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# *The External Geological Forces Causing Erosion of the Earth's Crust*

## 5.1. The External and Internal Geological Forces, Causing Erosion of the Earth's Crust

The rock surface of the continents of the Earth, on which we are living, is undergoing constant and continuous destruction, a process called '*denundation*'. This rock surface is broken into fragments by *weathering,** and by erosion, which is defined as the *destructive mechanisms caused by the agents of transportation.* The erosion caused by the agents of erosion or transportation such as *water, ice* and *wind* is widely exhibited on the Earth's surface, in the form of resultant landscapes, such as, formation of gullies on hillsides, landslides, continuous wearing down of the continent's surface, etc. It has been estimated that if the present rate of erosion continues, then theoretically, the entire topography will be removed in about 12 million years. But in practice, we know that our Earth is about 4 to 5 billion years old, and even in this long time, the topography has not been removed, though undergone a lot of changes. The reason being that there is *something* which is counter-balancing the erosive work of water and other agents of erosion. This *some thing* must be uplifting the continents ; and this is done by what are known as *internal forces***. Some familiar demonstrations of the internal forces *which cause uplift,* are *earthquakes,**** *volcanoes*, etc. This etc. is important and may include all those internal forces (called **orogenic forces**), which are still not very well known, and may cause the formation of *fold mountains* (*i.e.* mountains found to contain folded sedimentary rocks), which must had originally been formed as flat beds or below sea level. *There is thus, infact, a battle going on between the internal forces causing uplift of the Earth's crust, and*

*Discussed in the previous chapter under article 4.13.

**Will be discussed in details in chapter 6.

***Precisely speaking, earthquakes may also cause erosion by loosening the rocks.

*the external forces causing erosion and down levelling of the uplifted Earth's crust segments to sea level.* Both these internal and external forces are, infact, going on together, and are studied under "Physical Geology". We will discuss both these types of forces separately in our separate chapters. In this chapter, therefore, we are confining ourselves to the effects of external forces (*i.e.* erosion) alone ; and internal forces shall be dealt in the next chapter.

### 5.2. Agents of Erosion

As pointed out above, the erosion is caused mainly by the three agents : *viz* :

1. Water ;
2. Wind ; and
3. Ice.

The fourth agent which helps is 'gravity'.

Out of these three agents, the first agent *i.e.*, water is the most important, and is responsible for the maximum havoc it creates in the form of erosional damages to the land surface. It may act in three forms, *i.e.* as *falling rain drops, running overland flow*, and as *running rivers and streams.*

The erosion caused by water is generally quite devastating, and may create various engineering problems, if not properly checked or accounted for, while planning the engineering projects. Infact, in the past, and especially here in our India, all our efforts were based on controlling water erosion ; and the other types of erosion *i.e.*, wind and ice erosion were not paid much attention to. That is why, we are now starting to feel the evil effects of wind erosion in the form of extending deserts. The third agent of erosion *i.e. ice* or *glaciers* may also cause a lot of erosional damages, although it becomes slightly less important in a tropical country like India. All these three types of erosions will now be discussed in details in the following pages.

## WATER EROSION AND GEOLOGICAL WORK OF WATER

As pointed out earlier, water is a very important agent of erosion, and acts in two ways ; *i.e.*, firstly it itself acts as a wethering agent, and secondly, it acts as a transporting agent for transporting not only the material weathered by other weathering agents like atmospheric gases, frost, heat, gravity, organisms, etc ; but also the material denundated by itself. The effects of water erosion can be well discussed under the following headings :

(1) Erosion caused by *falling rains.*

(2) *Downslope movement* of the denundated or weathered materials, called *mass wasting.*

(3) Erosion caused by *Rivers and Streams,* and their other geological works, including the transportation and deposition of the weathered material, received as over-burden.

All these effects are discussed below :

## 5.3. Erosion Caused by the Falling Rains

Our ancestors used to believe that water erodes the *soil, only* when if flows over the surface in the form of surface run off. But today, this idea has been proved to be almost wrong, because the investigations have shown that a major part of the erosional damage done by water is infact due to the impact of the falling rain drops. The erosion capacity of surface run off is very small, and it acts only as a partner.

Water causes erosion by detaching the soil particles, and then transporting them usually downhill. This can happen on any area, where there is a natural precipitation or where water is applied artificially. *This erosive action of the water has been found to be most destructive at the places where the natural vegetative covers have been removed, and the bare land surfaces are exposed to the direct action of the storms.*

The water erosion process starts as soon as a rain starts, and the falling rain erodes the surface material in two ways. Firstly, there is the impact caused by the falling rain drop on the soil, on which it falls like a bomb. The energy of the falling water is applied from above, and is utilised in detaching the soil particles. The loosened or detached material is separated and splashed into the air, in all 360° directions. This is called *splash-erosion* process. It may also be mentioned here that under this process, the amount of material eroded from a hilly land will always be more than that from a flat land. This is because, when the rain falls over a flat area, the incoming splash balances the outgoing splash ; while when the rain strikes the sloping land surfaces, a major proportion of splash moves downhill. *Hence, relatively larger quantities of material will be eroded when the land surface is sloping than when it is flatter.*

*Secondly,* the rain water that does not percolate to the under ground, will flow as run off, and will cause erosion in the same manner as water causes erosion in a river. The erosion caused in this fashion by the run off will largely depend upon the slope of the land surface, and the nature and extent of vegetative covers. Hence, a lot of erosion will be produced in this way, if the land area is hilly with steep slopes, and where vegetative covers have been removed by fires or by the activities of man.

