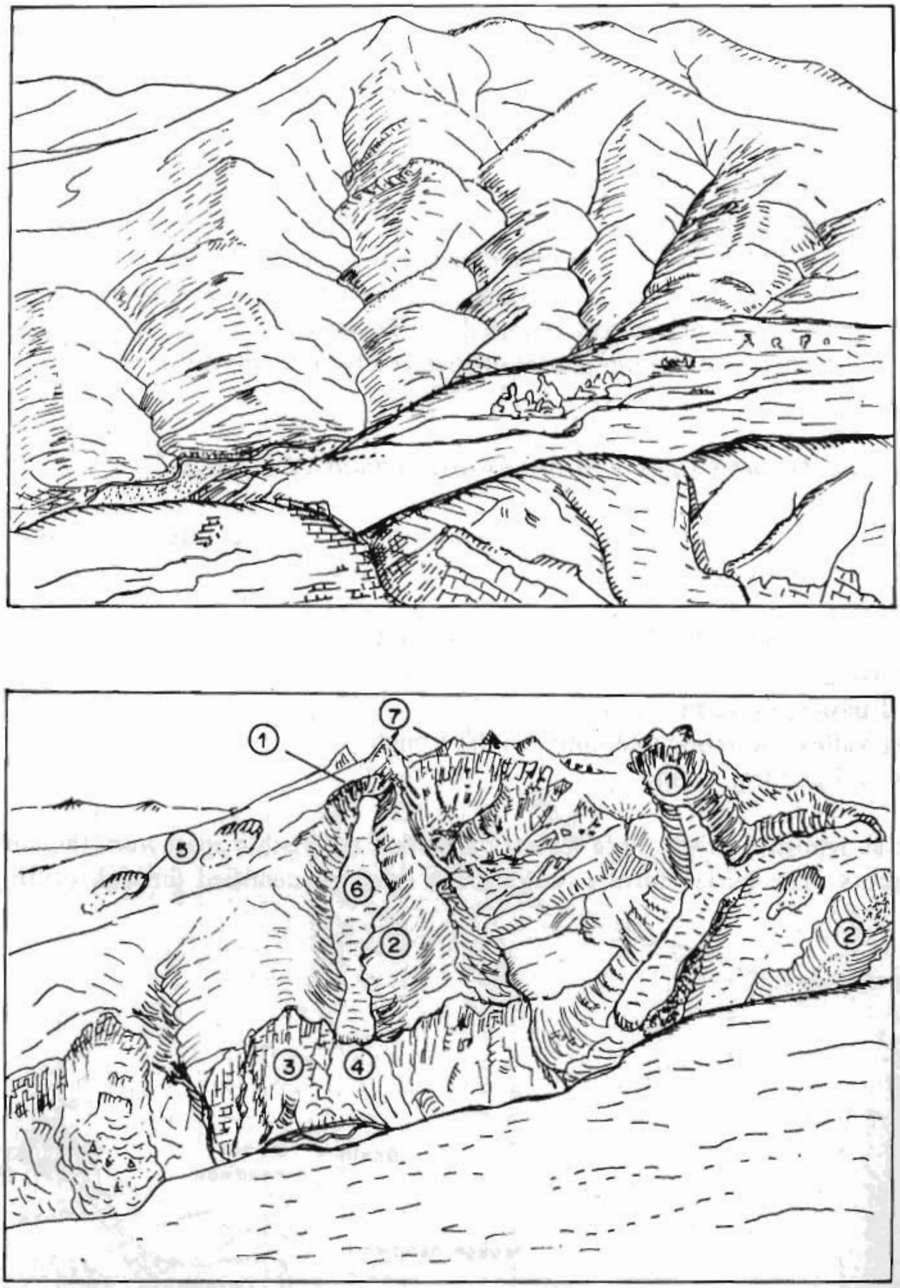


Fig. 1.8 Diagram to show the effects of glacial erosion upon a mountain landscape

A. Before glaciation. B. After glaciation.
1. Cirque; 2. Glacial Trough; 3. Truncated Spur;
4. Hanging Valley; 5. Nivation Cirque; 6. Glacier (in regressive stage);
7. Horn

The truncated spurs and hanging valleys are due to the action of the principal glacier which eroded and then partly filled the main valley.

1. *The Cirque*

The cirque (Figs. 1.7 and 1.8) is the most striking land form in glaciated mountains. An empty cirque displays three distinguishable parts:

- o the headwall,
- o the basin, and
- o the threshold.

The <u>cirque headwall</u> may be as much as 700 to 1000 m high.

The <u>basin</u> caused by a definite basining of the cirque floor which extends from the headwall and terminates at a bedrock riser called its <u>threshold</u>. Consequently cirque basins are often sites of small cirque lakes. These lakes may gradually fill in.

2. *Troughs*

Next to the cirque (Figs. 1.7 and 1.8), the most distinctive topographical feature in glaciated or formerly glaciated mountains is the <u>glacial trough</u>. Most glacial troughs were originally stream-cut valleys, but glaciers have usually altered them so much that neither in cross profile nor in long profiles do they resemble stream-carved valleys. The steps may be attributed to various causes: varying rock hardness; abration in the constricted and open sections of valleys; crevassing of ice with consecutive sapping at the base of the terrace, and so on.

