CHAPTER

6

Geomorphic Processes

After learning about how the earth was born, how it evolved its crust and other inner layers, how its crustal plates moved and are moving, and other information on earthquakes, the forms of volcanism and about the rocks and minerals the crust is composed of, it is time to know in detail about the surface of the earth on which we live. Let us start with this question.

Why is the surface of the earth uneven?

First of all, the earth's crust is dynamic. You are well aware that it has moved and moves vertically and horizontally. Of course, it moved a bit faster in the past than the rate at which it is moving now. The differences in the internal forces operating from within the earth which built up the crust have been responsible for the variations in the outer surface of the crust. The earth's surface is being continuously subjected to external forces induced basically by energy (sunlight). Of course, the internal forces are still active though with different intensities. That means, the earth's surface is being continuously subjected to by external forces originating within the earth's atmosphere and by internal forces from within the earth. The external forces are known as *exogenic forces* and the internal forces are known as *endogenic forces*. The actions of exogenic forces result in wearing down (degradation) of relief/elevations and filling up (aggradation) of basins/depressions, on the earth's surface. The phenomenon of wearing down of relief variations of the surface of the earth through erosion is known as *gradation*. The endogenic forces continuously elevate or build up parts of the earth's surface and hence the exogenic processes fail to even out the relief variations of the surface of the earth. So, variations remain as long as the opposing actions of exogenic and endogenic forces continue. In general terms, the endogenic forces are mainly land building forces and the exogenic processes are mainly land wearing forces. The surface of the earth is sensitive. Humans depend on it for their sustenance and have been using it extensively and intensively. So, it is essential to understand its nature in order to use it effectively without disturbing its balance and diminishing its potential for the future. Almost all organisms contribute to sustain the earth's environment. However, humans have caused over use of resources. Use we must, but must also leave it potential enough to sustain life through the future. Most of the surface of the earth had and has been shaped over very long periods of time (hundreds and thousands of years) and because of its use and misuse by humans its potential is being diminished at a fast rate. If the processes which shaped and are shaping the surface of the earth into varieties of forms (shapes) and the nature of materials of which it is composed of, are understood, precautions can be taken to minimise the detrimental effects of human use and to preserve it for posterity.

Geomorphic Processes

You would like to know the meaning of geomorphic processes. The endogenic and exogenic forces causing physical stresses and chemical actions on earth materials and bringing about changes in the configuration of the surface of the earth are known as *geomorphic processes*. Diastrophism and volcanism are endogenic geomorphic processes. These have already been discussed in brief in the preceding unit. Weathering, mass wasting, erosion and deposition are exogenic geomorphic processes. These exogenic processes are dealt with in detail in this chapter.

Any exogenic element of nature (like water, ice, wind, etc.,) capable of acquiring and transporting earth materials can be called a geomorphic agent. When these elements of nature become mobile due to gradients, they remove the materials and transport them over slopes and deposit them at lower level. Geomorphic processes and geomorphic agents especially exogenic, unless stated separately, are one and the same.

A process is a force applied on earth materials affecting the same. An agent is a mobile medium (like running water, moving ice masses, wind, waves and currents etc.) which removes, transports and deposits earth materials. Running water, groundwater, glaciers, wind, waves and currents, etc., can be called *geomorphic agents*.

> Do you think it is essential to distinguish geomorphic agents and geomorphic processes?

Gravity besides being a directional force activating all downslope movements of matter also causes stresses on the earth's materials. Indirect gravitational stresses activate wave and tide induced currents and winds. Without gravity and gradients there would be no mobility and hence no erosion, transportation and deposition are possible. So, gravitational stresses are as important as the other geomorphic processes. Gravity is the force that is keeping us in contact with the surface and it is the force that switches on the movement of all surface material on earth. All the movements either within the earth or on the surface of the earth occur due to gradients — from higher levels to lower levels, from high pressure to low pressure areas etc.

Endogenic Processes

The energy emanating from within the earth is the main force behind endogenic geomorphic processes. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth. This energy due to geothermal gradients and heat flow from within induces diastrophism and volcanism in the lithosphere. Due to variations in geothermal gradients and heat flow from within, crustal thickness and strength, the action of endogenic forces are not uniform and hence the tectonically controlled original crustal surface is uneven.

Diastrophism

All processes that move, elevate or build up portions of the earth's crust come under *diastrophism*. They include: (i) *orogenic* processes involving mountain building through severe folding and affecting long and narrow belts of the earth's crust; (ii) *epeirogenic* processes involving uplift or warping of large parts of the earth's crust; (iii) earthquakes involving local relatively minor movements; (iv) plate tectonics involving horizontal movements of crustal plates.

In the process of orogeny, the crust is severely deformed into folds. Due to epeirogeny, there may be simple deformation. Orogeny is a mountain building process whereas epeirogeny is continental building process. Through the processes of orogeny, epeirogeny, earthquakes and plate tectonics, there can be faulting and fracturing of the crust. All these processes cause pressure, volume and temperature (PVT) changes which in turn induce metamorphism of rocks.

> Epeirogeny and orogeny, cite the differences.

Volcanism

Volcanism includes the movement of molten rock (magma) onto or toward the earth's surface and also formation of many intrusive and extrusive volcanic forms. Many aspects of volcanism have already been dealt in detail under volcanoes in the Unit II and under igneous rocks in the preceding chapter in this unit.

What do the words volcanism and volcanoes indicate?

Exogenic Processes

The exogenic processes derive their energy from atmosphere determined by the ultimate energy from the sun and also the gradients created by tectonic factors.

Why do you think that the slopes or gradients are created by tectonic factors?

Gravitational force acts upon all earth materials having a sloping surface and tend to produce movement of matter in down slope direction. Force applied per unit area is called *stress*. Stress is produced in a solid by pushing or pulling. This induces deformation. Forces acting along the faces of earth materials are shear stresses (separating forces). It is this stress that breaks rocks and other earth materials. The shear stresses result in angular displacement or slippage. Besides the gravitational stress earth materials become subjected to molecular stresses that may be caused by a number of factors amongst which temperature changes, crystallisation and melting are the most common. Chemical processes normally lead to loosening of bonds between grains, dissolving of soluble minerals or cementing materials. Thus, the basic reason that leads to weathering, mass movements, erosion and deposition is development of stresses in the body of the earth materials.

As there are different climatic regions on the earth's surface the exogenic geomorphic processes vary from region to region. Temperature and precipitation are the two important climatic elements that control various processes.

All the exogenic geomorphic processes are covered under a general term, *denudation*. The word 'denude' means to strip off or to uncover. Weathering, mass wasting/movements, erosion and transportation are included in denudation. The flow chart (Figure 6.1) gives the denudation processes and their respective driving forces. It should become clear from this chart that for each process there exists a distinct driving force or energy.

As there are different climatic regions on the earth's surface owing to thermal gradients created by latitudinal, seasonal and land and water spread variations, the exogenic geomorphic processes vary from region to region. The density, type and distribution of vegetation which largely depend upon

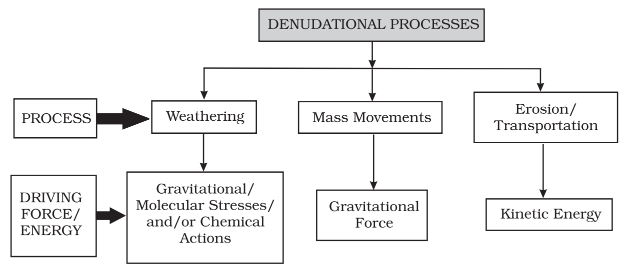

Figure 6.1 : Denudational processes and their driving forces

precipitation and temperature exert influence indirectly on exogenic geomorphic processes. Within different climatic regions there may be local variations of the effects of different climatic elements due to altitudinal differences, aspect variations and the variation in the amount of insolation received by north and south facing slopes as compared to east and west facing slopes. Further, due to differences in wind velocities and directions, amount and kind of precipitation, its intensity, the relation between precipitation and evaporation, daily range of temperature, freezing and thawing frequency, depth of frost penetration, the geomorphic processes vary within any climatic region.

What is the sole driving force behind all the exogenic processes?

Climatic factors being equal, the intensity of action of exogenic geomorphic processes depends upon type and structure of rocks. The term structure includes such aspects of rocks as folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, chemical susceptibility of mineral constituents; the permeability or impermeability etc. Different types of rocks with differences in their structure offer varying resistances to various geomorphic processes. A particular rock may be resistant to one process and non-resistant to another. And, under varying climatic conditions, particular rocks may exhibit different degrees of resistance to geomorphic processes and hence they operate at differential rates and give rise to differences in topography. The effects of most of the exogenic geomorphic processes are small and slow and may be imperceptible in a short time span, but will in the long run affect the rocks severely due to continued fatigue.

Finally, it boils down to one fact that the differences on the surface of the earth though originally related to the crustal evolution continue to exist in some form or the other due to differences in the type and structure of earth materials, differences in geomorphic processes and in their rates of operation.

Some of the exogenic geomorphic processes have been dealt in detail here.

Weathering

Weathering is action of elements of weather and climate over earth materials. There are a number of processes within weathering which act either individually or together to affect the earth materials in order to reduce them to fragmental state.

> Weathering is defined as mechanical disintegration and chemical decom-position of rocks through the actions of various elements of weather and climate.

As very little or no motion of materials takes place in weathering, it is an *in-situ* or on-site process.

> Is this little motion which can occur sometimes due to weathering synonymous with transportation? If not, why?

Weathering processes are conditioned by many complex geological, climatic, topographic and vegetative factors. Climate is of particular importance. Not only weathering processes differ from climate to climate, but also the depth of the weathering mantle (Figure 6.2).

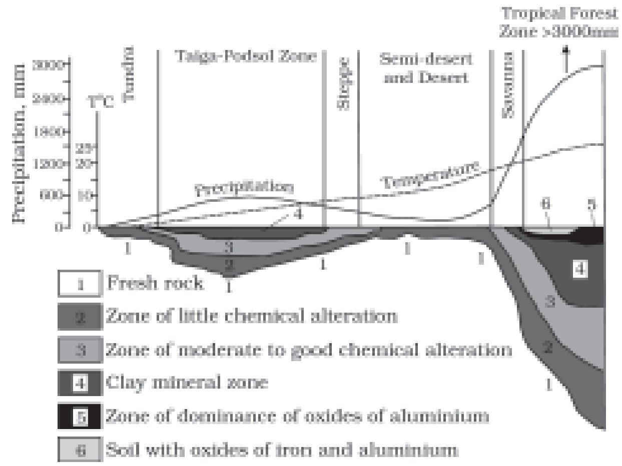

Figure 6.2 : Climatic regimes and depth of weathering mantles (adapted and modified from Strakhov, 1967)

> **Activity**
>
> Mark the latitude values of different climatic regimes in Figure 6.2 and compare the details.

There are three major groups of weathering processes : (i) chemical; (ii) physical or mechanical; (iii) biological weathering processes. Very rarely does any one of these processes ever operate completely by itself, but quite often a dominance of one process can be seen.

Chemical Weathering Processes

A group of weathering processes viz; solution, carbonation, hydration, oxidation and reduction act on the rocks to decompose, dissolve or reduce them to a fine clastic state through chemical reactions by oxygen, surface and/or soil water and other acids. Water and air (oxygen and carbon dioxide) along with heat must be present to speed up all chemical reactions. Over and above the carbon dioxide present in the air, decomposition of plants and animals increases the quantity of carbon dioxide underground. These chemical reactions on various minerals are very much similar to the chemical reactions in a laboratory.