## 5.4. Downslope Movement of Weathered Material

All the material that is dislodged from the Earth's crust by weathering or in any other manner, tends to move downslope under the influence of gravity, and reach upto the river or the stream, from where it is carried away up to the sea. This downslope movement of the material under the action of gravity is generally lubricated and facilitated by water*. and that is why we are discussing it under "water erosion". This surface material which flows up to the river or the stream, under the action of gravity, is called *overburden.*

Infact, both the rivers and the downslope movements act together to shape the Earth's landscape. A small example of this (as will be discussed under river erosion) is provided by the fact that although a river downcuts to form a valley, the shapes of the valley sides are determined by the downslope movements, which widen the narrow cut made by the river. The efficiency of downslope movements can be shown by the analysis of slopes. Such analysis shows that most of the Earth's surface slopes less than 5 degrees, and that, a very little of the Earth's surface slopes more than 45 degrees. The downslope movements are generally slow processes, but however, when slopes are disturbed by construction of engineering structures, such as railways, roads, buildings etc., more rapid movements may be triggered off, causing much damage, as shown in Fig. 5.1.

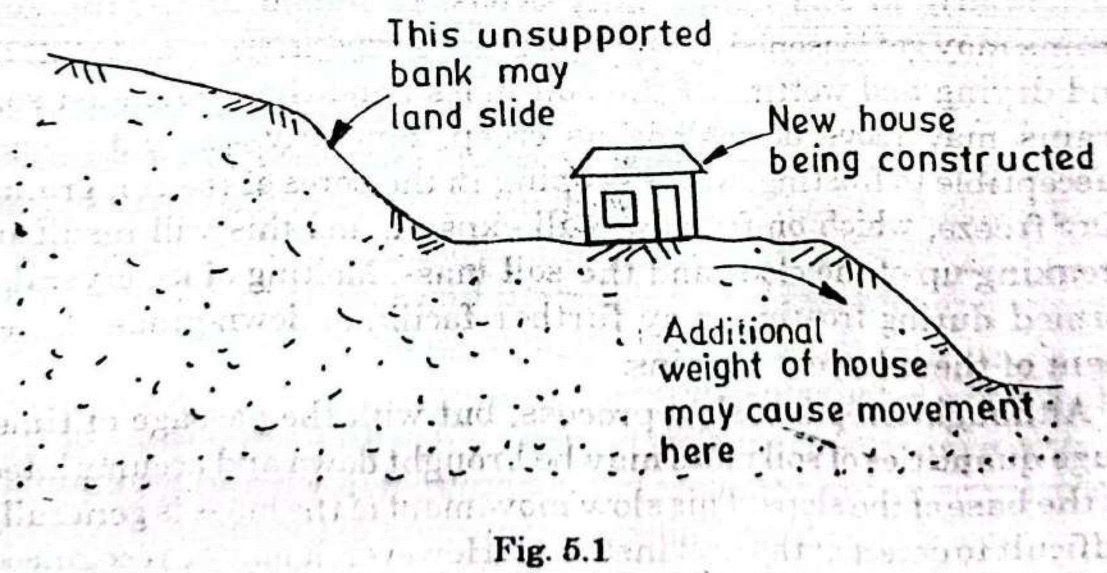


Fig. 5.1

The downslope movements will be generally *slow* when smaller amount of overburden or water is involved ; but they may be rapid when massive thickness of overburden or large quantities of water and especially on steeper slopes, are involved, such as in mud-flows or landslides. The massive downslope movements, which involve

*Strictly speaking, the downslope movement of the material will also sometimes be aided by other erosion agents *i.e.*, wind and ice.

appreciable thickness of the surface material are sometimes called *mass movements,* although they are the part and parcel of 'surface erosion'. These **mass movements** may be triggered on in many ways, such as by :

(*a*) *Undercutting of the slope* ;

(*b*) *Overloading of the slope,* so that it is unable to support its new weight and therefore slides out ;

(*c*) *Vibrations* from earthquakes or explosions that break the bond holding the slope in place ; and

(*d*) *Additional water*, which lessens the internal cohesion of the overburden by filling the void space,* acts as lubricant for the movement, and also by adding more weight to the overburden.

**5.4.1. Types of Mass Movements.** In general, the mass movements or earth movements can be of the following three types :

(*i*) *Creep* ;

(*ii*) *Earthflows and mudflows* ; and

(*iii*) *Landslides or rockslides.*

These are briefly discussed below :

(*i*) **Creep.** Creep may be defined as the slow downward movement of soil or uncosolidated bed rock on hill sides.

It may generally occur in the regions of diverse climates and particularly in cold humid hilly areas. In humid areas, the soil grains may get loosened by the continuous expansion or contraction and drying and wetting of the soil mass ; and these loosened soil grains may move downslope as creep. Similarly, in cold areas, susceptible to frosting, water seeping in the pores of the soil grains may freeze, which on freezing will expand, and this will result in breaking up of the clods and the soil mass. Melting of ice crystals, formed during frosting, may further facilitate down-grade movement of these loosened grains.

Although creep is a slow process, but with the passage of time, huge quantities of soil mass may be brought down and accumulated at the base of the slope. This slow movement of the mass is generally difficult to detect at the first instance. However, it may be recognised by careful observation of its surrounding associated features, such as, *tilted* or *dislocated poles and fencing posts, absence of any trees,*

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*A simple experiment with sand will illustrate this point. This is : dry sand can be piled only in cones with slopes slightly over 30° ; wet or damp sand can be piled even vertically because the small amount of moisture present between the grains tend to hold the grains together by surface tension ; and when more water is added so as to fill the grains with water, mud will form, which flows outward as fluid, due to the absence of any surface tension to hold the grains together.