The <u>cross-profile of a glacial trough</u> (Fig. 1.8) is generally significantly different from that of an unglaciated valley in a mountainous area. The difference is usually described as the difference between a U-shaped valley and a V-shaped valley. Probably the best description of the cross profile of a glacial trough is that it resembles a catenary curve. If a piece of rope is held at each end, it is possible to reproduce most of the cross profiles exhibited by glacial troughs by varying the distances that the ends of the rope are held apart. Differences in cross profiles may be related to such factors as the varying lithology and structure of the rock in which the trough is cut and the number of times a valley was glaciated. The bedrock of a glacial trough, which is commonly covered with moraines or other glacial deposits, shows ordinary or flat floor.

Portions of glacial troughs may exhibit <u>remarkably flat morphology;</u> this is fairly noticeable within the Himalayan ridge valleys. The flat sections may be the result of deposition, subsequent to trough development, or uniform glacial erosion of the glacier. The flat sections may also represent aggraded post-glacial alluvial floors; outwash materials deposited, accompanying glacial recession; or lacustrine plains produced by the filling of lakes.

After deglaciation, the bedrock may display a typically polished surface which may be even or undulated (like the whalebacks) and striated clasts in moraine (boulders, cobbles, and gravels) may sometimes display striations.

1.4.3 *Depositional Glacial Forms*

The glacial deposits that remain after glacial melting are marked by heterogeneity of materials, which are subangular in shape, and lack of stratification. Glacially fed streams and glacial lakes, on the contrary, commonly deposit stratified sediment, which material presents sub-angular to subrounded shape particles.

Most of these depositional forms may be recognized within the inner valleys of the Himalayan ridge. In the northern belt of the foothills, whenever present, they have been drastically reworked and eroded, and are very often covered with colluvium and even alluvium. It is therefore difficult to locate and to identify them.

There are three types of glacial deposit:

- o front moraine, end moraine, or terminal moraine (and recessional moraine),
- o lateral moraine, and
- o ground moraine, or lodgement moraine

The deposition of front moraine takes place at the end of an ice stream whereas the deposition of lateral moraine takes place at the side of it. The ground moraine is deposited beneath the ice stream. The term recessional moraine refers to a series of end moraines marking successive pauses in the position of a retreating ice front. Lateral moraine forms along the sides of an ice stream; chiefly from materials that are contributed from the valley sides above the glacier by weathering, snowslides, avalanches, and other types of mass movement. This material remains, after the ice has retreated, on both sides of the glacial trough. Because of the action of post-glacial streams, lateral moraines are usually patchy. Small lakes are sometimes found perched above the floor of a glacial trough between the lateral moraine and the trough wall (Figs. 1.9, 1.10).

1. *Lateral Moraines and Front Moraines*

Lateral moraines and front moraines consist typically of unsorted materials. Their matrices are silty, sometimes clayey, and relatively abundant. The matrix is principally a result of the grinding action of the ice. As the walls of bedrock are in the trough, the particles may show striations due to the rubbing action between them. The rock particles of the moraines are subangular to subrounded.

2. *Ground Moraine*

Ground moraine (Fig. 1.11) is rather scarce because an ice stream is a particularly effective erosional agent which vigourously abrades and plucks its bedrock floor. Furthermore, ground moraine is deposited on the valley floor and is particularly susceptible to erosion by post-glacial streams. Hence, ground moraine is likely to be rather thin and patchy in glacial troughs. The material of ground moraine is clayey in general due to the grinding action of the glacier under high pressure. The particles are usually subrounded and normally less angular than in the end and lateral moraines. More then the other types of moraines they often bear striations owing to the rubbing action among particles and to scrapping against the bedrock floor (Fig. 1.12).

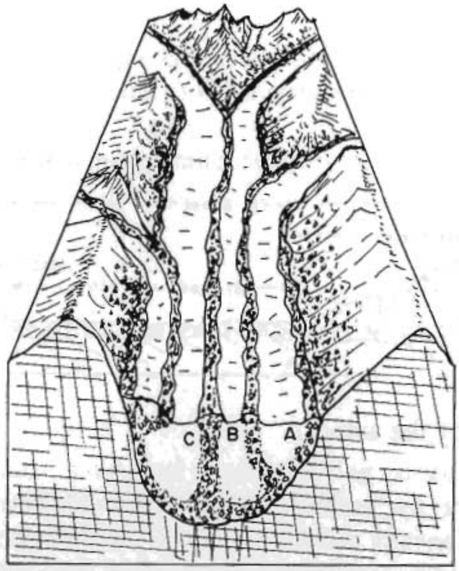
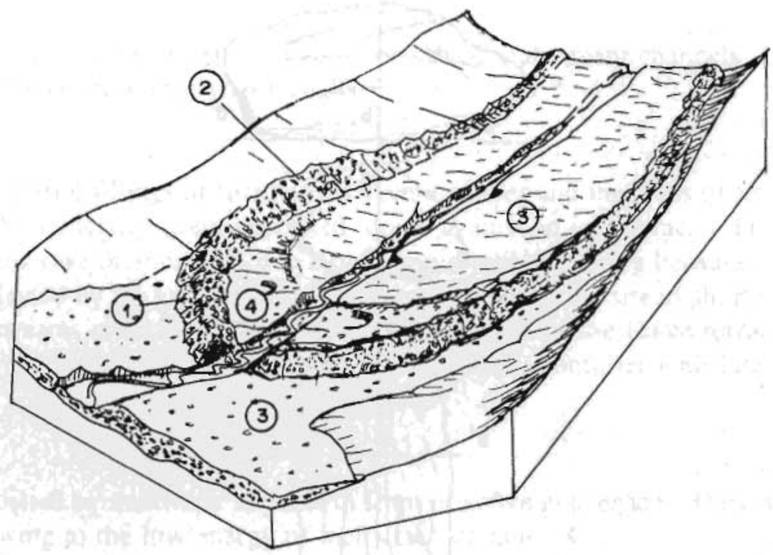