Solution

When something is dissolved in water or acids, the water or acid with dissolved contents is called *solution*. This process involves removal of solids in solution and depends upon solubility of a mineral in water or weak acids. On coming in contact with water many solids disintegrate and mix up as suspension in water. Soluble rock forming minerals like nitrates, sulphates, and potassium etc. are affected by this process. So, these minerals are easily leached out without leaving any residue in rainy climates and accumulate in dry regions. Minerals like calcium carbonate and calcium magnesium bicarbonate present in limestones are soluble in water containing carbonic acid (formed with the addition of carbon dioxide in water), and are carried away in water as solution. Carbon dioxide produced by decaying organic matter along with soil water greatly aids in this reaction. Common salt (sodium chloride) is also a rock forming mineral and is susceptible to this process of solution.

Carbonation

Carbonation is the reaction of carbonate and bicarbonate with minerals and is a common process helping the breaking down of feldspars and carbonate minerals. Carbon dioxide from the atmosphere and soil air is absorbed by water, to form carbonic acid that acts as a weak acid. Calcium carbonates and magnesium carbonates are dissolved in carbonic acid and are removed in a solution without leaving any residue resulting in cave formation.

> Why are clay minerals easily erodible?

Hydration

Hydration is the chemical addition of water. Minerals take up water and expand; this expansion causes an increase in the volume of the material itself or rock. Calcium sulphate takes in water and turns to gypsum, which is more unstable than calcium sulphate. This process is reversible and long, continued repetition of this process causes fatigue in the rocks and may lead to their disintegration. Many clay minerals swell and contract during wetting and drying and a repetition of this process results in cracking of overlying materials. Salts in pore spaces undergo rapid and repeated hydration and help in rock fracturing. The volume changes in minerals due to hydration will also help in physical weathering through exfoliation and granular disintegration.

Oxidation and Reduction

In weathering, oxidation means a combination of a mineral with oxygen to form oxides or hydroxides. Oxidation occurs where there is ready access to the atmosphere and oxygenated waters. The minerals most commonly involved in this process are iron, manganese, sulphur etc. In the process of oxidation rock breakdown occurs due to the disturbance caused by addition of oxygen. Red colour of iron upon oxidation turns to brown or yellow. When oxidised minerals are placed in an environment where oxygen is absent, reduction takes place. Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground. Red colour of iron upon reduction turns to greenish or bluish grey.

These weathering processes are inter-related. Hydration, carbonation and oxidation go hand in hand and hasten the weathering process.

> Can we give iron rusting as an example of oxidation? How essential is water in chemical weathering processes? Can chemical weathering processes dominate in water scarce hot deserts?

Physical Weathering Processes

Physical or mechanical weathering processes depend on some applied forces. The applied forces could be: (i) gravitational forces such as overburden pressure, load and shearing stress; (ii) expansion forces due to temperature changes, crystal growth or animal activity; (iii) water pressures controlled by wetting and drying cycles. Many of these forces are applied both at the surface and within different earth materials leading to rock fracture. Most of the physical weathering processes are caused by thermal expansion and pressure release. These processes are small and slow but can cause great damage to the rocks because of continued fatigue the rocks suffer due to repetition of contraction and expansion.

Unloading and Expansion

Removal of overlying rock load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand producing disintegration of rock masses. Fractures will develop roughly parallel to the ground surface. In areas of curved ground surface, arched fractures tend to produce massive sheets or exfoliation slabs of rock. Exfoliation sheets resulting from expansion due to unloading and pressure release may measure hundreds or even thousands of metres in horizontal extent. Large, smooth rounded domes called *exfoliation domes* (Figure 6.3) result due to this process.

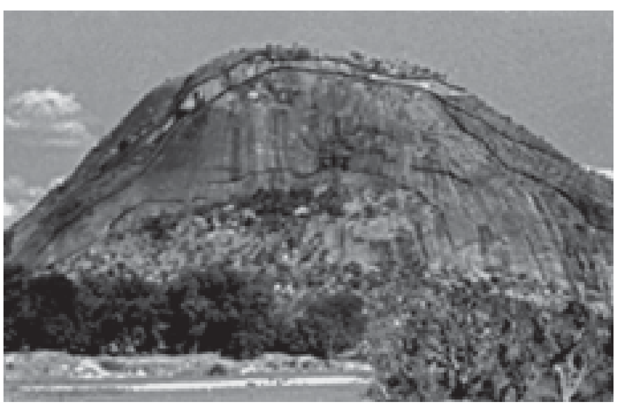

Figure 6.3 : A large exfoliation dome in granite rock near bhongir (Bhuvanagiri) town in Andhra Pradesh

Temperature Changes and Expansion

Various minerals in rocks possess their own limits of expansion and contraction. With rise in temperature, every mineral expands and pushes against its neighbour and as temperature falls, a corresponding contraction takes place. Because of diurnal changes in the temperatures, this internal movement among the mineral grains of the superficial layers of rocks takes place regularly. This process is most effective in dry climates and high elevations where diurnal temperature changes are drastic. As has been mentioned earlier though these movements are very small they make the rocks weak due to continued fatigue. The surface layers of the rocks tend to expand more than the rock at depth and this leads to the formation of stress within the rock resulting in heaving and fracturing parallel to the surface. Due to differential heating and resulting expansion and contraction of surface layers and their subsequent exfoliation from the surface results in smooth rounded surfaces in rocks. In rocks like granites, smooth surfaced and rounded small to big boulders called *tors* form due to such exfoliation.

What is the difference between exfoliation domes and exfoliated tors?

Freezing, Thawing and Frost Wedging

Frost weathering occurs due to growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting. This process is most effective at high elevations in mid-latitudes where freezing and melting is often repeated. Glacial areas are subject to frost wedging daily. In this process, the rate of freezing is important. Rapid freezing of water causes its sudden expansion and high pressure. The resulting expansion affects joints, cracks and small inter granular fractures to become wider and wider till the rock breaks apart.

Salt Weathering

Salts in rocks expand due to thermal action, hydration and crystallisation. Many salts like calcium, sodium, magnesium, potassium and barium have a tendency to expand. Expansion of these salts depends on temperature and their thermal properties. High temperature ranges between 30 and 50°C of surface temperatures in deserts favour such salt expansion. Salt crystals in near-surface pores cause splitting of individual grains within rocks, which eventually fall off. This process of falling off of individual grains may result in granular disintegration or granular foliation.

Salt crystallisation is most effective of all salt-weathering processes. In areas with alternating wetting and drying conditions salt crystal growth is favoured and the neighbouring grains are pushed aside. Sodium chloride and gypsum crystals in desert areas heave up overlying layers of materials and with the result polygonal cracks develop all over the heaved surface. With salt crystal growth, chalk breaks down most readily, followed by limestone, sandstone, shale, gneiss and granite etc.

Biological Activity and Weathering

Biological weathering is contribution to or removal of minerals and ions from the weathering environment and physical changes due to growth or movement of organisms. Burrowing and wedging by organisms like earthworms, termites, rodents etc., help in exposing the new surfaces to chemical attack and assists in the penetration of moisture and air. Human beings by disturbing vegetation, ploughing and cultivating soils, also help in mixing and creating new contacts between air, water and minerals in the earth materials. Decaying plant and animal matter help in the production of humic, carbonic and other acids which enhance decay and solubility of some elements. Algae utilise mineral nutrients for growth and help in concentration of iron and manganese oxides. Plant roots exert a tremendous pressure on the earth materials mechanically breaking them apart.

Some Special Effects of Weathering

This has already been explained under physical weathering processes of unloading, thermal contraction and expansion and salt weathering. Exfoliation is a result but not a process. Flaking off of more or less curved sheets of shells from over rocks or bedrock results in smooth and rounded surfaces (Figure 6.4). Exfoliation can occur due to expansion and contraction induced by

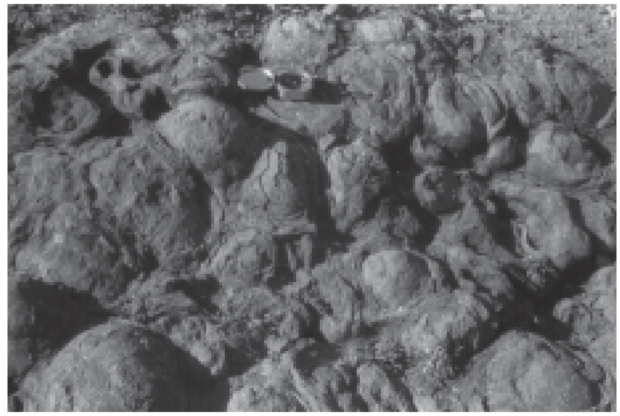

Fig.6.4 : Exfoliation (Flacking) and granular disintegration

temperature changes. Exfoliation domes and tors result due to unloading and thermal expansion respectively.

Significance of Weathering

Weathering processes are responsible for breaking down the rocks into smaller fragments and preparing the way for formation of not only regolith and soils, but also erosion and mass movements. Biomes and bio-diversity is basically a result of forests (vegetation) and forests depend upon the depth of weathering mantles. Erosion cannot be significant if the rocks are not weathered. That means, weathering aids mass wasting, erosion and reduction of relief and changes in landforms are a consequence of erosion. Weathering of rocks and deposits helps in the enrichment and concentrations of certain valuable ores of iron, manganese, aluminium, copper etc., which are of great importance for the national economy. Weathering is an important process in the formation of soils.

> When rocks undergo weathering, some materials are removed through chemical or physical leaching by groundwater and thereby the concentration of remaining (valuable) materials increases. Without such a weathering taking place, the concentration of the same valuable material may not be sufficient and economically viable to exploit, process and refine. This is what is called enrichment.

Mass Movements

These movements transfer the mass of rock debris down the slopes under the direct influence of gravity. That means, air, water or ice do not carry debris with them from place to place but on the other hand the debris may carry with it air, water or ice. The movements of mass may range from slow to rapid, affecting shallow to deep columns of materials and include creep, flow, slide and fall. Gravity exerts its force on all matter, both bedrock and the products of weathering. So, weathering is not a pre-requisite for mass movement though it aids mass movements. Mass movements are very active over weathered slopes rather than over unweathered materials.

Mass movements are aided by gravity and no geomorphic agent like running water, glaciers, wind, waves and currents participate in the process of mass movements. That means mass movements do not come under erosion though there is a shift (aided by gravity) of materials from one place to another. Materials over the slopes have their own resistance to disturbing forces and will yield only when force is greater than the shearing resistance of the materials. Weak unconsolidated materials, thinly bedded rocks, faults, steeply dipping beds, vertical cliffs or steep slopes, abundant precipitation and torrential rains and scarcity of vegetation etc., favour mass movements.

Several activating causes precede mass movements. They are : (i) removal of support from below to materials above through natural or artificial means; (ii) increase in gradient and height of slopes; (iii) overloading through addition of materials naturally or by artificial filling; (iv) overloading due to heavy rainfall, saturation and lubrication of slope materials; (v) removal of material or load from over the original slope surfaces; (vi) occurrence of earthquakes, explosions or machinery; (vii) excessive natural seepage; (viii) heavy drawdown of water from lakes, reservoirs and rivers leading to slow outflow of water from under the slopes or river banks; (ix) indiscriminate removal of natural vegetation.

Heave (heaving up of soils due to frost growth and other causes), *flow* and *slide* are the three forms of movements. Figure 6.5 shows the relationships among different types of mass movements, their relative rates of movement and moisture limits.

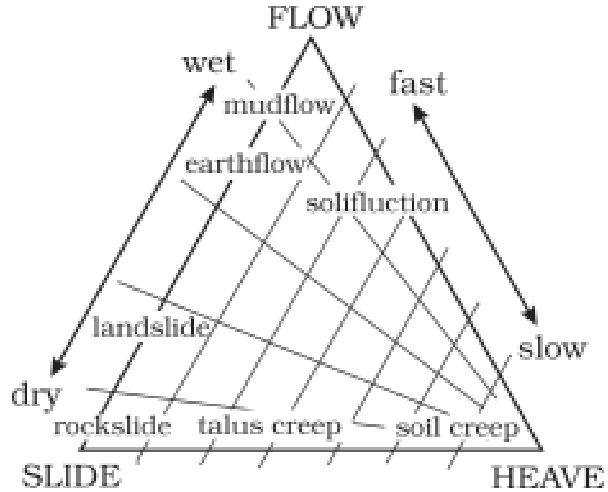

Figure 6.5 : Relationships among different types of mass movements, their relative rates of movement and moisture limits (after Whitehead, 2001)

Mass movements can be grouped under three major classes: (i) slow movements; (ii) rapid movements; (iii) landslides.