*buldging of retaining walls, downward bending of strata,* etc. as shown in Fig. 5.2.

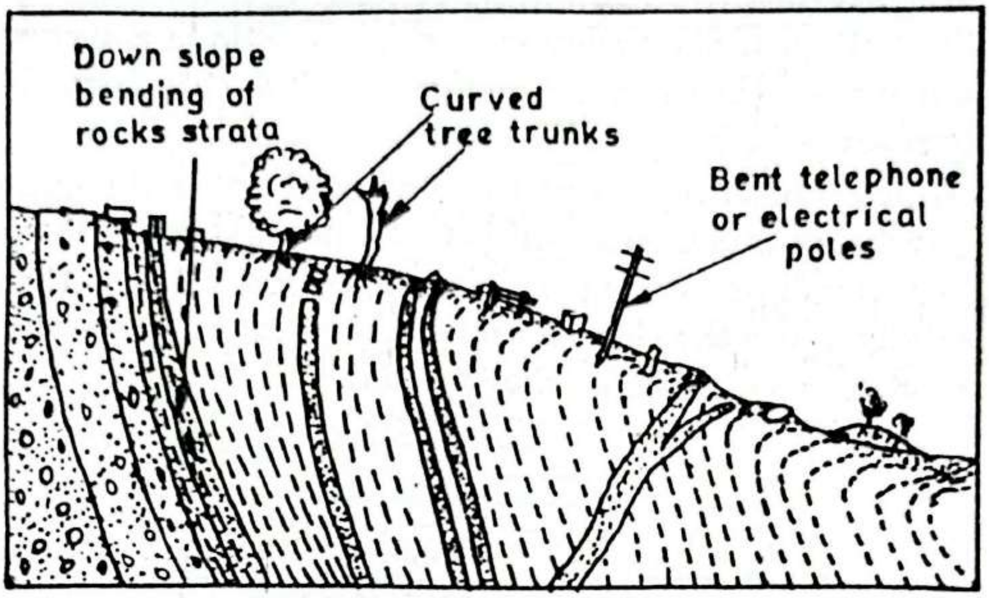



Fig. 5.2. Figure showing evidence of creep.

(*ii*) **Earthflows and Mudflows.** These terms represent a rapid flowage or movement of soil mass, down the slope under gravity. They are confined mostly to open textured soils or unconsolidated rocks, and occur usually after rains or heavy melting of snow or ice.

Clayey or silty soils are most susceptible to failure, in this way. Clays, infact, on becoming wet, are rendered plastic and start almost slipping under their own weight in the presence of water.

A *mudflow* differs from an *earthflow* in the sense that in mudflows the quantity of water present is generally higher so that the whole soil mass is reduced to a slush or mud. The behaviour of mudflows is similar to that of fluids. Falling rains may transport large quantities of pyroclastic volcanic materials, as mud flows.

**Solifluction** is the term used for representing the mudflow in the regions of extremly cold humid climates. In such areas, when the frozen ground mass melts from the top towards the bottom, the surface mud, flows downslope. Such a thing may happen during warm spring days in temperate regions or during the summer days in permafrost* areas.

(*iii*) **Landslides or Rockslides.** A landslide (or rockslide as it is generally called, so as to differentiate it from earthslide or mudflow) is defined as a *true movement of one solid rock mass over another.* This weak or superficial mass fails along a definite failure plane, called shear surface or ***slip surface.***

*Permafrost areas, as the very name indicates, are the areas where the deeply frozen ground does not melt completely, even during the summer season.

In many cases, the bedrock is broken into many fragments during the fall, and the resulting debris behave as a fluid and spreads out in the valley. It may even flow some distance uphill on the opposite side of the valley, if the valley into which it falls is narrow. Such rockfalls are sometimes called *avalanches,* but this term is most generally reserved for snow slides.

*Rock slides* which represent the sliding of one rock mass over another, are very much susceptible to develop easily, if the planes of weakness, such as bedding or jointing, are parallel to the slope, and especially when the slope is undercut by a river, or by a glacier, or by the activities of man, as shown in Fig. 5.3.