Fig. 1.9 **Cross-section of a glacier with:**
A: lateral moraine; B: compound medial moraine; C: medial moraine

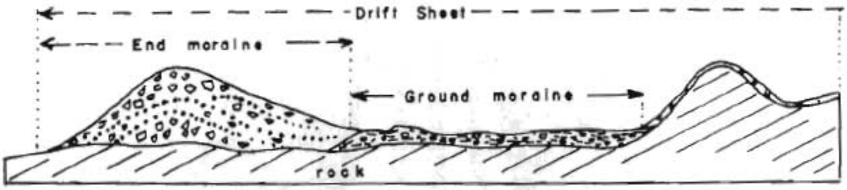


Source: Flint 1977

Fig. 1.10 **Sketch of a valley lobe of drift**

This shows the terminal and lateral elements of an end moraine, an area of ground moraine, and a body of outwash. At first, the latter was fed by streams originating along an extensive segment of the end moraine. Later, after the margin of the glacier had retreated a short distance, outwash was deposited inside the front moraine, over the ice. After further retreat, the proximal part of the outwash collapsed, forming an outwash head.

1: front moraine
2: lateral moraine
3: ground moraine
4: outwash head
5: outwash plain



Source: Flint 1971 (modified by the author)

Fig. 1.11 **Ideal longitudinal profile showing relationship of frontal moraine, ground moraine, and drift sheet**
Dotted profiles suggest three earlier phases of upbuilding of the frontal moraine.

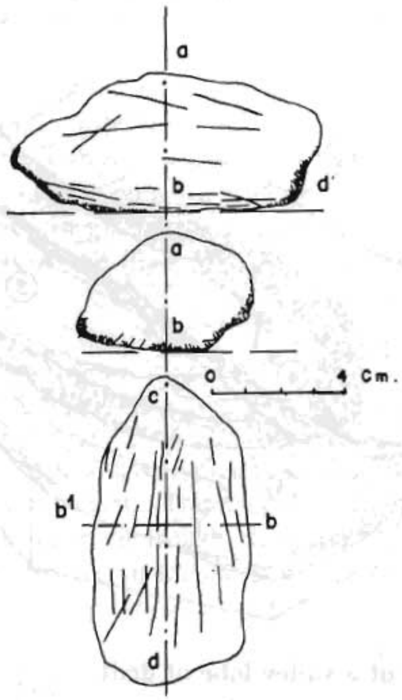


Fig. 1.12 **Features of glaciated particle**
Striations are represented by fine lines.

3. *Glacio-fluviatile Forms*

Much of the material acquired and transported by an ice stream is ultimately transported and finally deposited by streams flowing on, .within, beneath, and beyond the glacier. Deposits of such origin are classified as glacio-fluviatile.

Glacio-fluviatile deposits may retain some of the characteristics of moraines but they show a degree of assortment and stratification roughly proportional to the distance that they were carried by the streams.

The most common land forms in the glacio-fluviatile category are the following (see Figs. 1.10 and 1.13):

- the **valley trains** and **outwash fans**,
- the **eskers**,
- the **Kame terraces**, and
- the outwash fans **(deltas)**.

Valley trains consist mainly of outwash, sand, and gravel starting usually from an end moraine and extending sometimes over long distances down valley from it. They are marked by terraces, above the present valley floor. Close to the end moraine, they may contain **varves** that are a pair of contrasting laminae representing seasonal sedimentation, such as summer (light) and winter (dark), within a single year. Valley trains may contain cross-bedded layers. They may show similar features to the alluvial bodies but their fine ratio is commonly higher, the particles are subrounded and generally not so well assorted.

Eskers represent the filling of super-glacial, englacial, or sub-glacial stream channels. Common in continental glaciation and relatively rare in glacial troughs.

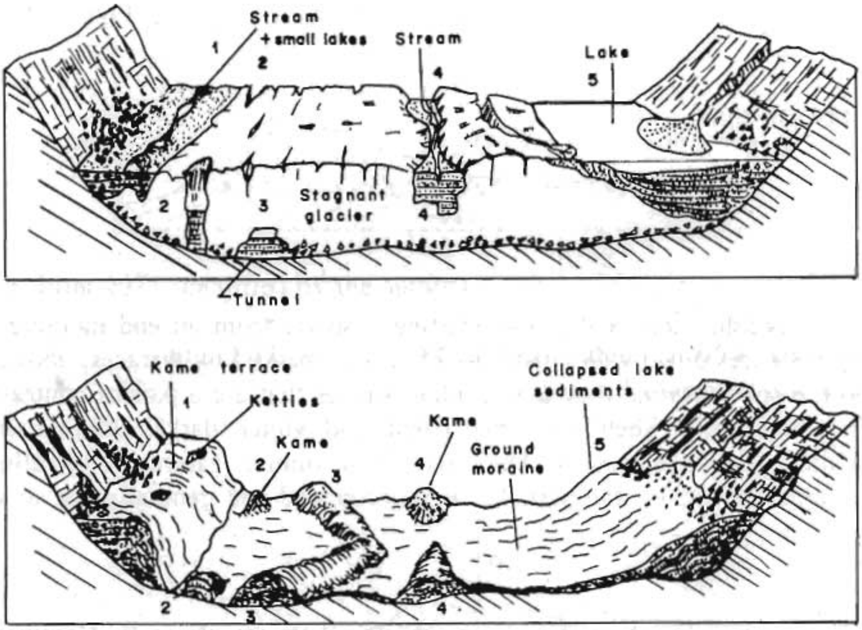
Kame terraces are fillings or partial fillings of furrows between a glacier and the sides of its trough. By definition the materials of a Kame terrace were deposited down against an ice surface. These furrows are commonly called **fosses** and owe their existence to a more rapid rate of melting because of the added effect of heat absorbed or reflected by the valley sides. These fosses may be the site of short lakes named **Kettles** and they may have streams emanating from them. The materials of the Kame terrace are often poorly assorted because they do not move far. They may be, therefore, confused with lateral moraine material.