Slow Movements

Creep is one type under this category which can occur on moderately steep, soil covered slopes. Movement of materials is extremely slow and imperceptible except through extended observation. Materials involved can be soil or rock debris. Have you ever seen fence posts, telephone poles lean downslope from their vertical position and in their linear alignment? If you have, that is due to the creep effect. Depending upon the type of material involved, several types of creep viz., soil creep, talus creep, rock creep, rock-glacier creep etc., can be identified. Also included in this group is *solifluction* which involves slow downslope flowing soil mass or fine grained rock debris saturated or lubricated with water. This process is quite common in moist temperate areas where surface melting of deeply frozen ground and long continued rain respectively, occur frequently. When the upper portions get saturated and when the lower parts are impervious to water percolation, flowing occurs in the upper parts.

Rapid Movements

These movements are mostly prevalent in humid climatic regions and occur over gentle to steep slopes. Movement of water-saturated clayey or silty earth materials down low-angle terraces or hillsides is known as *earthflow*. Quite often, the materials slump making step-like terraces and leaving arcuate scarps at their heads and an accumulation bulge at the toe. When slopes are steeper, even the bedrock especially of soft sedimentary rocks like shale or deeply weathered igneous rock may slide downslope.

Another type in this category is *mudflow*. In the absence of vegetation cover and with heavy rainfall, thick layers of weathered materials get saturated with water and either slowly or rapidly flow down along definite channels. It looks like a stream of mud within a valley. When the mudflows emerge out of channels onto the piedmont or plains, they can be very destructive engulfing roads, bridges and houses. Mudflows occur frequently on the slopes of erupting or recently erupted volcanoes. Volcanic ash, dust and other fragments turn into mud due to heavy rains and flow down as tongues or streams of mud causing great destruction to human habitations.

A third type is the debris *avalanche*, which is more characteristic of humid regions with or without vegetation cover and occurs in narrow tracks on steep slopes. This debris avalanche can be much faster than the mudflow. Debris avalanche is similar to snow avalanche.

> In Andes mountains of South America and the Rockies mountains of North America, there are a few volcanoes which erupted during the last decade and very devastating mudflows occurred down their slopes during eruption as well as after eruption.

Landslides

These are known as relatively rapid and perceptible movements. The materials involved are relatively dry. The size and shape of the detached mass depends on the nature of discontinuities in the rock, the degree of weathering and the steepness of the slope. Depending upon the type of movement of materials several types are identified in this category.

Slump is slipping of one or several units of rock debris with a backward rotation with respect to the slope over which the movement takes place (Figure 6.6). Rapid rolling or sliding

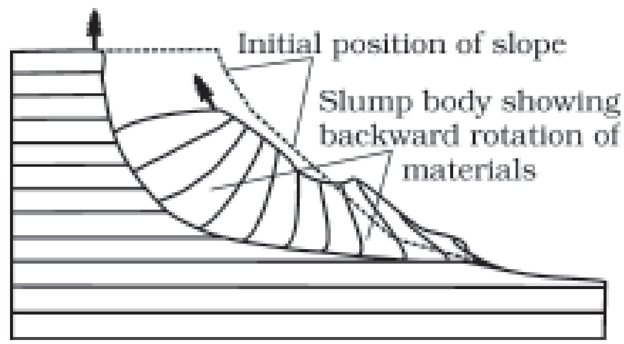

Figure 6.6 : Slumping of debris with backward rotation

of earth debris without backward rotation of mass is known as *debris slide*. Debris fall is nearly a free fall of earth debris from a vertical or overhanging face. Sliding of individual rock masses down bedding, joint or fault surfaces is *rockslide*. Over steep slopes, rock sliding is very fast and destructive. Figure 6.7 shows landslide scars over steep slopes. Slides occur as planar failures along discontinuities like bedding planes that dip steeply. Rock fall is free falling of rock blocks over any steep slope keeping itself away from the slope. Rock falls occur from the superficial layers of the rock

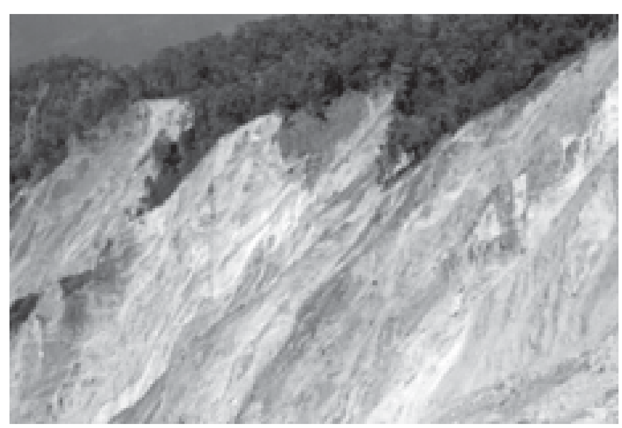

Figure 6.7 : Landslide scars in Shiwalik Himalayan ranges near river Sarada at India-Nepal border, Uttar Pradesh

face, an occurrence that distinguishes it from rockslide which affects materials up to a substantial depth.

> Between mass wasting and mass movements, which term do you feel is most appropriate? Why? Can solifluction be included under rapid flow movements? Why it can be and can't be?

> In our country, debris avalanche and landslides occur very frequently in the Himalayas. There are many reasons for this. One, the Himalayas are tectonically active. They are mostly made up of sedimentary rocks and unconsolidated and semi-consolidated deposits. The slopes are very steep. Compared to the Himalayas, the Nilgiris bordering Tamilnadu, Karnataka, Kerala and the Western Ghats along the west coast are relatively tectonically stable and are mostly made up of very hard rocks; but, still, debris avalanches and landslides occur though not as frequently as in the Himalayas, in these hills. Why? Many slopes are steeper with almost vertical cliffs and escarpments in the Western Ghats and Nilgiris. Mechanical weathering due to temperature changes and ranges is pronounced. They receive heavy amounts of rainfall over short periods. So, there is almost direct rock fall quite frequently in these places along with landslides and debris avalanches.

EROSION AND DEPOSITION

Erosion involves acquisition and transportation of rock debris. When massive rocks break into smaller fragments through weathering and any other process, erosional geomorphic agents like running water, groundwater, glaciers, wind and waves remove and transport it to other places depending upon the dynamics of each of these agents. Abrasion by rock debris carried by these geomorphic agents also aids greatly in erosion. By erosion, relief degrades, i.e., the landscape is worn down. That means, though weathering aids erosion it is not a pre-condition for erosion to take place. Weathering, mass-wasting and erosion are degradational processes. It is erosion that is largely responsible for continuous changes that the earth's surface is undergoing. As indicated in Figure 6.1, denudational processes like erosion and transportation are controlled by kinetic energy. The erosion and transportation of earth materials is brought about by wind, running water, glaciers, waves and ground water. Of these the first three agents are controlled by climatic conditions.

> Can you compare the three climatically controlled agents?

They represent three states of matter — gaseous (wind), liquid (running water) and solid (glacier) respectively. The erosion can be defined as "application of the kinetic energy associated with the agent to the surface of the land along which it moves". Kinetic energy is computed as $KE = {}^1/_2 mv^2$ where 'm' is the mass and 'v' is the velocity. Hence the energy available to perform work will depend on the mass of the material and the velocity with which it is moving. Obviously then you will find that though the glaciers move at very low velocities due to tremendous mass are more effective as the agents of erosion and wind, being in gaseous state, are less effective.

The work of the other two agents of erosion-waves and ground water is not controlled by climate. In case of waves it is the location along the interface of litho and hydro sphere — coastal region — that will determine the work of waves, whereas the work of ground water is determined more by the lithological character of the region. If the rocks are permeable and soluble and water is available only then karst topography develops. In the next chapter we shall be dealing with the landforms produced by each of the agents of erosion.

Deposition is a consequence of erosion. The erosional agents loose their velocity and hence energy on gentler slopes and the materials carried by them start to settle themselves. In other words, deposition is not actually the work of any agent. The coarser materials get deposited first and finer ones later. By deposition depressions get filled up. The same erosional agents viz., running water, glaciers, wind, waves and groundwater act as aggradational or depositional agents also.

What happens to the surface of the earth due to erosion and deposition is elaborated in the next chapter on landforms and their evolution.

> There is a shift of materials in mass movements as well as in erosion from one place to the other. So, why can't both be treated as one and the same? Can there be appreciable erosion without rocks undergoing weathering?

Soil Formation

Soil and Soil Contents

You see plants growing in soils. You play in the ground and come into contact with soil. You touch and feel soil and soil your clothes while playing. Can you describe it?

A pedologist who studies soils defines soil as a collection of natural bodies on the earth's surface containing living matter and supporting or capable of supporting plants.

Soil is a dynamic medium in which many chemical, physical and biological activities go on constantly. Soil is a result of decay, it is also the medium for growth. It is a changing and developing body. It has many characteristics that fluctuate with the seasons. It may be alternatively cold and warm or dry and moist. Biological activity is slowed or stopped if the soil becomes too cold or too dry. Organic matter increases when leaves fall or grasses die. The soil chemistry, the amount of organic matter, the soil flora and fauna, the temperature and the moisture, all change with the seasons as well as with more extended periods of time. That means, soil becomes adjusted to conditions of climate, landform and vegetation and will change internally when these controlling conditions change.

Process of Soil Formation

Soil formation or pedogenesis depends first on weathering. It is this weathering mantle (depth of the weathered material) which is the basic input for soil to form. First, the weathered material or transported deposits are colonised by bacteria and other inferior plant bodies like mosses and lichens. Also, several minor organisms may take shelter within the mantle and deposits. The dead remains of organisms and plants help in humus accumulation. Minor grasses and ferns may grow; later, bushes and trees will start growing through seeds brought in by birds and wind. Plant roots penetrate down, burrowing animals bring up particles, mass of material becomes porous and sponge-like with a capacity to retain water and to permit the passage of air and finally a mature soil, a complex mixture of mineral and organic products forms.

> Is weathering solely responsible for soil formation? If not, why?

> Pedology is soil science. A pedologist is a soil-scientist.

Soil-forming Factors

Five basic factors control the formation of soils: (i) parent material; (ii) topography; (iii) climate; (iv) biological activity; (v) time. In fact soil forming factors act in union and affect the action of one another.

Parent Material

Parent material is a passive control factor in soil formation. Parent materials can be any *in-situ* or on-site weathered rock debris (residual soils) or transported deposits (transported soils). Soil formation depends upon the texture (sizes of debris) and structure (disposition of individual grains/particles of debris) as well as the mineral and chemical composition of the rock debris/deposits.

Nature and rate of weathering and depth of weathering mantle are important consideration under parent materials. There may be differences in soil over similar bedrock and dissimilar bedrocks may have similar soils above them. But when soils are very young and have not matured these show strong links with the type of parent rock. Also, in case of some limestone areas, where the weathering processes are specific and peculiar, soils will show clear relation with the parent rock.

Topography

Topography like parent materials is another passive control factor. The influence of topography is felt through the amount of exposure of a surface covered by parent materials to sunlight and the amount of surface and sub-surface drainage over and through the parent materials. Soils will be thin on steep slopes and thick over flat upland areas. Over gentle slopes where erosion is slow and percolation of water is good, soil formation is very favourable. Soils over flat areas may develop a thick layer of clay with good accumulation of organic matter giving the soil dark colour. In middle latitudes, the south facing slopes exposed to sunlight have different conditions of vegetation and soils and the north facing slopes with cool, moist conditions have some other soils and vegetation.