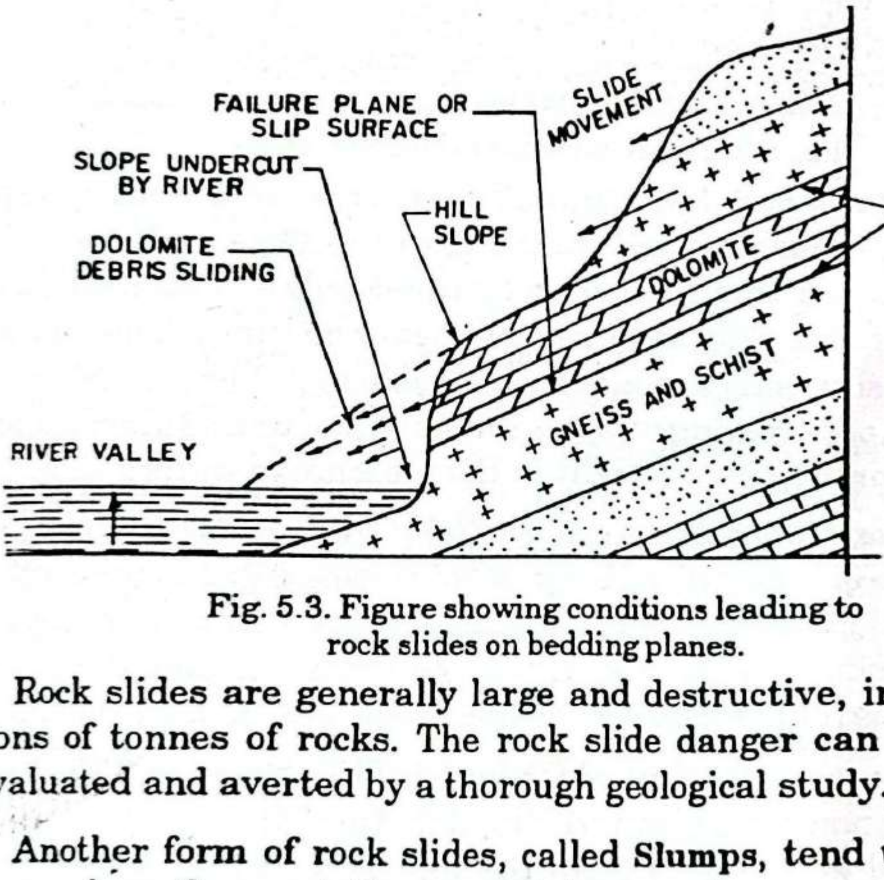



Fig. 5.3. Figure showing conditions leading to rock slides on bedding planes.

Rock slides are generally large and destructive, involving millions of tonnes of rocks. The rock slide danger can however, be evaluated and averted by a thorough geological study.

Another form of rock slides, called **Slumps**, tend to develop in cases where there exist heavy and strong rock masses, overlying the weaker and easily lubricated formations. In such cases, the failure will occur along a curved plane of slippage ; and will be represented by the reverse tilt of the stronger rock unit, which will provide a basin for a pond to develop, and the rise of the toe of the slump. This rise at the toe is most pronounced in case the underlying rock is very weak and can flow plastically.

Unlike the rockfalls, slumps develop new cliffs, though slightly lesser in heights than those existing previous to the slump, thus setting a stage for a new slump to take place. *Thus, slumpping is a*

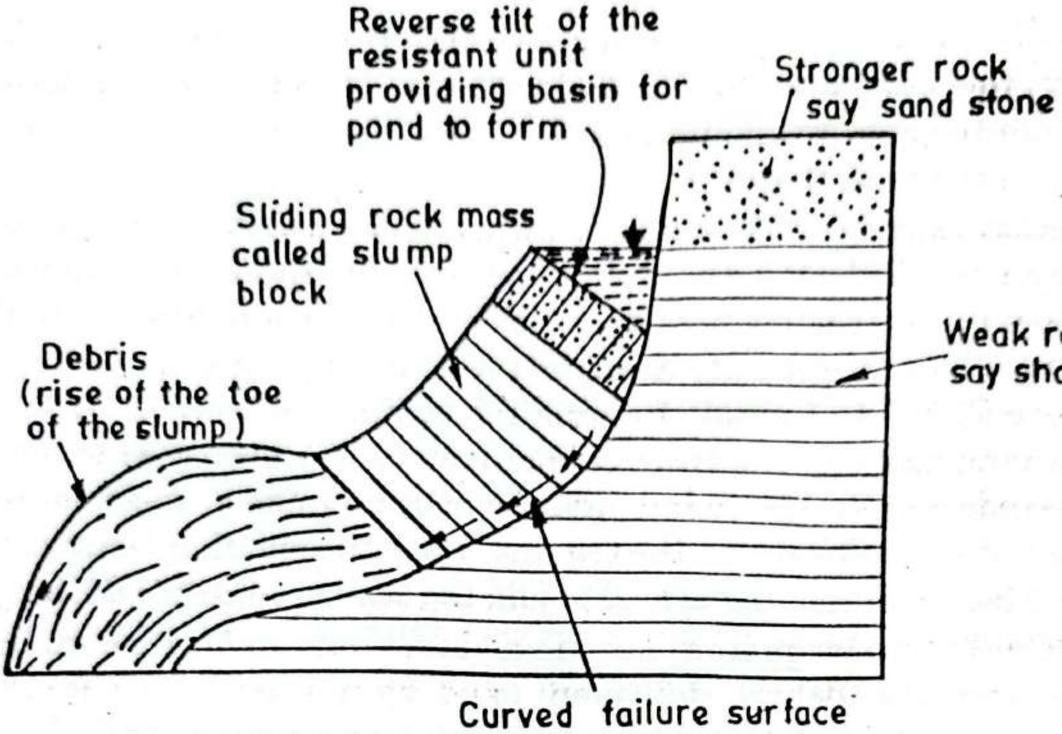



Fig. 5.4. Rotational slump block, showing curved plane of slippage and reverse tilt of the slump block.

*continous process,* and its many stages can be seen for, infront of the present cliffs, as shown in Fig. 5.5

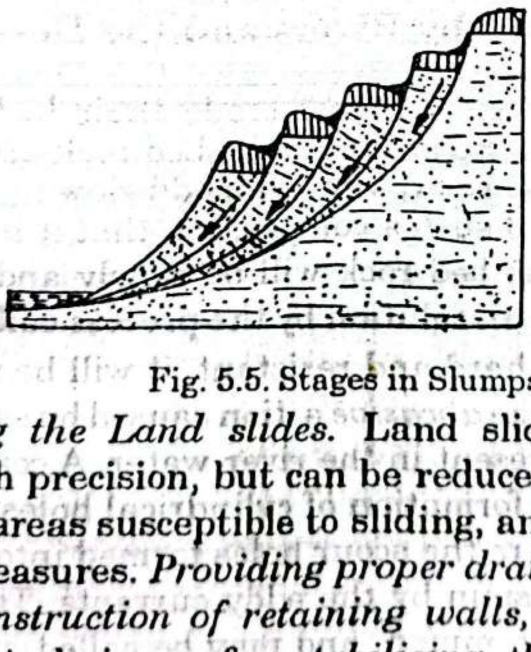


Fig. 5.5. Stages in Slumps.