Outwash Fans are drifts deposited by meltwater streams in front of active glacier ice. They may contain a rather high ratio of fines owing to the low energy of meltwater streams.

Glacio-lacustrine Features: Lakes, present or extinct, are common features of glaciated valleys. The more common types are listed below.

- Rock-basin lakes in cirques and upon the treads of glacial steps.
- Lakes at the back of front and lateral moraines.
- Lakes formed by the damming of a tributary valley by a valley train in the main valley.

Varves are typical of a glacial lake. As already mentioned, varves are thin and regular alternations of layers of different composition forming pairs and attributed to an annual rhythm of sedimentation. A more general term in use for regular alternation is the term **rhythmite**.



Source: Flint 1971

Fig. 1.13 Origin of bodies of ice-contact stratified drift

A. Stagnant glacier ice affords temporary retaining walls of bodies of sediment built by streams and in lakes.

B. As ice melts, bodies of sediment are let down and in the process are deformed.

1.4.4 *Glacial Lake Outburst Flood (GLOF)*

Glacial lake outbursts are common in the glaciated Himalayan ridges and may have drastic consequences within the lower valley sections (bank undercutting, slides, debris flows). Figure 1.14 shows a common mechanism of a glacial lake outburst flood (GLOF). Due to changes in temperature, voluminous ice segments of the nearby glacier tongue collapse into a lake formed by a frontal moraine. The result is a burst or a submerging of the moraine followed by a flood.

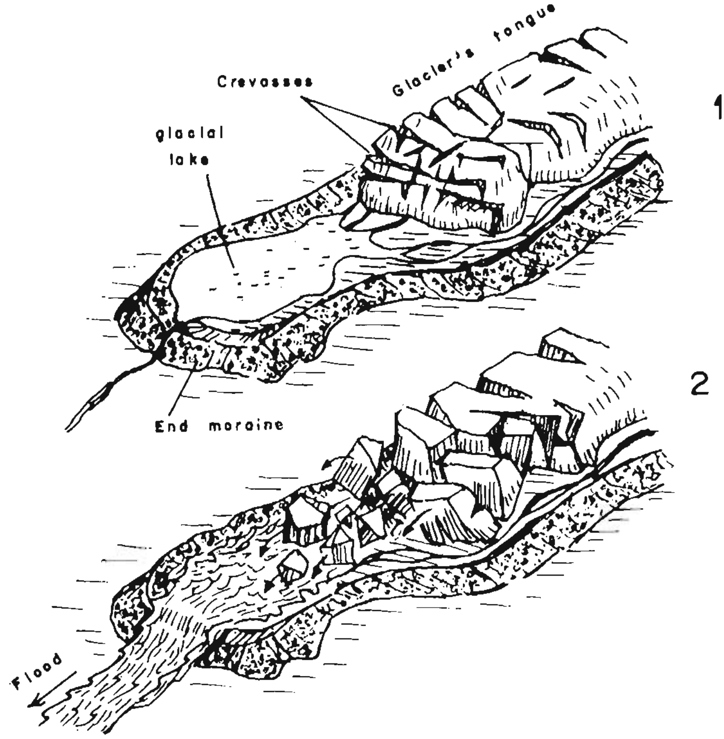


Fig. 1.14 Common mechanism of a glacial lake outburst flood (GLOF) in the *Himalaya*

1.5 REMARKS ON THE POSSIBLE PRESENCE OF GLACIAL DEPOSITS WITHIN THE NORTHERN BELT OF THE HIMALAYAN FOOTHILLS

Many wide regions of the northern hemisphere were deeply glaciated in the past. In Europe, two principal glacial periods took place. The first one, the Riss Period began about 90,000 years ago. After a period of temperature rise, a new glacial age, the Wurm, re-glaciated Europe. The Wurm ended about 30,000 years ago.

Although the Northern Himalayan foothills are located far more to the south than Europe and other formerly glaciated regions of the northern hemisphere, there is reason to believe that the northern Himalayan foothills were also affected by the glacial ages.

Very little consideration has been given to this question which, as already stated, is of importance when considering the soil slope stability in the northern Himalayan foothills. It is, however, well known that huge front moraines dammed the main Himalayan rivers at their exit points in the Himalayan ridge. The Kali Gandaki front moraine, at an elevation of between 2,000 and 2,500 m, is a good example of this type of glacial deposit which marks the river profile strongly. These front moraines are fresh and relatively young. They, may be, therefore, recessional and the remains of a glacier's retreat. If this is so, there is reason to believe that the glaciation reached more southern regions.