Climate

Climate is an important active factor in soil formation. The climatic elements involved in soil development are : (i) moisture in terms of its intensity, frequency and duration of precipitation - evaporation and humidity; (ii) temperature in terms of seasonal and diurnal variations.

Precipitation gives soil its moisture content which makes the chemical and biological activities possible. Excess of water helps in the downward transportation of soil components through the soil (eluviation) and deposits the same down below (illuviation). In climates like wet equatorial rainy areas with high rainfall, not only calcium, sodium, magnesium, potassium etc. but also a major part of silica is removed from the soil. Removal of silica from the soil is known as *desilication*. In dry climates, because of high temperature, evaporation exceeds precipitation and hence ground water is brought up to the surface by capillary action and in the process the water evaporates leaving behind salts in the soil. Such salts form into a crust in the soil known as hardpans. In tropical climates and in areas with intermediate precipitation conditions, calcium carbonate nodules (*kanker*) are formed.

Temperature acts in two ways — increasing or reducing chemical and biological activity. Chemical activity is increased in higher temperatures, reduced in cooler temperatures (with an exception of carbonation) and stops in freezing conditions. That is why, tropical soils with higher temperatures show deeper profiles and in the frozen tundra regions soils contain largely mechanically broken materials.

Biological Activity

The vegetative cover and organisms that occupy the parent materials from the beginning and also at later stages help in adding organic matter, moisture retention, nitrogen etc. Dead plants provide humus, the finely divided organic matter of the soil. Some organic acids which form during humification aid in decomposing the minerals of the soil parent materials.

Intensity of bacterial activity shows up differences between soils of cold and warm climates. Humus accumulates in cold climates as bacterial growth is slow. With undecomposed organic matter because of low bacterial activity, layers of peat develop in sub-arctic and tundra climates. In humid tropical and equatorial climates, bacterial growth and action is intense and dead vegetation is rapidly oxidised leaving very low humus content in the soil. Further, bacteria and other soil organisms take gaseous nitrogen from the air and convert it into a chemical form that can be used by plants. This process is known as nitrogen fixation. Rhizobium, a type of bacteria, lives in the root nodules of leguminous plants and fixes nitrogen beneficial to the host plant. The influence of large animals like ants, termites, earthworms, rodents etc., is mechanical, but, it is nevertheless important in soil formation as they rework the soil up and down. In case of earthworms, as they feed on soil, the texture and chemistry of the soil that comes out of their body changes.

Time

Time is the third important controlling factor in soil formation. The length of time the soil forming processes operate, determines

Is it necessary to separate the process of soil formation and the soil forming control factors?

Why are time, topography and parent material considered as passive control factors in soil formation?

maturation of soils and profile development. A soil becomes mature when all soil-forming processes act for a sufficiently long time developing a profile. Soils developing from recently deposited alluvium or glacial till are considered young and they exhibit no horizons or only poorly developed horizons. No specific length of time in absolute terms can be fixed for soils to develop and mature.

EXERCISES

1. Multiple choice questions.

   (i) Which one of the following processes is a gradational process?

   (a) Deposition (c) Volcanism

   (b) Diastrophism (d) Erosion

   (ii) Which one of the following materials is affected by hydration process?

   (a) Granite (c) Quartz

   (b) Clay (d) Salts

   (iii) Debris avalanche can be included in the category of:

   (a) Landslides (c) Rapid flow mass movements

   (b) Slow flow mass movements (d) Subsidence

2. Answer the following questions in about 30 words.

   (i) It is weathering that is responsible for bio-diversity on the earth. How?

   (ii) What are mass movements that are real rapid and perceptible? List.

   (iii) What are the various mobile and mighty exogenic geomorphic agents and what is the prime job they perform?

   (iv) Is weathering essential as a pre-requisite in the formation of soils? Why?

3. Answer the following questions in about 150 words.

   (i) "Our earth is a playfield for two opposing groups of geomorphic processes." Discuss.

   (ii) Exogenic geomorphic processes derive their ultimate energy from the sun's heat. Explain.

   (iii) Are physical and chemical weathering processes independent of each other? If not, why? Explain with examples.

   (iv) How do you distinguish between the process of soil formation and soil-forming factors? What is the role of climate and biological activity as two important control factors in the formation of soils?

Project Work

Depending upon the topography and materials around you, observe and record climate, possible weathering process and soil contents and characteristics.

CHAPTER

7

LANDFORMS AND THEIR EVOLUTION

After weathering processes have had their actions on the earth materials making up the surface of the earth, the geomorphic agents like running water, ground water, wind, glaciers, waves perform erosion. It is already known to you that erosion causes changes on the surface of the earth. Deposition follows erosion and because of deposition too, changes occur on the surface of the earth.

As this chapter deals with landforms and their evolution first start with the question, what is a landform? In simple words, small to medium tracts or parcels of the earth's surface are called landforms.

If landform is a small to medium sized part of the surface of the earth, what is a landscape?

Several related landforms together make up landscapes, (large tracts of earth's surface). Each landform has its own physical shape, size, materials and is a result of the action of certain geomorphic processes and agent(s). Actions of most of the geomorphic processes and agents are slow, and hence the results take a long time to take shape. Every landform has a beginning. Landforms once formed may change in their shape, size and nature slowly or fast due to continued action of geomorphic processes and agents.

Due to changes in climatic conditions and vertical or horizontal movements of landmasses, either the intensity of processes or the processes themselves might change leading to new modifications in the landforms. Evolution here implies stages of transformation of either a part of the earth's surface from one landform into another or transformation of individual landforms after they are once formed. That means, each and every landform has a history of development and changes through time. A landmass passes through stages of development somewhat comparable to the stages of life — youth, mature and old age.

What are the two important aspects of the evolution of landforms?

The evolutionary history of the continually changing surface of the earth is essential to be understood in order to use it effectively without disturbing its balance and diminishing its potential for the future. Geomorphology deals with the reconstruction of the history of the surface of the earth through a study of its forms, the materials of which it is made up of and the processes that shape it.

Changes on the surface of the earth owe mostly to erosion by various geomorphic agents. Of course, the process of deposition too, by covering the land surfaces and filling the basins, valleys or depressions, brings changes in the surface of the land. Deposition follows erosion and the depositional surfaces too are ultimately subjected to erosion. Running water, ground-water, glaciers, wind and waves are powerful erosional and depositional agents shaping and changing the surface of the earth aided by weathering and mass wasting processes. These geomorphic agents acting over long periods of time produce systematic changes leading to sequential development of landforms. Each geomorphic agent produces its own assemblage of landforms. Not only this, each geomorphic process and agent leave their distinct imprints on the landforms they produce. You know that most of the geomorphic processes are imperceptible functions and can only be seen and measured through their results. What are the results? These results are nothing but landforms and their characteristics. Hence, a study of landforms, will reveal to us the process and agent which has made or has been making those landforms.

> Most of the geomorphic processes are imperceptible. Cite a few processes which can be seen and a few which can't be seen.

As the geomorphic agents are capable of erosion and deposition, two sets — erosional or destructional and depositional or constructional — of landforms are produced by them. Many varieties of landforms develop by the action of each of the geomorphic agents depending upon especially the type and structure i.e. folds, faults, joints, fractures, hardness and softness, permeability and impermeability, etc. come under structure of rocks. There are some other independent controls like (i) stability of sea level; (ii) tectonic stability of landmasses; (iii) climate, which influence the evolution of landforms. Any disturbance in any of these three controlling factors can upset the systematic and sequential stages in the development and evolution of landforms.

In the following pages, under each of the geomorphic regimes i.e. running water; groundwater, glaciers, waves, and winds, first a brief discussion is presented as to how landmasses are reduced in their relief through erosion and then, development of some of the erosional and depositional landforms is dealt with.

Running Water

In humid regions, which receive heavy rainfall running water is considered the most important of the geomorphic agents in bringing about the degradation of the land surface. There are two components of running water. One is overland flow on general land surface as a sheet. Another is linear flow as streams and rivers in valleys. Most of the erosional landforms made by running water are associated with vigorous and youthful rivers flowing along gradients. With time, stream channels over steep gradients turn gentler due to continued erosion, and as a consequence, lose their velocity, facilitating active deposition. There may be depositional forms associated with streams flowing over steep slopes. But these phenomena will be on a small scale compared to those associated with rivers flowing over medium to gentle slopes. The gentler the river channels in gradient or slope, the greater is the deposition. When the stream beds turn gentler due to continued erosion, downward cutting becomes less dominant and lateral erosion of banks increases and as a consequence the hills and valleys are reduced to plains.

> Is complete reduction of relief of a high land mass possible?

Overland flow causes sheet erosion. Depending upon irregularities of the land surface, the overland flow may concentrate into narrow to wide paths. Because of the sheer friction of the column of flowing water, minor or major quantities of materials from the surface of the land are removed in the direction of flow and gradually small and narrow rills will form. These rills will gradually develop into long and wide gullies; the gullies will further deepen, widen, lengthen and unite to give rise to a network of valleys. In the early stages, down-cutting dominates during which irregularities such as waterfalls and cascades will be removed. In the middle stages, streams cut their beds slower, and lateral erosion of valley sides becomes severe. Gradually, the valley sides are reduced to lower and lower slopes. The divides between drainage basins are likewise lowered until they are almost completely flattened leaving finally, a lowland of faint relief with some low resistant remnants called *monadnocks* standing out here and there. This type of plain forming as a result of stream erosion is called a *peneplain* (an almost plain). The characteristics of each of the stages of landscapes developing in running water regimes may be summarised as follows:

Youth

Streams are few during this stage with poor integration and flow over original slopes showing shallow V-shaped valleys with no floodplains or with very narrow floodplains along trunk streams. Streams divides are broad and flat with marshes, swamp and lakes. Meanders if present develop over these broad upland surfaces. These meanders may eventually entrench themselves into the uplands. Waterfalls and rapids may exist where local hard rock bodies are exposed.

Mature

During this stage streams are plenty with good integration. The valleys are still V-shaped but deep; trunk streams are broad enough to have wider floodplains within which streams may flow in meanders confined within the valley. The flat and broad inter stream areas and swamps and marshes of youth disappear and the stream divides turn sharp. Waterfalls and rapids disappear.

Old

Smaller tributaries during old age are few with gentle gradients. Streams meander freely over vast floodplains showing natural levees, oxbow lakes, etc. Divides are broad and flat with lakes, swamps and marshes. Most of the landscape is at or slightly above sea level.

Erosional Landforms

Valleys

Valleys start as small and narrow rills; the rills will gradually develop into long and wide gullies; the gullies will further deepen, widen and lengthen to give rise to valleys. Depending upon dimensions and shape, many types of valleys like *V-shaped valley, gorge, canyon*, etc. can be recognised. A gorge is a deep valley with very steep to straight sides (Figure 7.1) and a canyon is characterised by steep step-like side slopes (Figure 7.2) and may be as deep as a gorge. A gorge is almost equal in width at its top as well as its bottom. In contrast, a canyon is wider at its top than at its bottom. In fact, a canyon is a variant of gorge. Valley types depend upon the type and structure of rocks in which they form. For example, canyons commonly form in horizontal bedded sedimentary rocks and gorges form in hard rocks.