*Controlling the Land slides.* Land slides, infact, cannot be predicted with precision, but can be reduced by keeping thorough watch in the areas susceptible to sliding, and by adopting suitable controlling measures. *Providing proper drainage* of water through the rocks, *construction of retaining walls,* and by adopting soil conservation techniques for *stabilising the slopes,* are certain methods which may be adopted for controlling land slides.

## 5.5. The Geological Work of Rivers

Rivers, as pointed out earlier, cause erosion from their beds (including removal of material and its transportation), receive and transport the products of weathering that are fed into them by runoff from precipitation as well as by downslope movement, and finally carry the entire denundated material into the sea* for deposition. Infact, the *weathering*, *downslope movement*, and the *rivers*, work together to shape the landscape.

From the head to its junction with the sea (called the mouth), a river may exhibit a variety of geological activity. In the head regions it flows with roaring speeds capable of cutting down even the hardest rocks. It actually does cut them. Deep gorges and valleys, so formed, are the proof. In middle reaches, the stream becomes mature for most of the time doing the cutting job only selectively and changing its course where it finds insurmountable obstructions. It meanders profusely. In the flat land near its mouth, it behaves as an old body just moving ahead to join the sea through its delta.

During its passage from head to mouth, river erodes its own bed ; transports the debris delivered to it by its own erosion, its tributaries, downslope movement, and rain wash ; and finally deposits the transported material into the ocean. The entire geologic work of a river can, therefore, be studied under :

1. *Erosion*
2. *Transportation*, and
3. *Deposition, as discussed below* :

### 5.5.1. Erosion caused by Rivers and the Developed Features

**5.5.1.1. Erosion processes.** Rivers erode their beds by several processes, depending on the nature of the bed rock and the quality of water contained in the river, as explained below :

(*i*) If the bed rock is of such a composition that it is dissolved by the rain water, then the bed rock will be slowly and steadily get eroded away chemically in solution by the process called *corrosion*.

(*ii*) If the bed rock is hard and resistant, it will be mechanically eroded away slowly by the *abrasive* action caused by sands, gravels, and other fragments present in the river water. A common type of abrasion results in the formation of cylindrical holes, called **pothholes**. Such pothholes are the scour holes formed into the bed rock by the stones that are spun by the eddy currents. This process of stream erosion is very common, and may be called as **abrasion** or **corrosion**.

(*iii*) Softer bed rock and loose material may be eroded away by the simple hydraulic action of flowing water by *pressure* and *shearing effect*. The fractured bed rocks containing planes of weakness, such as joints, faults, beds, foliations, etc. are also very much liable to erosion by this process ; because during a strong current, water may

*A *river* (large body) ends into a sea, whereas a *stream* (a smaller body) ends into a river or a lake or a pond.

enter under the fractures of the bed rock, with a force sufficient to displace and dislodge them.

Sometimes, when the river acquires an exceptionally high velocity, say 12 to 14 m/sec, such as at the points of water falls, etc ; then naturally the water pressure at such points may become equal to its vapour pressure, changing the liquid into vapour, and back at that point. The creation of such vapour or development of negative pressures will result in virtual sucking out of the rock pieces, creating depressions, holes or hollows within the rock mass. This phenomenon, as you may be knowing, is called **cavitation**, and is of great engineering importance in hydro-power generation projects, where the blades of the turbines may get pitted by cavitation, when the water jet impinges on them at high velocities of the order of 12 to 14 metres per second. Similarly, the bed rocks in a river just downstream of a water fall, may get quickly eroded away by cavitation.

**5.5.1.2. Rate of erosion.** The rate of stream bed erosion may depend upon three important factors, as pointed out below :

(*i*) If the *velocity* of river water is high, greater amount of erosion will occur. Fast moving streams may cause more erosion, firstly due to exertion of more pressure and shearing forces on the channel bed ; and secondly because of their large capacity to carry sediment load which causes erosion by abrasion. Hence, the erosive capacity of a stream depends very much on its velocity, which itself depends on factors, such as the bed gradient, roughness of the stream, volume of water contained in the stream, etc.

(*ii*) The rate of stream bed erosion may also depend upon the *nature and characteristics of the bed rock,* as softer rocks like Limestones will get more easily eroded away compared to harder rocks like Granites.

(*iii*) The rate of stream-bed erosion may also depend upon the **sediment load** present in the stream, and its sediment carrying capacity, which directly depends on the discharge flowing in the stream. Thus, if a channel is already *fully loaded*, it will not cause much erosion from its bed ; but on the other hand, if it is under-loaded, large scale bed erosion may take place.

**5.5.1.3. Formation of river valleys.** Our ancestors used to think that the huge valleys through which our great rivers flow were perhaps formed by earthquakes or other upheavals. But today, this idea has been proved to be wrong. The established fact today is that a river cuts its own valley, through the passage of time, by eroding the rock or the soil material from its path, and transporting it down to the sea. The cross-sectional shape of the valley so formed, generally varies along the length of the river. It is generally *deep and narrow* (*i.e.* V-shaped) in the upper hilly reaches, and *very wide* (much wider than the meander belt*) in the lower reaches in plains. It is generally formed so, by deepening or downcutting in the upper reaches, and by widening in the lower reaches.

The excellent landscape traced by a river in the form of formation of its valley, is itself sufficient to prove the excellent zeological work which can be performed by the running water. Infact, most of the Earth's landscape, and not only the river valleys, are sculptured by the running water.