There are studies that tend to prove the former presence of glaciers in the northern foothills. Among them, two detailed surveys resulted in some interesting findings.

1.5.1 *The Charnawati Valley Study*

The Charnawati Valley is a small valley crossed by the Lamosangu-Jiri road. This valley is close to Charikot (Dolakha district) in Central Nepal. Charnavati River is a right bank tributary of the Tama

Koshi. Its upper catchment is narrow and cirque-like with high steep rockwalls (see Fig. 1.15). The morphology of the upper catchment is typically prone to cloudbursts and therefore floods.

In 1987 a major flood occurred, resulting in a 5-10 m deepening of the river bed with trigerring of many slides and major damages to the Lamosangu-Jiri road. Detailed studies, including boreholes and electrical soundings, were undertaken for the rehabilitation of the road.

They revealed the following features:

1. the soil affected by bank undercutting and slides is abnormally thick (up to 100m); it is silty, rarely clayey, and contains sparse subangular cobbles (Fig. 1.16); and

2. the underlying bedrock shows a trough-like morphology, i.e., a flat bottom becoming steep upwards (Figs. 1.16 and 1.17).

These features suggest the presence of moraine material lying within a glacial trough.

Other features of the Charnawati upper catchment seem to confirm the glacial origin of the Charnawati Valley;

o The presence of clayey soil within the bottom section of the valley which shows characteristics of ground moraine containing striated cobbles.

o Polished rock surfaces.

o The glacial-like profile of the river with high headwall, threshold, Riegels, and threads (see Fig. 1.16 and refer to Fig. 1.7)

1.5.2 *The Study of Sun Koshi and Bothe Koshi Valley (Central Nepal)*

Detailed studies were undertaken during rehabilitation of the Arniko Highway, also heavily affected by a major flood in 1987.

The accumulation of thick (up to 200m) fine material within the lower sections of these rivers has been confirmed by boreholes and electrical soundings undertaken between Balephi and Kodari. As already discussed in Annex 1.3.1, these deposits may be a wash off of former morainic sediments, lying in the valley's upper sections.

The present river bed, rocky cross-sections have a V shape which cannot be of glacial origin. In many places, however, 200 to 400 metres above the river bed, gentle slopes, limited upwards by rockwalls, are visible. This morphology is trough-like and may be of glacial origin (see Fig. 1.3). Big boulders, often visible far away from the upper rocky wall, may be so-called **erratic boulders** deposited by a glacier.

In the case of these major river valleys, the possible traces of glaciation are therefore far predominant above the river bed because strong river erosion has quarried V-shaped valleys through the hypothetical glacial trough after the glacier's retreat. If the general uplift of the Himalayan ridge (2 to 5 mm per year according to various authors) is considered, a deepening of a glacial trough by a V-valley could be of 200 m to 500 m in a period of 100,000 years. These figures fit the elevation of the trough-like upper sections of the valleys and coincide with the glacial Riss and Wurm periods in Europe.

The question of former glaciation within the main valleys crossing the northern foothills calls, however, for more proof, although there are already some converging features. Detailed research, including careful examination of the soils of the upper main valley sections, datation, sedimentological and petrographical tests of these materials, and other studies related to glacial science should produce the answers.