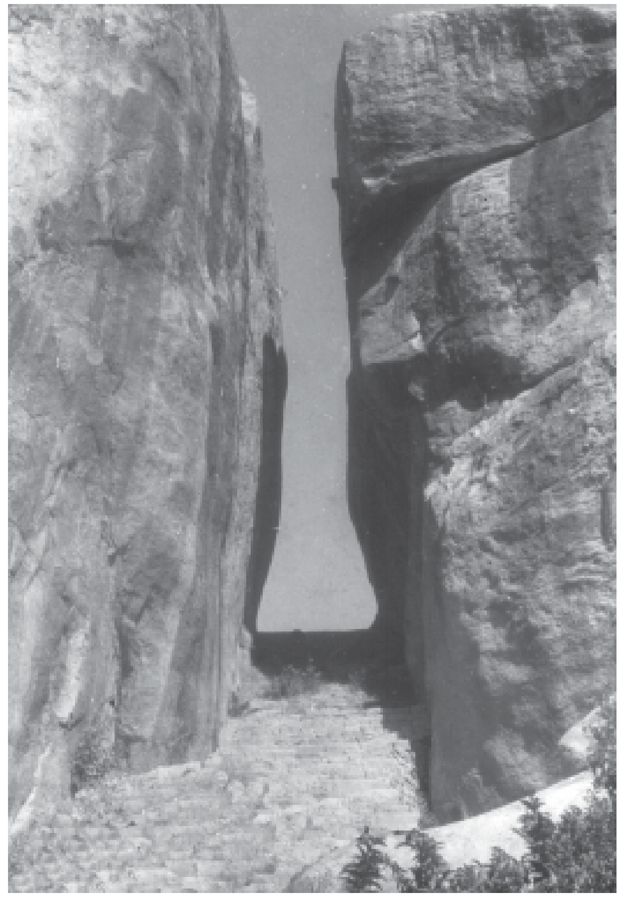

Figure 7.1 : The Valley of Kaveri river near Hogenekal, Dharmapuri district, Tamilnadu in the form of gorge

Figure 7.2 : An entrenched meander loop of river Colorado in USA showing step-like side slopes of its valley typical of a canyon

Potholes and Plunge Pools

Over the rocky beds of hill-streams more or less circular depressions called *potholes* form because of stream erosion aided by the abrasion of rock fragments. Once a small and shallow depression forms, pebbles and boulders get collected in those depressions and get rotated by flowing water and consequently the depressions grow in dimensions. A series of such depressions eventually join and the stream valley gets deepened. At the foot of waterfalls also, large potholes, quite deep and wide, form because of the sheer impact of water and rotation of boulders. Such large and deep holes at the base of waterfalls are called *plunge pools*. These pools also help in the deepening of valleys. Waterfalls are also transitory like any other landform and will recede gradually and bring the floor of the valley above waterfalls to the level below.

Incised or Entrenched Meanders

In streams that flow rapidly over steep gradients, normally erosion is concentrated on the bottom of the stream channel. Also, in the case of steep gradient streams, lateral erosion on the sides of the valleys is not much when compared to the streams flowing on low and gentle slopes. Because of active lateral erosion, streams flowing over gentle slopes, develop sinuous or meandering courses. It is common to find meandering courses over floodplains and delta plains where stream gradients are very gentle. But very deep and wide meanders can also be found cut in hard rocks. Such meanders are called *incised or entrenched meanders* (Figure 7.2). Meander loops develop over original gentle surfaces in the initial stages of development of streams and the same loops get entrenched into the rocks normally due to erosion or slow, continued uplift of the land over which they start. They widen and deepen over time and can be found as deep gorges and canyons in hard rock areas. They give an indication on the status of original land surfaces over which streams have developed.

> What are the differences between incised meanders and meanders over flood and delta plains?

River Terraces

River terraces are surfaces marking old valley floor or floodplain levels. They may be bedrock surfaces without any alluvial cover or alluvial terraces consisting of stream deposits. River terraces are basically products of erosion as they result due to vertical erosion by the stream into its own depositional floodplain. There can be a number of such terraces at different heights indicating former river bed levels. The river terraces may occur at the same elevation on either side of the rivers in which case they are called *paired terraces* (Figure 7.3).

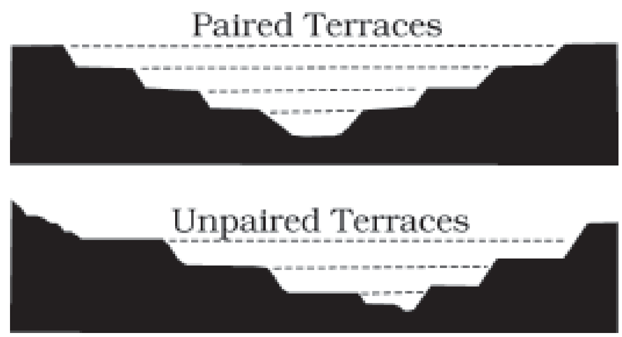

Figure 7.3 : Paired and unpaired river terraces

When a terrace is present only on one side of the stream and with none on the other side or one at quite a different elevation on the other side, the terraces are called *non-paired terraces*. Unpaired terraces are typical in areas of slow uplift of land or where the water column changes are not uniform along both the banks. The terraces may result due to (i) receding water after a peak flow; (ii) change in hydrological regime due to climatic changes; (iii) tectonic uplift of land; (iv) sea level changes in case of rivers closer to the sea.

Depositional Landforms

Alluvial Fans

Alluvial fans (Figure 7.4) are formed when streams flowing from higher levels break into foot slope plains of low gradient. Normally very coarse load is carried by streams flowing over mountain slopes. This load becomes too heavy for the streams to be carried over gentler gradients and gets dumped and spread as a broad low to high cone shaped deposit called *alluvial fan*. Usually, the streams which flow over fans are not confined to their original channels for long and shift their position across the fan forming many channels called *distributaries*. Alluvial fans in humid areas show normally low cones with gentle slope from head to toe and they appear as high cones with steep slope in arid and semi-arid climates.

Figure 7.4 : An alluvial fan deposited by a hill stream on the way to Amarnath, Jammu and Kashmir

Deltas

Deltas are like alluvial fans but develop at a different location. The load carried by the rivers is dumped and spread into the sea. If this load is not carried away far into the sea or distributed along the coast, it spreads and accumulates as a low cone. Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest materials settle out first and the finer fractions like silts and clays are carried out into the sea. As the delta grows, the river distributaries continue to increase in length (Figure 7.5) and delta continues to build up into the sea.

Figure 7.5 : A satellite view of part of Krishna river delta, Andhra Pradesh

Floodplains, Natural Levees and Point Bars

Deposition develops a floodplain just as erosion makes valleys. Floodplain is a major landform of river deposition. Large sized materials are deposited first when stream channel breaks into a gentle slope. Thus, normally, fine sized materials like sand, silt and clay are carried by relatively slow moving waters in gentler channels usually found in the plains and deposited over the bed and when the waters spill over the banks during flooding above the bed. A river bed made of river deposits is the active floodplain. The floodplain above the bank is inactive floodplain. Inactive floodplain above the banks basically contain two types of deposits — flood deposits and channel deposits. In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually. Such areas over flood plains built up by abandoned or cut-off channels contain coarse deposits. The flood deposits of spilled waters carry relatively finer materials like silt and clay. The flood plains in a delta are called *delta plains*.

Natural levees and point bars (Figure 7.6) are some of the important landforms found associated with floodplains. *Natural levees* are found along the banks of large rivers. They are low, linear and parallel ridges of coarse deposits along the banks of rivers, quite often cut into individual mounds. During flooding as the water spills over the bank, the velocity of the water comes down and large sized and high specific gravity materials get dumped in the immediate vicinity of the bank as ridges. They are high nearer the banks and slope gently away from the river. The levee deposits are coarser than the deposits spread by flood waters away from the river. When rivers shift laterally, a series of natural levees can form.

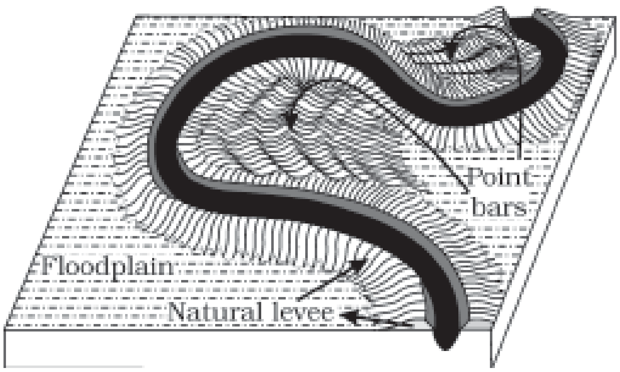

Figure 7.6 : Natural levee and point bars

Point bars are also known as *meander bars*. They are found on the convex side of meanders of large rivers and are sediments deposited in a linear fashion by flowing waters along the bank. They are almost uniform in profile and in width and contain mixed sizes of sediments. If there more than one ridge, narrow and elongated depressions are found in between the point bars. Rivers build a series of them depending upon the water flow and supply of sediment. As the rivers build the point bars on the convex side, the bank on the concave side will erode actively.

In what way do natural levees differ from point bars?

Meanders

In large flood and delta plains, rivers rarely flow in straight courses. Loop-like channel patterns called *meanders* develop over flood and delta plains (Figure 7.7).

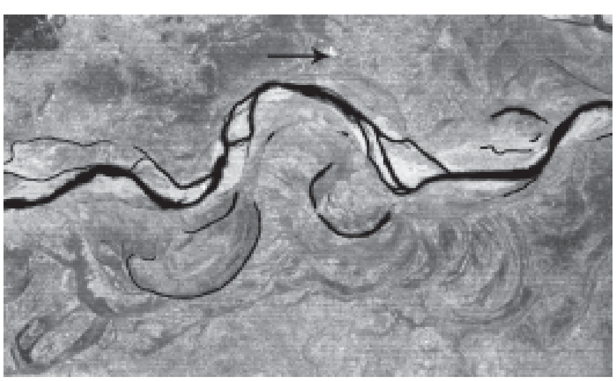

Figure 7.7 : A satellite scene showing meandering Burhi Gandak river near Muzaffarpur, Bihar, showing a number of oxbow lakes and cut-offs

Meander is not a landform but is only a type of channel pattern. This is because of (i) propensity of water flowing over very gentle gradients to work laterally on the banks; (ii) unconsolidated nature of alluvial deposits making up the banks with many irregularities which can be used by water exerting pressure laterally; (iii) coriolis force acting on the fluid water deflecting it like it deflects the wind. When the gradient of the channel becomes extremely low, water flows leisurely and starts working laterally. Slight irregularities along the banks slowly get transformed into a small curvature in the banks; the curvature deepens due to deposition on the inside of the curve and erosion along the bank on the outside. If there is no deposition and no erosion or undercutting, the tendency to meander is reduced. Normally, in meanders of large rivers, there is active deposition along the convex bank and undercutting along the concave bank.

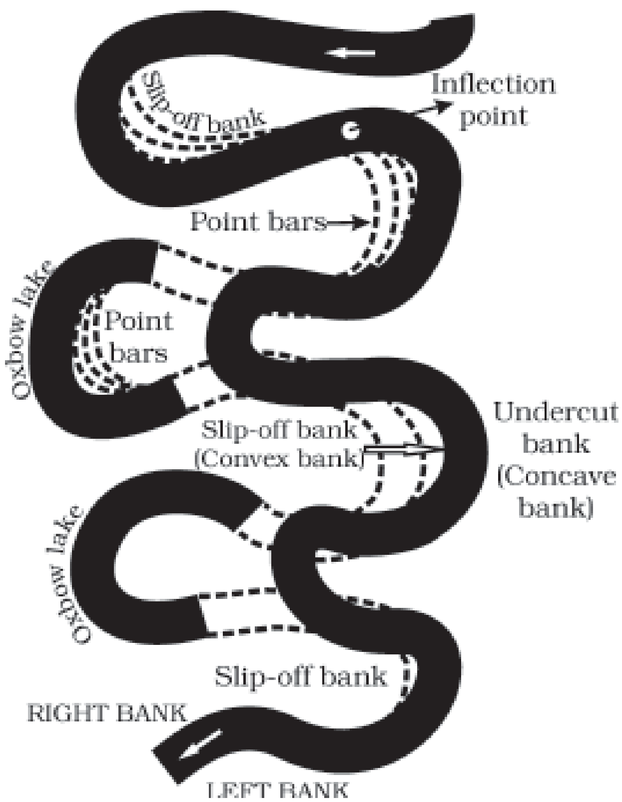

Figure 7.8 : Meander growth and cut-off loops and slip-off and undercut banks

The concave bank is known as cut-off bank which shows up as a steep scarp and the convex bank presents a long, gentle profile and is known as slip-off bank (Figure 7.8). As meanders grow into deep loops, the same may get cut-off due to erosion at the inflection points and are left as *ox-bow lakes*.