Now, before we explain the actual formation of a river valley caused by erosion, let us first differentiate between a 'river channel' and its 'valley'. *A river channel is the trough occupied by a non-flooding river during any one particular time of its history ; whereas the river valley is the incision made by the river during the entire period it has been in existence.* A river valley, thus, represents the width confined between the *khadir banks* of the river, which are defined as the left and right extremes upto which a river is ever known to have vandered in its history.

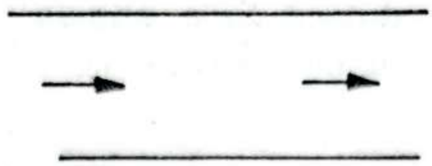
Now, we will discuss as to how actually a river valley is formed :

A river, as pointed out earlier, is formed by the continued-erosion of the path along which it flows. The process of development of a river valley starts, when the water after rainfall concentrates its movement along the naturally available ground slope, slowly cutting the ground by erosion in the form of small gullies, which on further development, with the passage of time, acquire the shape of

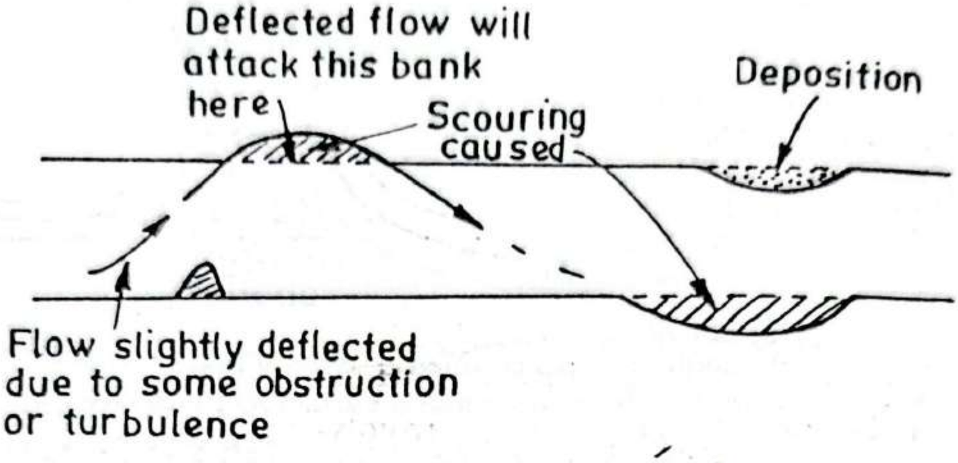
*Rivers generally flow in a zig zig *sinuous* course characterised by a series of S-shaped bands, called *meanders*. The distance between the outer edges of the clockwise and antidockwise loops of the meander is called the *meander belt* or the *meander width*. [Refer Fig. 5.6.]

The process of meandering starts by a slight deviation in the uniform axial flow of the river [(Fig. 5.6 (*a*))], which helps in moving more and more flow towards one bank than towards the other. The process continues with more and more vigour, thus causing more and more flow towards the former bank and forming shoals along the other, thus accentuating the curvature of flow, and finally producing meanders in its wake. When once the curvature has come in, the *concave bank goes on eroding.* and *convex bank goes on silting, thus further developing* the meanders. [Fig. 5.6 (*c*)]. A full fledged meandering river, as shown in Fig. 5.6 (*d*), will ultimately result.

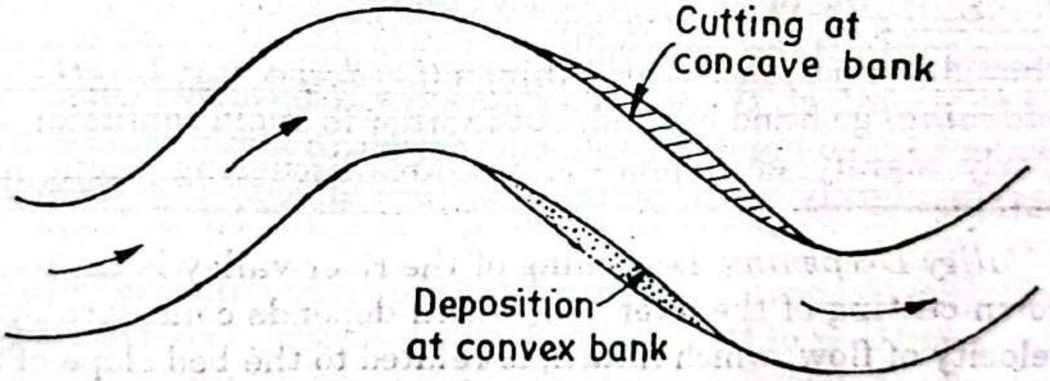
For more detailed discussion on the topic of 'meandering', the needy readers may refer to "Irrigation Engineering and Hydraulic Structures" by the same author, or C.B.I. manual No. 60.