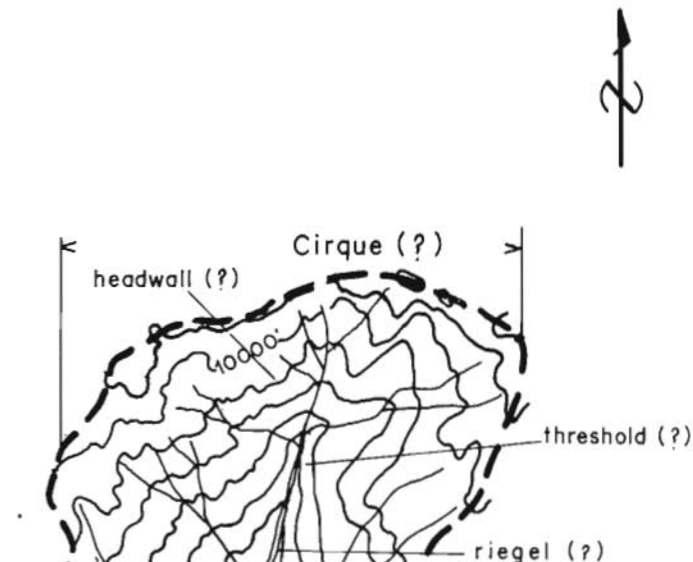


Fig. 1.15 Charnawati (Central Nepal)
Upper catchment area

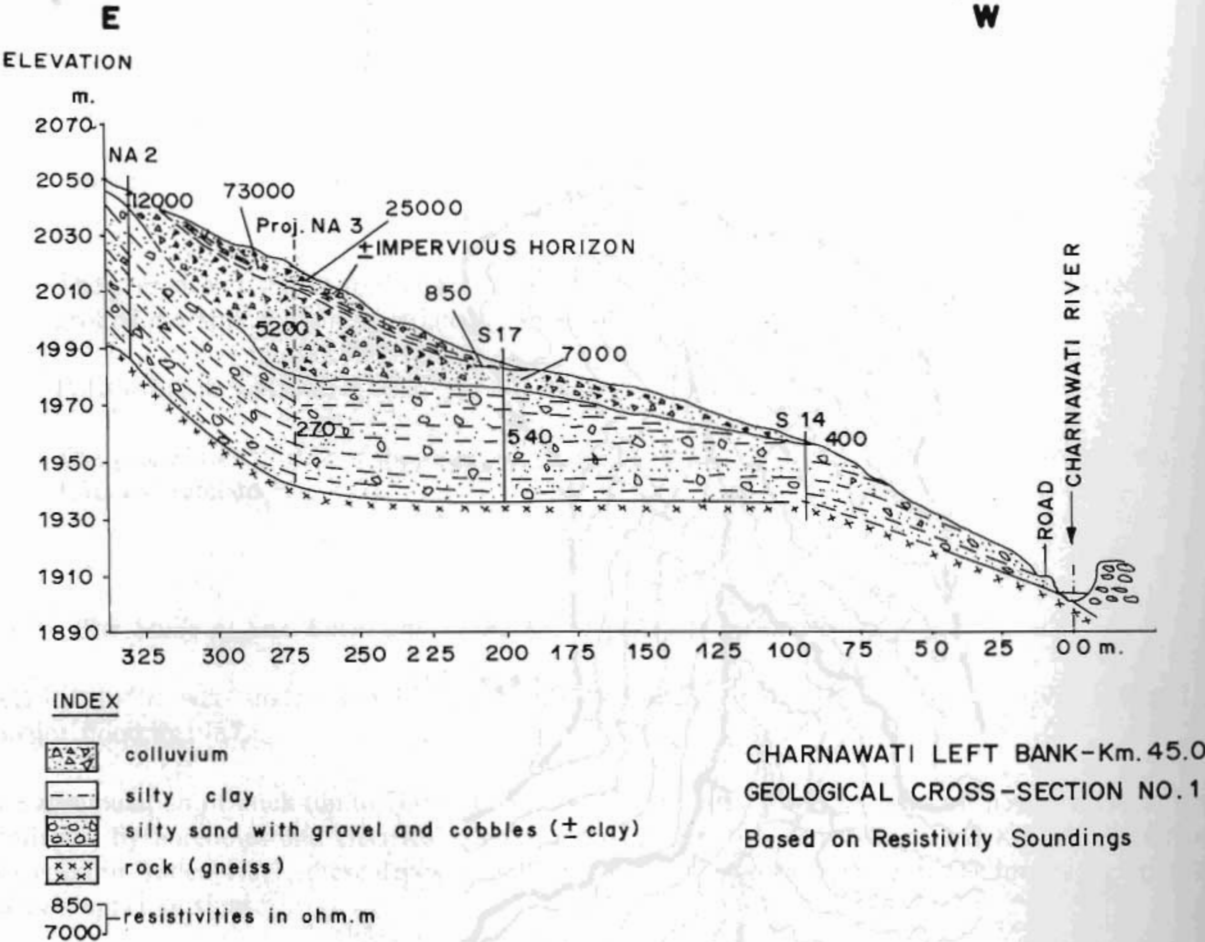


Fig. 1.16 **Charnawati left bank - Km. 45.0**
Geological cross-section No. 1
Based on resistivity soundings

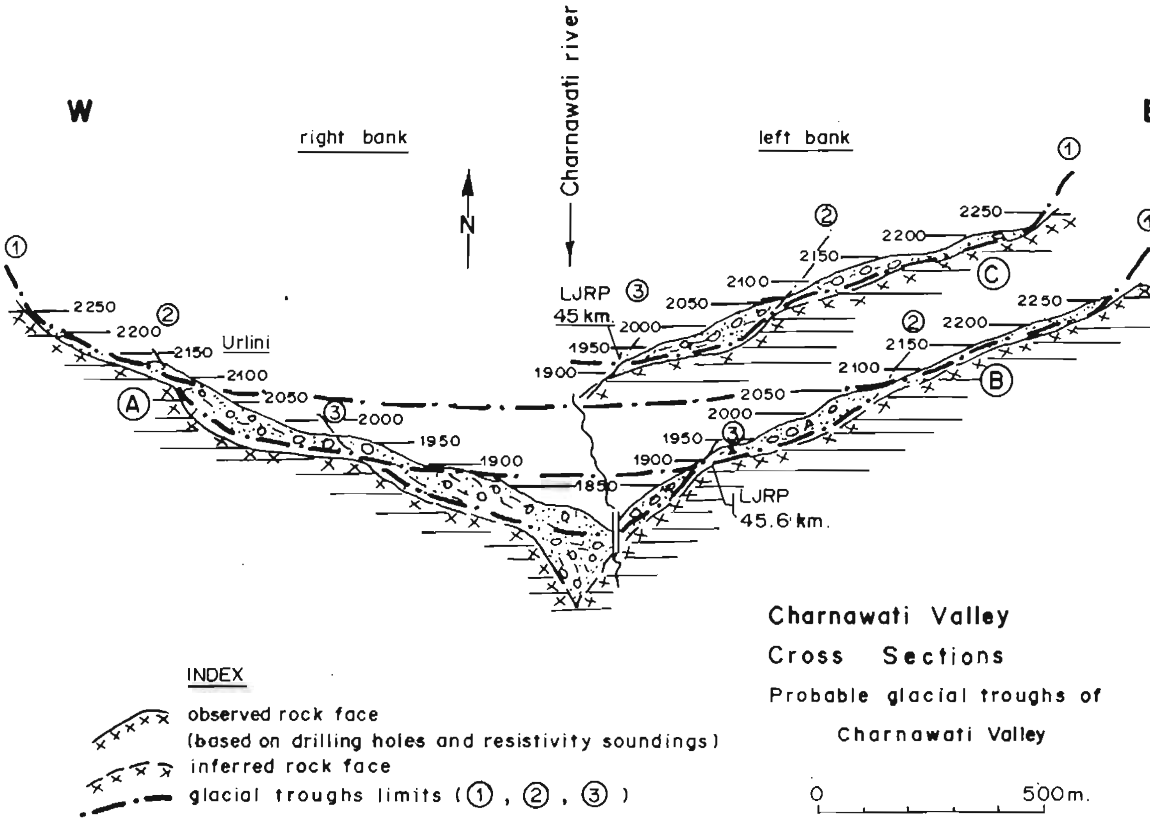


Fig. 1.17 Charnawati valley
Cross sections
Probable glacial troughs of Charnawati valley