Braided Channels

When rivers carry coarse material, there can be selective deposition of coarser materials causing formation of a central bar which diverts the flow towards the banks; and this flow increases lateral erosion on the banks. As the valley widens, the water column is reduced and more and more materials get deposited as islands and lateral bars developing a number of separate channels of water flow. Deposition and lateral erosion of banks are essential for the formation of braided pattern. Or, alternatively, when discharge is less and load is more in the valley, channel bars and islands of sand, gravel and pebbles develop on the floor of the channel and the water flow is divided into multiple threads. These thread-like streams of water rejoin and subdivide repeatedly to give a typical braided pattern (Figure 7.9).

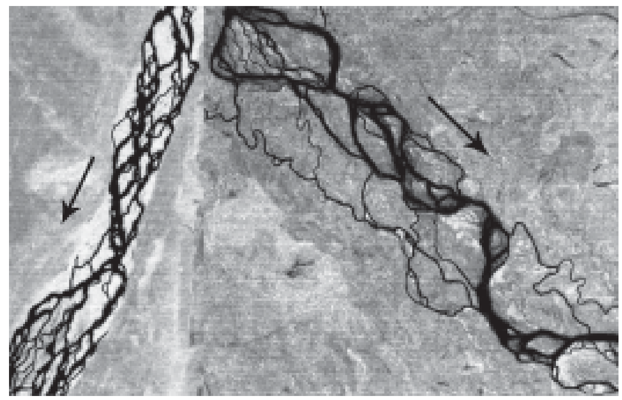

Figure 7.9 : Satellite scenes showing braided channel segments of Gandak (left) and Son (right) rivers Arrows show the direction of flow

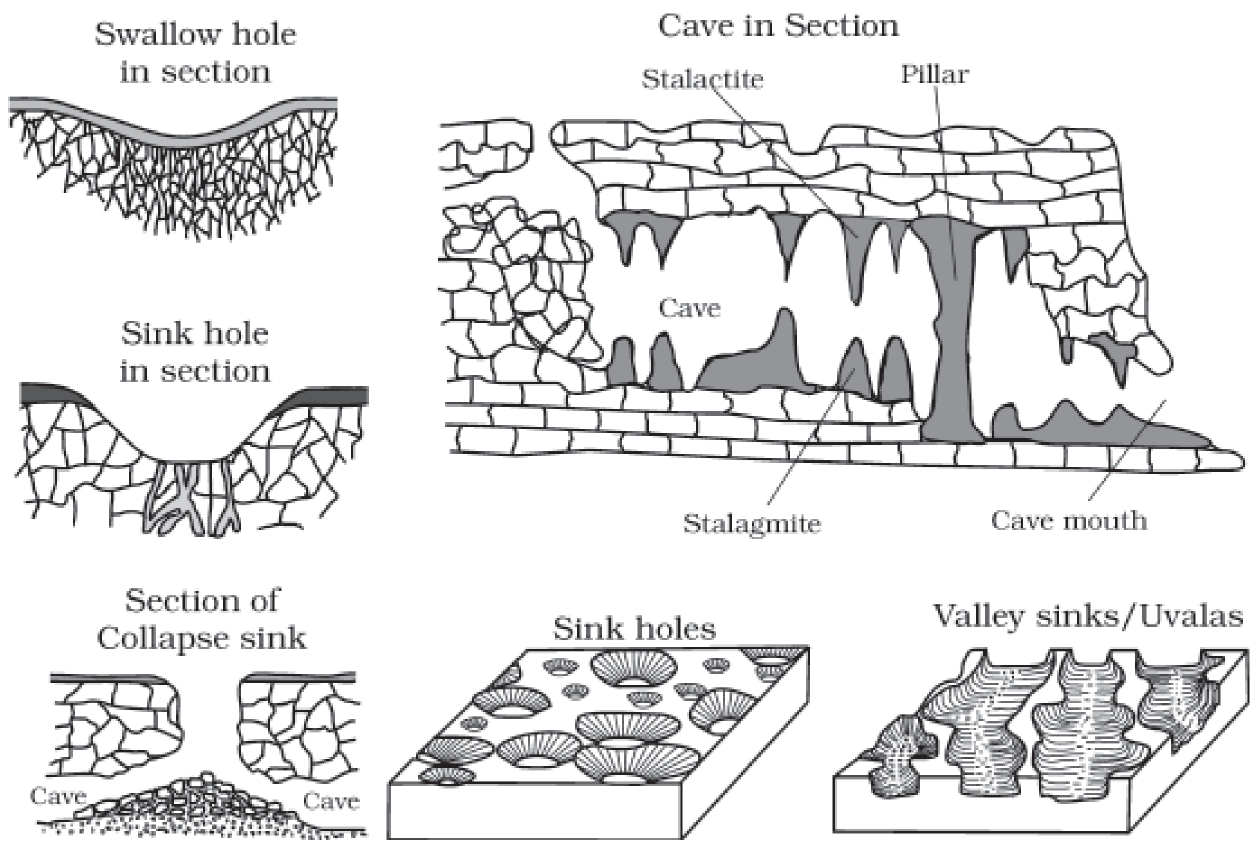

Figure 7.10 : Various karst features

GROUNDWATER

Here the interest is not on groundwater as a resource. Our focus is on the work of groundwater in the erosion of landmasses and evolution of landforms. The surface water percolates well when the rocks are permeable, thinly bedded and highly jointed and cracked. After vertically going down to some depth, the water under the ground flows horizontally through the bedding planes, joints or through the materials themselves. It is this downward and horizontal movement of water which causes the rocks to erode. Physical or mechanical removal of materials by moving groundwater is insignificant in developing landforms. That is why, the results of the work of groundwater cannot be seen in all types of rocks. But in rocks like limestones or dolomites rich in calcium carbonate, the surface water as well as groundwater through the chemical process of solution and precipitation deposition develop varieties of landforms. These two processes of solution and precipitation are active in limestones or dolomites occurring either exclusively or interbedded with other rocks. Any limestone or dolomitic region showing typical landforms produced by the action of groundwater through the processes of solution and deposition is called *Karst topography* after the typical topography developed in limestone rocks of Karst region in the Balkans adjacent to Adriatic sea.

The karst topography is also characterised by erosional and depositional landforms.

EROSIONAL LANDFORMS

Pools, Sinkholes, Lapies and Limestone Pavements

Small to medium sized round to sub-rounded shallow depressions called *swallow holes* form on the surface of limestones through solution. Sinkholes are very common in limestone/karst areas. *A sinkhole* is an opening more or less circular at the top and funnel-shapped towards the bottom with sizes varying in area from a few sq. m to a hectare and with depth from a less than half a metre to thirty metres or more. Some of these form solely through solution action (solution sinks) and others might start as solution forms first and if the bottom of a sinkhole forms the roof of a void or cave underground, it might collapse leaving a large hole opening into a cave or a void below (collapse sinks). Quite often, sinkholes are covered up with soil mantle and appear as shallow water pools. Anybody stepping over such pools would go down like it happens in quicksands in deserts. The term *doline* is sometimes used to refer the collapse sinks. Solution sinks are more common than collapse sinks. Quite often the surface run-off simply goes down swallow and sink holes and flow as underground streams and re-emerge at a distance downstream through a cave opening. When sink holes and dolines join together because of slumping of materials along their margins or due to roof collapse of caves, long, narrow to wide trenches called *valley sinks* or *Uvalas* form. Gradually, most of the surface of the limestone is eaten away by these pits and trenches, leaving it extremely irregular with a maze of points, grooves and *ridges* or *lapies*. Especially, these ridges or lapies form due to differential solution activity along parallel to sub-parallel joints. The lapie field may eventually turn into somewhat smooth *limestone pavements*.

Caves

In areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between or in areas where limestones are dense, massive and occurring as thick beds, cave formation is prominent. Water percolates down either through the materials or through cracks and joints and moves horizontally along bedding planes. It is along these bedding planes that the limestone dissolves and long and narrow to wide gaps called *caves* result. There can be a maze of caves at different elevations depending upon the limestone beds and intervening rocks. Caves normally have an opening through which cave streams are discharged. Caves having openings at both the ends are called tunnels.

Depositional Landforms

Many depositional forms develop within the limestone caves. The chief chemical in limestone is calcium carbonate which is easily soluble in carbonated water (carbon dioxide absorbed rainwater). This calcium carbonate is deposited when the water carrying it in solution evaporates or loses its carbon dioxide as it trickles over rough rock surfaces.

Stalactites, Stalagmites and Pillars

Stalactites hang as icicles of different diameters. Normally they are broad at their bases and taper towards the free ends showing up in a variety of forms. *Stalagmites* rise up from the floor of the caves. In fact, stalagmites form due to dripping water from the surface or through the thin pipe, of the stalactite, immediately below it (Figure 7.11).

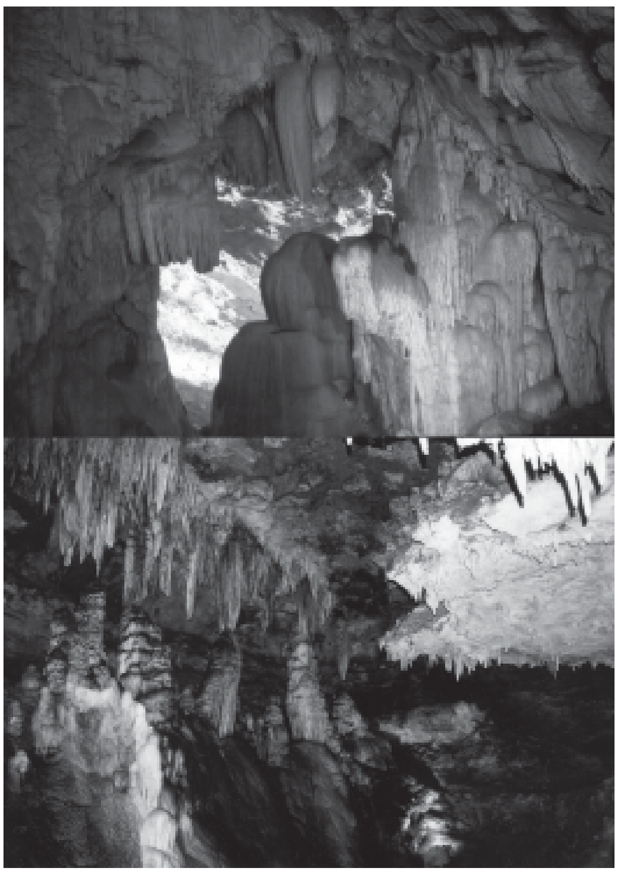

Figure 7.11 : Stalactites and stalagmites in a limestone cave

Stalagmites may take the shape of a column, a disc, with either a smooth, rounded bulging end or a miniature crater like depression. The stalagmite and stalactites eventually fuse to give rise to *columns and pillars* of different diameters.

Glaciers

Masses of ice moving as sheets over the land (continental glacier or pidmont glacier if a vast sheet of ice is spread over the plains at the foot of mountains) or as linear flows down the slopes of mountains in broad trough-like valleys (mountain and valley glaciers) are called *glaciers* (Figure 7.12). The movement of glaciers

Figure 7.12 : A glacier in its valley

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.

> We have many glaciers in our country moving down the slopes and valleys in Himalayas. Higher reaches of Uttaranchal, Himachal Pradesh and Jammu and Kashmir, are places to see some of them. Do you know where one can see river Bhagirathi is basically fed by meltwaters from under the snout (Gaumukh) of the Gangotri glacier. In fact, Alkapuri glacier feeds waters to Alakananda river. Rivers Alkananda and Bhagirathi join to make river Ganga near Deoprayag.