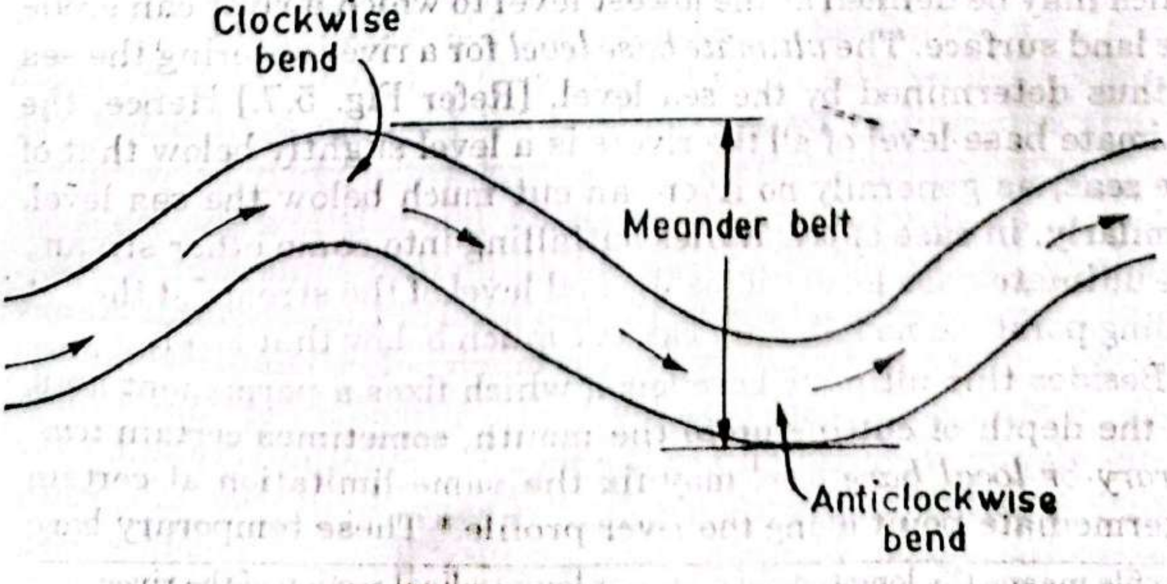
(*a*) Initial straight river channel.



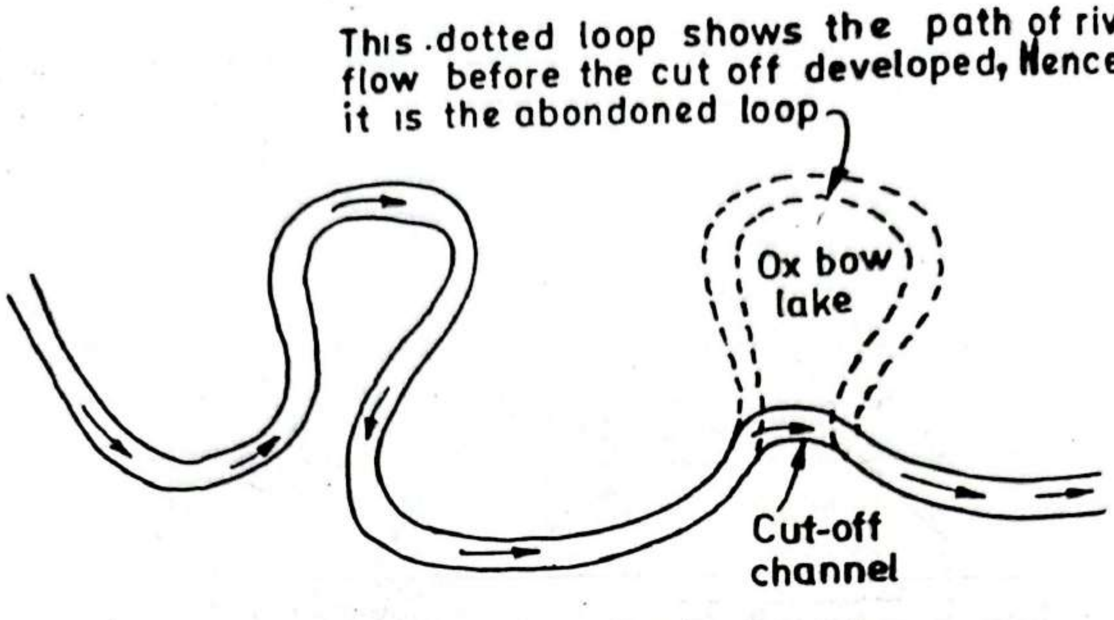

(*b*) First phase (*i.e.* start) in the development of meander.




**(*c*) Further development of meander.**




**(*d*) Full fledged development of meander.**




(*e*) Meanders with cutoff and ox-bow lake.
Fig. 5.6. Showing development of meanders in the river.

a valley The three physical processes involved in the formation of a river valley are :

(*i*) *deepening* of the river valley ;
(*ii*) *lengthening* of the river valley ; and
(*iii*) *widening* of the river valley.

Although, infact, these three things (*i.e. deepening, lengthening* and *widening*) go hand in hand, but inorder to avoid confusion and to clearly signify each process, we are discussing them here separately :

(*i*) *Valley Deepening.* Deepening of the river valley is caused by the down-cutting of the river bed, which depends considerably on the velocity of flow, which inturn, is related to the bed slope of the channel. However, this down-cutting or deepening of a river cannot go to indefinite depths, as it is controlled by the *base level of erosion.* which may be defined as the lowest level to which a river can erode the land surface. The *ultimate base level* for a river entering the sea is thus determined by the sea level. [Refer Fig. 5.7.] Hence, the ultimate base level of all the rivers is a level slightly below that of the seas, as generally no river can cut much below the sea level. Similarly, in case of tributaries outfalling into some other stream, the ultimate base level will be the bed level of the stream at the out falling point, as no tributary can cut much below that level.

Besides this ultimate base level, which fixes a permanent limit on the depth of cutting up to the mouth, sometimes certain *temporary or local base level* may fix the same limitation at certain intermediate point along the river profile.* These temporary base

*Profile means the longitudinal profile or longitudinal section of the river.