Material Table 1.1: Earth Material Deposits According to Origin

Origin	Process Involved in Formation	Nature of Deposit	Typical Gradation	Morphological Features of Material Environment
Alluvial	Material transported and re-deposited by the action of water.	Usually with pronounced stratification. Typical river deposits may consist of fine grained material of recent original overlying coarser material from an earlier stage of river development.	Ranges from finest grained fresh water or marine clays to very coarse gravel. Sand is commonly found in stream deposits.	- Flat terrace fans - In connection with running water, but not limited to modern streams
Glacial	Material transported and redeposited by glacial ice or by melt waters flowing from glaciers (Rock debris).	Stratification varies greatly according to deposits from heterogeneous boulder moraines or till to finely stratified (varved) silt and clay in glacial lakes, or irregularly layered ice contact deposits and outwash plains.	Till and moraines are typically of broad gradation ranging from clay to boulders. Grain size in outwash generally decreases with distance from source of melt water.	- Row ridges or deposits across the floor mountain (front moraines) or parallel to lower slopes or valleys (lateral moraines) - Flat outwash area beyond advance ancient or actual glacier - Cirque, steps, hanging valley, U-shape through due to action of ice on bedrock.
Eolian	Material transported and deposited by wind.	Loess may have stratification but is usually indistinct except for weathered zones. Dunes have indistinct stratification and graded bedding.	Most uniform of all principal deposits. Loess range from clayey silt to silt fine sand. Dune sand generally fine to medium size lacking silt or clay.	- Very rare (?) in Himalayan Foothill Regions.

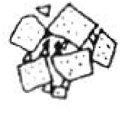
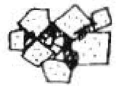
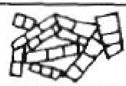
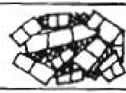
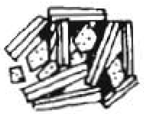
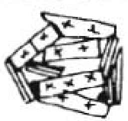
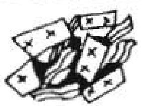
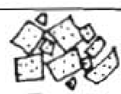
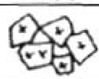
Material Table 1.1: Earth Material Deposits According to Origin (Contd.)

Origin	Process Involved in Formation	Nature of Deposit	Typical Gradation	Morphological Features of Material Environment
Residual	Material weathered in place from parent rocks with little or no alteration by transport	Almost invariably becomes more compact, rockier, and less weathered with increasing depth. May reflect alternation of hard and soft layers of stratification of parent rock if weathering is incomplete.	Product of complete weathering is clay, of a type depending upon the weathering process and parent rock, plus varying amounts of resistant silica particles. Material at intermediate stage reflects composition of parent rock.	- Gentle slopes - Present on hill, ridge and spur top lines and slides.
Colluvium	Material transported by fall, rolling, bounce, and slide. (Rock debris)	Commonly loose or fragment to fragment contact. Angular to subangular commonly. May present hard horizon below surface. Usually found with steep slopes.	Variation in size enormous: From giant fragments to fine particles. Very little material below sand size.	- Relatively steep terrain, with commonly 30-38 degrees (up to 45 degrees) of slope - Present at the tops of steep slopes which normally are rock slopes - Present in areas where the gradient flattens - Rock mass detachment features such as wedge or parallelipipedic voids on feeder rock slopes.
	Material transported by gravity, slope wash, and flows. (Colluvium, sensu stricto)	Commonly found on steep slopes or at the feet of steep slopes. Subangular to subrounded fragments. May have indistinct stratification in some units.	Variation in size is great. Material does have size below sand intermixed.	

Material Table 1.2: Residual Soil Behaviour and Parent Rock Type

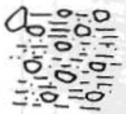
Parent Rock	Potential Degree of Weathering	Residual Soil and Perched Water Table	Potential Type of Slide	Stability
Calcite-sandstone	Strong	Deep residual soil. ABC soil profile well developed where calcite favours constitution of perched water table on B.	Rotational or translational slide on B (perched water table), rare on rock face. Gully erosion.	high to moderate
Clay matrix sandstone	Strong	Moderately deep to deep soil. ABC well developed where clay may favour constitution of perched water table on B.	id. - As above, but more easily weathered by chemical processes. Clay B horizon with perched water: rotational slide. Gully erosion.	moderate
Shale, mudstone and marl	Strong especially when beds are deeping	Shallow to moderately deep soil when horizontal. Deep when beds inclined. ABC well developed with clay in B, and perched water.	Shallow translational slide, rot. slide when bedding horizontal. Rotational slide on B horizon. Translational slides and mudflows on weathering front when beds inclined. Gully erosion.	low
Limestone (marbles)	Weak for pure limestone Moderate with clay limestone	Shallow in general: deeper with clay-bearing limestone: ABC rare.	Rare failure	high
Granite and other coarse grain, igneous rock	Moderate to strong	1) May be deep with clay leaching, ABC profile and perched water on B. 2) Deep with granular disintegration. No ABC profile.	Mostly gully erosion. Translational slides on B.	moderate
Gneiss	Moderate	Similar to granite	Similar to granite but rather rare	high
Slate, phyllite and schist	Strong	Similar to shale, mudstone, and marl, but soil more gravelly.	Similar to shale, mudstones and marls but less development mudslides rare. Gully erosion.	moderate to low
Quartzite	Weak, only mechanical	Very shallow. No perched water table.	Very rare failures.	high