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.

As glaciers continue to move, debris gets removed, divides get lowered and eventually the slope is reduced to such an extent that glaciers will stop moving leaving only a mass of low hills and vast outwash plains along with other depositional features. Figures 7.13 and 7.14 show various glacial erosional and depositional forms described in the text.

EROSIONAL LANDFORMS

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 can be two or more cirques one leading into another down below in a stepped sequence.

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 side walls 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 zig-zag outline.

> The highest peak in the Alps, Matterhorn and the highest peak in the Himalayas, Everest are in fact horns formed through headward erosion of radiating cirques.

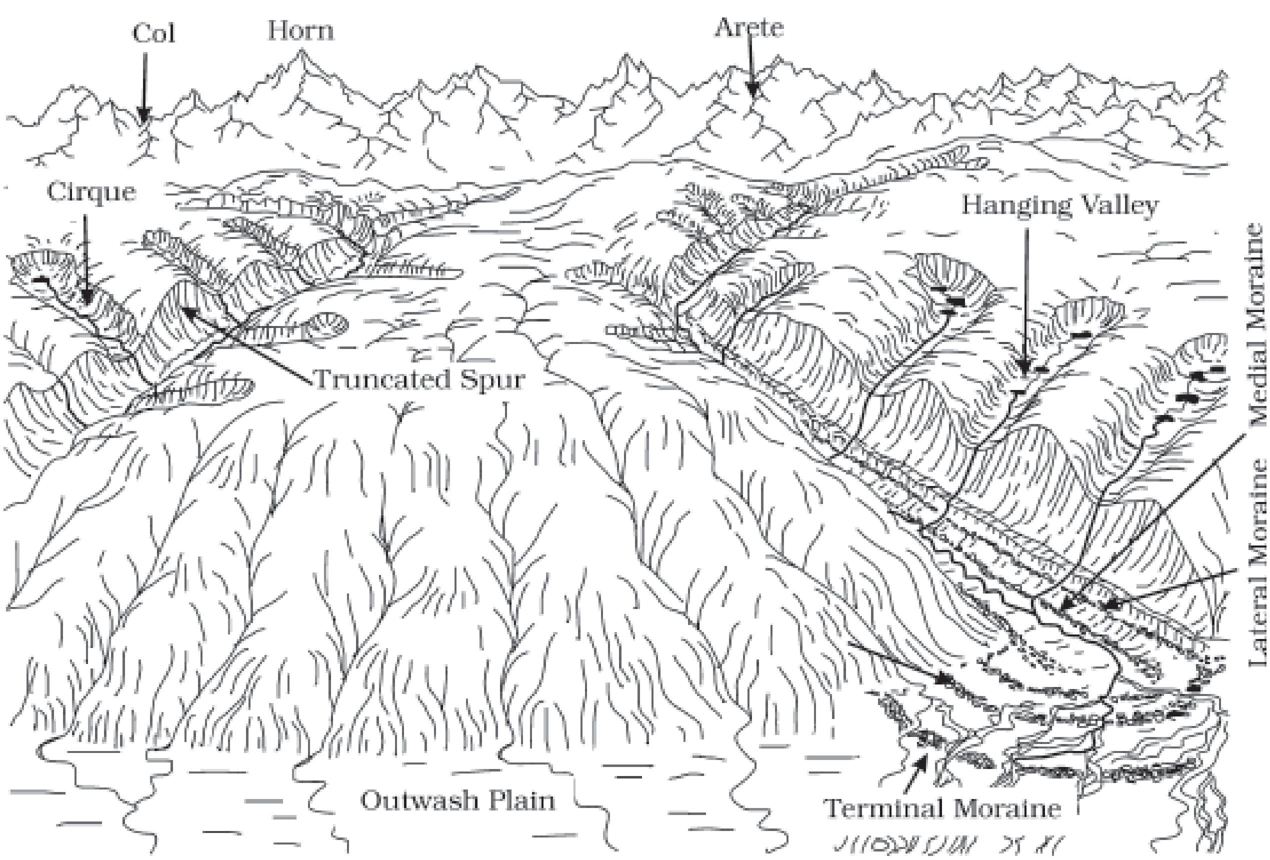

Figure 7.13 : Some glacial erosional and depositional forms (adapted and modified from Spencer, 1962)

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*.

> What are the basic differences between glacial valleys and river valleys?

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 7.14 shows a few depositional landforms commonly found in glaciated areas.

Moraines

They are long ridges of deposits of glacial till. Terminal moraines are long ridges of debris deposited at the end (toe) of the glaciers. *Lateral moraines* form along the sides parallel to the glacial valleys. The lateral moraines may join a terminal moraine forming a horse-shoe shaped ridge. There can be many lateral moraines on either side in a glacial valley. These moraines partly or fully owe their origin to glacio-fluvial waters pushing up materials to the sides of glaciers. Many valley glaciers retreating rapidly leave an irregular sheet of till over their valley floors. Such deposits varying greatly in thickness and in surface topography are called *ground moraines*. The moraine in the centre of the

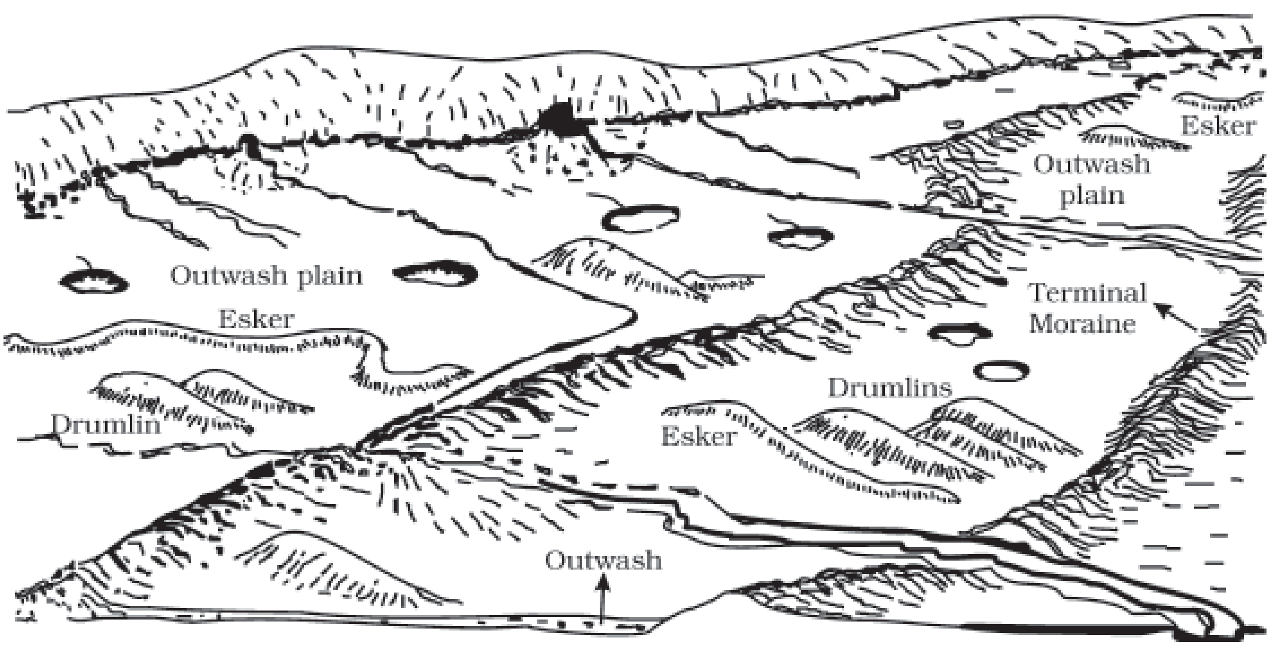

Figure 7.14 : A panoramic diagram of glacial landscape with various depositional landforms (adapted and modified from Spencer, 1962)

glacial valley flanked by lateral moraines is called *medial moraine*. They are imperfectly formed as compared to lateral moraines. Sometimes medial moraines are indistinguishable from ground moraines.

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.

> Distinguish between river alluvial plains and glacial outwash plains.

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.

> What is the difference between till and alluvium?

Waves and Currents

Coastal processes are the most dynamic and hence most destructive. So, don't you think it is important to know about the coastal processes and forms?

Some of the changes along the coasts take place very fast. At one place, there can be erosion in one season and deposition in another. Most of the changes along the coasts are accomplished by waves. When waves break, the water is thrown with great force onto the shore, and simultaneously, there is a great churning of sediments on the sea bottom. Constant impact of breaking waves drastically affects the coasts. Storm waves and tsunami waves can cause far-reaching changes in a short period of time than normal breaking waves. As wave environment changes, the intensity of the force of breaking waves changes.

> Do you know about the generating forces behind waves and currents? If not, refer to the chapter on movements in ocean waters.

Other than the action of waves, the coastal landforms depend upon (i) the configuration of land and sea floor; (ii) whether the coast is advancing (emerging) seaward or retreating (submerging) landward. Assuming sea level to be constant, two types of coasts are considered to explain the concept of evolution of coastal landforms: (i) high, rocky coasts (submerged coasts); (ii) low, smooth and gently sloping sedimentary coasts (emerged coasts).

High Rocky Coasts

Along the high rocky coasts, the rivers appear to have been drowned with highly irregular coastline. The coastline appears highly indented with extension of water into the land where glacial valleys *(fjords)* are present. The hill sides drop off sharply into the water. Shores do not show any depositional landforms initially. Erosion features dominate.

Along high rocky coasts, waves break with great force against the land shaping the hill sides into cliffs. With constant pounding by waves, the cliffs recede leaving a *wave-cut platform* in front of the sea cliff. Waves gradually minimise the irregularities along the shore.

The materials which fall off, and removed from the sea cliffs, gradually break into smaller fragments and roll to roundness, will get deposited in the offshore. After a considerable period of cliff development and retreat when coastline turns somewhat smooth, with the addition of some more material to this deposit in the offshore, a wave-built terrace would develop in front of wave-cut terrace. As the erosion along the coast takes place a good supply material becomes available to longshore currents and waves to deposit them as beaches along the shore and as bars (long ridges of sand and/or shingle parallel to the coast) in the nearshore zone. Bars are submerged features and when bars show up above water, they are called *barrier bars*. Barrier bar which get keyed up to the headland of a bay is called a *spit*. When barrier bars and spits form at the mouth of a bay and block it, a *lagoon* forms. The lagoons would gradually get filled up by sediments from the land giving rise to a coastal plain.

Low Sedimentary Coasts

Along low sedimentary coasts the rivers appear to extend their length by building coastal plains and deltas. The coastline appears smooth with occasional incursions of water in the form of *lagoons and tidal creeks*. The land slopes gently into the water. Marshes and swamps may abound along the coasts. Depositional features dominate.

When waves break over a gently sloping sedimentary coast, the bottom sediments get churned and move readily building *bars, barrier bars, spits and lagoons*. Lagoons would eventually turn into a swamp which would subsequently turn into a coastal plain. The maintenance of these depositional features depends upon the steady supply of materials. Storm and tsunami waves cause drastic changes irrespective of supply of sediments. Large rivers which bring lots of sediments build deltas along low sedimentary coasts.

The west coast of our country is a high rocky retreating coast. Erosional forms dominate in the west coast. The east coast of India is a low sedimentary coast. Depositional forms dominate in the east coast.

What are the various differences between a high rocky coast and a low sedimentary coast in terms of processes and landforms?

Erosional Landforms

Cliffs, Terraces, Caves and Stacks

Wave-cut cliffs and terraces are two forms usually found where erosion is the dominant shore process. Almost all sea cliffs are steep and may range from a few m to 30 m or even more. At the foot of such cliffs there may be a flat or gently sloping platform covered by rock debris derived from the sea cliff behind. Such platforms occurring at elevations above the average height of waves is called a *wave-cut terrace*. The lashing of waves against the base of the cliff and the rock debris that gets smashed against the cliff along with lashing waves create hollows and these hollows get widened and deepened to form *sea caves*. The roofs of caves collapse and the sea cliffs recede further inland. Retreat of the cliff may leave some remnants of rock standing isolated as small islands just off the shore. Such resistant masses of rock, originally parts of a cliff or hill are called *sea stacks*. Like all other features, sea stacks are also temporary and eventually coastal hills and cliffs will disappear because of wave erosion giving rise to narrow coastal plains, and with onrush of deposits from over the land behind may get covered up by alluvium or may get covered up by shingle or sand to form a wide beach.

DEPOSITIONAL LANDFORMS

Beaches and Dunes

Beaches are characteristic of shorelines that are dominated by deposition, but may occur as patches along even the rugged shores. Most of the sediment making up the beaches comes from land carried by the streams and rivers or from wave erosion. Beaches are temporary features. The sandy beach which appears so permanent may be reduced to a very narrow strip of coarse pebbles in some other season. Most of the beaches are made up of sand sized materials. Beaches called shingle beaches contain excessively small pebbles and even cobbles.

Just behind the beach, the sands lifted and winnowed from over the beach surfaces will be deposited as sand dunes. Sand dunes forming long ridges parallel to the coastline are very common along low sedimentary coasts.

Bars, Barriers and Spits

A ridge of sand and shingle formed in the sea in the off-shore zone (from the position of low tide waterline to seaward) lying approximately parallel to the coast is called an *off-shore bar*. An off-shore bar which is exposed due to further addition of sand is termed a *barrier bar*. The off-shore bars and barriers commonly form across the mouth of a river or at the entrance of a bay. Sometimes such barrier bars get keyed up to one end of the bay when they are called *spits* (Figure 7.15). Spits may also develop attached to headlands/hills. The barriers, bars and spits at the mouth of the bay gradually extend leaving only a small opening of the bay into the sea and the bay will eventually develop into a lagoon. The lagoons get filled up gradually by sediment coming from the land or from the beach itself (aided by wind) and a broad and wide coastal plain may develop replacing a lagoon.

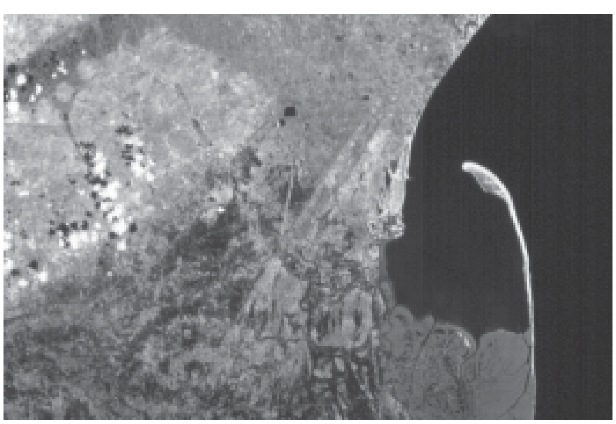

Figure 7.15 : A satellite picture of a part of Godavari river delta showing a spit

> Do you know, the coastal off-shore bars offer the first buffer or defence against storm or tsunami by absorbing most of their destructive force. Then come the barriers, beaches, beach dunes and mangroves, if any, to absorb the destructive force of storm and tsunami waves. So, if we do anything which disturbs the 'sediment budget' and the mangroves along the coast, these coastal forms will get eroded away leaving human habitations to bear first strike of storm and tsunami waves.

WINDS

Wind is one of the two dominant agents in hot deserts. The desert floors get heated up too much and too quickly because of being dry and barren. The heated floors heat up the air directly above them and result in upward movements in the hot lighter air with turbulence, and any obstructions in its path sets up eddies, whirlwinds, updrafts and downdrafts. Winds also move along the desert floors with great speed and the obstructions in their path create turbulence. Of course, there are storm winds which are very destructive. Winds cause deflation, abrasion and impact. Deflation includes lifting and removal of dust and smaller particles from the surface of rocks. In the transportation process sand and silt act as effective tools to abrade the land surface. The impact is simply sheer force of momentum which occurs when sand is blown into or against a rock surface. It is similar to sand-blasting operation. The wind action creates a number of interesting erosional and depositional features in the deserts.

In fact, many features of deserts owe their formation to mass wasting and running water as sheet floods. Though rain is scarce in deserts, it comes down torrentially in a short period of time. The desert rocks devoid of vegetation, exposed to mechanical and chemical weathering processes due to drastic diurnal temperature changes, decay faster and the torrential rains help in removing the weathered materials easily. That means, the weathered debris in deserts is moved by not only wind but also by rain/sheet wash. The wind moves fine materials and general mass erosion is accomplished mainly through sheet floods or sheet wash. Stream channels in desert areas are broad, smooth and indefinite and flow for a brief time after rains.

Erosional Landforms

Pediments and Pediplains

Landscape evolution in deserts is primarily concerned with the formation and extension of pediments. Gently inclined rocky floors close to the mountains at their foot with or without a thin cover of debris, are called *pediments*. Such rocky floors form through the erosion of mountain front through a combination of lateral erosion by streams and sheet flooding.

Erosion starts along the steep margins of the landmass or the steep sides of the tectonically controlled steep incision features over the landmass. Once, pediments are formed with a steep wash slope followed by cliff or free face above it, the steep wash slope and free face retreat backwards. This method of erosion is termed as parallel retreat of slopes through backwasting. So, through parallel retreat of slopes, the pediments extend backwards at the expense of mountain front, and gradually, the mountain gets reduced leaving an *inselberg* which is a remnant of the mountain. That's how the high relief in desert areas is reduced to low featureless plains called *pediplains*.

Playas

Plains are by far the most prominent landforms in the deserts. In basins with mountains and hills around and along, the drainage is towards the centre of the basin and due to gradual deposition of sediment from basin margins, a nearly level plain forms at the centre of the basin. In times of sufficient water, this plain is covered up by a shallow water body. Such types of shallow lakes are called as *playas* where water is retained only for short duration due to evaporation and quite often the playas contain good deposition of salts. The playa plain covered up by salts is called *alkali flats*.

Deflation Hollows and Caves

Weathered mantle from over the rocks or bare soil, gets blown out by persistent movement of wind currents in one direction. This process may create shallow depressions called *deflation hollows*. Deflation also creates numerous small pits or cavities over rock surfaces. The rock faces suffer impact and abrasion of wind-borne sand and first shallow depressions called blow outs are created, and some of the *blow outs* become deeper and wider fit to be called *caves*.

Mushroom, Table and Pedestal Rocks

Many rock-outcrops in the deserts easily susceptible to wind deflation and abrasion are worn out quickly leaving some remnants of resistant rocks polished beautifully in the shape of mushroom with a slender stalk and a broad and rounded pear shaped cap above. Sometimes, the top surface is broad like a table top and quite often, the remnants stand out like pedestals.

> List the erosional features carved out by wind action and action of sheet floods.

Depositional Landforms

Wind is a good sorting agent. Depending upon the velocity of wind, different sizes of grains are moved along the floors by rolling or saltation and carried in suspension and in this process of transportation itself, the materials get sorted. When the wind slows or begins to die down, depending upon sizes of grains and their critical velocities, the grains will begin to settle. So, in depositional landforms made by wind, good sorting of grains can be found. Since wind is there everywhere and wherever there is good source of sand and with constant wind directions, depositional features in arid regions can develop anywhere.

Sand Dunes

Dry hot deserts are good places for sand dune formation. Obstacles to initiate dune formation are equally important. There can be a great variety of dune forms (Figure 7.16).

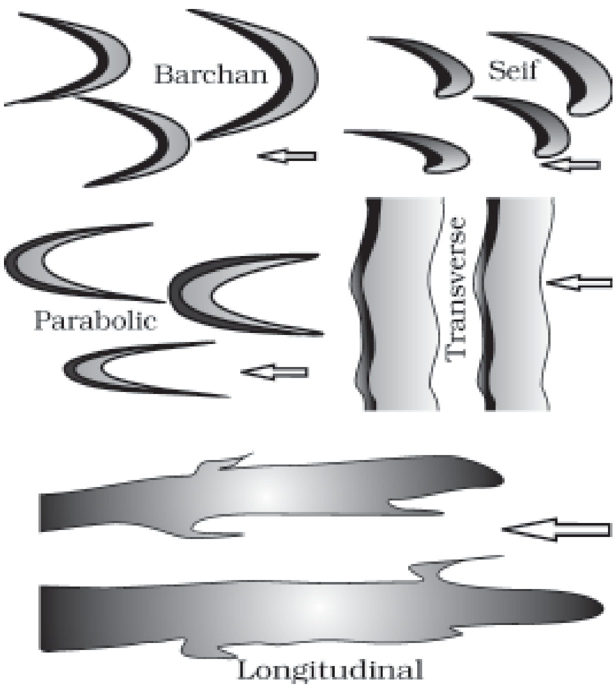

Figure 7.16 : Various types of sand dunes
Arrows indicate wind direction

Barchans

Crescent shaped dunes called *barchans* with the points or wings directed away from wind direction i.e., downwind, form where the wind direction is constant and moderate and where the original surface over which sand is moving is almost uniform. *Parabolic dunes* form when sandy surfaces are partially covered with vegetation. That means parabolic dunes are reversed barchans with wind direction being the same. *Seif* is similar to barchan with a small difference. Seif has only one wing or point. This happens when there is shift in wind conditions. The lone wings of seifs can grow very long and high. Longitudinal dunes form when supply of sand is poor and wind direction is constant. They appear as long ridges of considerable length but low in height. *Transverse dunes* are aligned perpendicular to wind direction. These dunes form when the wind direction is constant and the source of sand is an elongated feature at right angles to the wind direction. They may be very long and low in height. When sand is plenty, quite often, the regular shaped dunes coalesce and lose their individual characteristics. Most of the dunes in the deserts shift and a few of them will get stabilised especially near human habitations.

EXERCISES

1. Multiple choice questions.

   (i) In which of the following stages of landform development, downward cutting is dominated?

   (a) Youth stage (c) Early mature stage
   (b) Late mature stage (d) Old stage

   (ii) A deep valley characterised by steep step-like side slopes is known as

   (a) U-shaped valley (c) Blind valley
   (b) Gorge (d) Canyon

   (iii) In which one of the following regions the chemical weathering process is more dominant than the mechanical process?

   (a) Humid region (c) Arid region
   (b) Limestone region (d) Glacier region

(iv) Which one of the following sentences best defines the term ‘Lapies’?

(a) A small to medium sized shallow depression

(b) A landform whose opening is more or less circular at the top and funnel shaped towards bottom

(c) A landform forms due to dripping water from surface

(d) An irregular surface with sharp pinnacles, grooves and ridges

(v) A deep, long and wide trough or basin with very steep concave high walls at its head as well as in sides is known as:

(a) Cirque (c) Lateral Moraine

(b) Glacial valley (d) Esker

2. Answer the following questions in about 30 words.

(i) What do incised meanders in rocks and meanders in plains of alluvium indicate?

(ii) Explain the evolution of valley sinks or uvalas.

(iii) Underground flow of water is more common than surface run-off in limestone areas. Why?

(iv) Glacial valleys show up many linear depositional forms. Give their locations and names.

(v) How does wind perform its task in desert areas? Is it the only agent responsible for the erosional features in the deserts?

3. Answer the following questions in about 150 words.

(i) Running water is by far the most dominating geomorphic agent in shaping the earth’s surface in humid as well as in arid climates. Explain.

(ii) Limestones behave differently in humid and arid climates. Why? What is the dominant and almost exclusive geomorphic process in limestone areas and what are its results?

(iii) How do glaciers accomplish the work of reducing high mountains into low hills and plains?

Project Work

Identify the landforms, materials and processes around your area.