Material Table 1.3: Colluvial Deposits Features Summary

Source Colluvial Material Material	Fabric of Colluvial Material Recent	Weathered	Hydrogeological features of colluvial material	Frequency when conditions unfavourable in source mat.	Approx. phi	Approx. C	Pot. Types of Failure/Erosion	Stability
Ca-sst dominant with marl and shale			Highly pervious when recent, less pervious when weathered. Possible perched water table when weathered. Cemented through CaCO3 solutions. Water table when weathered.	Frequent	30-45°	Very low	Rare debris flows, tr. slides, gully erosion	Moderate - high
Cl.-sst dominant with shale and mudst.			More or less semi-pervious according to weathering stage. - When weathered: pot. perched with water table.	Frequent	25-35°	Low	Debris flow, tr slide rather rare, gully erosion	Moderate
Marl or shales dominant with Ca.- or cl.-sst			Semi-impervious, when recent to impervious, when weathered. Eventually perched water table when recent	Very frequent	25-30°	Moderate	Mudflow, tr. and rot. slides	Very low
Limestone dolomite, marble			Pervious, cemented through CaCO3 solutions.	Rare	35-40°	D	Slides in cuttings	High
Slate, phyllite and schist dom. with quartzite or gneiss			Semi-pervious, when recent, to impervious, when weathered Possible perched water table.	Frequent	25-30°	Low	Debris-flow tr. slides,, gully erosion.	Low
Calc-sl./ Calc-phyll/and calc.-sch/dom. lst. mrbl. or quartzite			± Semi-.pervious, cementation due to CaCO3 when weathered. Water table and percned water table.	Frequent	25° to high (cementation)	Low	Tr. slide, gully erosion	Moderate
Quartzite/ gneiss dom. with slate/ phyll/ schist			Pervious when recent to semi-pervious when weathered. Water table and perched water table.	Rather frequent	35-40°	D	Tr. slides, debris flow, gully erosion	Moderate
Gneiss, quartzite			Pervious, water table	Rare	35-40°	0	Slides in cutting	High
Granite and coarse igneous rocks			Pervious, water table when recent and perched water table when weathered.	Rare	30- 45°	0	Gully erosion	Moderate

Ca = Calcite Cl = Clay Sl = slate sst = sandstone mrbl = marble mudst = mudstone dom = dominant pot = potential tr = translational rot = rotational

Material Table 1.4: Glacial Deposits Features Summary

		Material, Thickness	Frequency in deglaciated valleys	Hydrogeological Features	Approx. Φ	Approx. C	Pot. Types of Failure/Erosion	Stability
Lateral Moraine		Sub-angular boulders and cobbles within abundant silty to silty-clay matrix. Thick to very thick. Rough alignment of boulder. Rather frequent.	Striking and widespread	Semi-pervious to impervious (K of silt = 10±7). High capacity of water storage. Water table and perched water tables.	30-35°	Very low	Frequent rather shallow translational slides. Rather rare rotational slides. Mudslides, deep gully erosion frequent.	Low
End Moraine		Sub-angular to angular boulders and cobbles. Silty matrix. Thick.	Striking but frequently eroded or dismanteled	Semi-pervious to pervious, high capacity of water storage. Water table and perched water table.	35°	Very low	Frequent rather shallow rotational slides. Gully erosion frequent	Low to moderate
Lodgement Moraine		Clay and silty clay with cobbles. Rather thick to thick.	Patchy, frequently eroded by post-glacial streams or not visible.	Impervious in general major aquifers may be stored on lodgement moraine when underlaying other material.	20° 25°	Moderate to high	When underlaying below more pervious material lodgement mor. favours storage of large water table and then wide rotational slides. Mudslides.	Low to very low
Kame Terrace		Interbedding of irregular layers of morainic and stratified glacio-fluviatile material. Moderately thick.	Found inside morainic material	Semi-pervious to pervious. Perched water table in Kame terrace mat. which may be artesian.	30-35°	Very low	id. lateral moraine. Frequent deep erosion gully.	Low to very low
Valley Trains and Outwash Fan		Interstratified silt, sand and coarser material, cross-bedding frequent. Disturbed layers. Thick.	Common downstream of morainic terrains	Pervious with semi-pervious or impervious horizon. Perched water table very common.	35° 40°	Very low	Shallow slides rather rare more or less deep rotational slides. Gully erosion.	Low
Glacio-lacustrine Sediments		Fine interstratifications of dark and clear silty-clay and silt (varves). Disturbed layers. Thick.	Rather common at confluence of deglaciated rivers	Impervious to semi-pervious. Perched water table.	25° 30°	Very low	Frequent shallow to deep rotational and translational slides. Mudslides. Deep gully erosion.	Very low