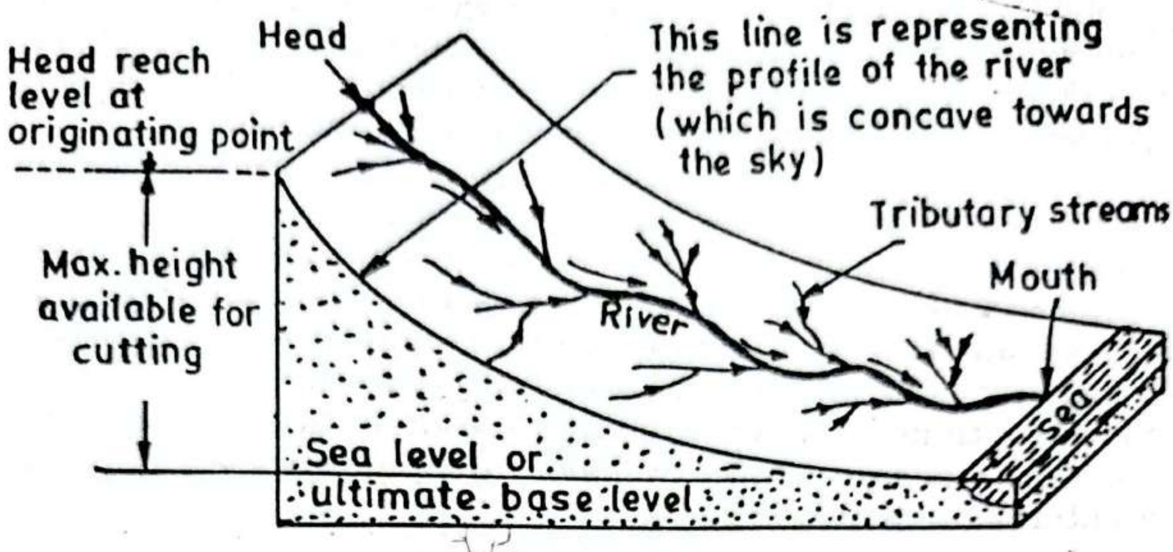



Fig. 5.7. Showing prospective view of the profile of a river.

levels will be determined by the obstructions, which will not allow down-cutting below that level, and may be due to : some resistant rock layers, lakes, artificial dams, etc. Hence, a valley, upstream of such a temporary base level, cannot cut below that level (unless the temporary level itself changes) and this will, therefore, govern the river profile.

Besides these base level limitations, placed on the depth of cutting and the consequent formation of the river profile, it is also necessary that the river possesses a certain bed gradient to flow ; and therefore, it cannot cut the entire upstream reach upto the base level, except in the reaches adjoining the governing base level.

Most of the rivers of the world have been found to have their profiles which are concave towards the sky, so as to have steeper gradients in the head reaches, and milder gradients in the lower reaches ; as shown in Figs. 5.7 and 5.8. Over a period of years, a stream profile gets fully developed, becomes smoother, and adjusts its slope and channel cross-section to the discharge, so as to develop just the velocity needed for transporting the sediment load entering the river from outside. Such a river is neither causing erosion from itself (*i.e.* it is not a *degarding river*), nor causing silting in it (*i.e.* it is not an *agrading* river). Such a regimed river, which is in *equilibrium* with its surroundings, is called a graded river, and such a graded river will have the *profile of equilibrium*. Normally, the profile of equilibrium is first reached near the river mouth, which progresses upstream, although in many rivers, different reaches become graded regardless of their position w.r. to mouth or head-waters. Precisely speaking, however, no river at any time or place can be fully in equilibrium. Annual and seasonal fluctuations in volume and velocity, bring about continual readjustments, and downward cutting ***never entirely ceases***, although reduced considerably. The graded profile of equilibrium therefore, is an approximate condition of equilibrium only. Hence, after this equilibrium profile is reached, there will be very less downcutting ; but the lateral widening and cutting due to abrasion may continue.

(*ii*) *Valley Lengthening.* Lengthening of a river or its valley is achieved during its deepening or downcutting, which generally continues in the head waters even when it has stopped in the lower reaches in plains due to their having reached equilibrium stage. This peculiar way of continued erosion or downcutting towards the headwaters in mountains is generally called *headward erosion*. Such a continued headward erosion lengthens the stream due to the backward extension of the river along the path of some of its original tributary, as shown in Fig. 5.8.

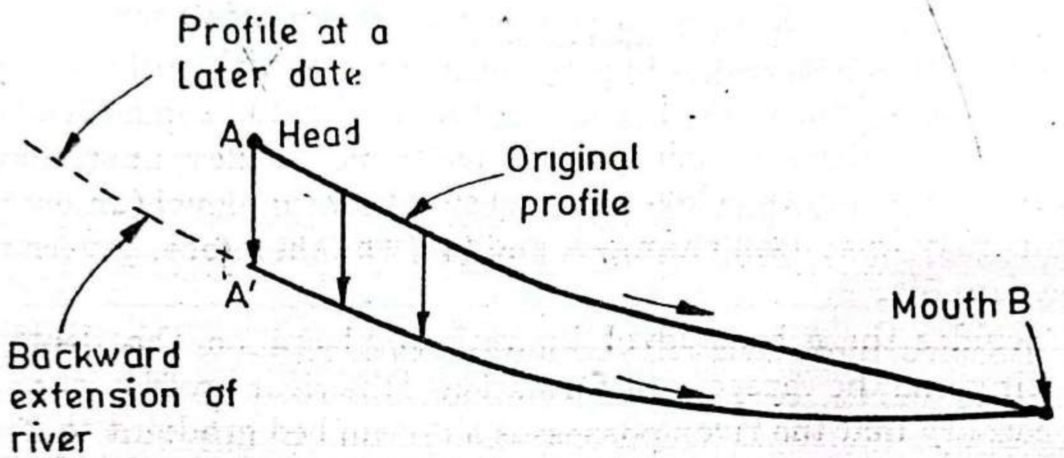



Fig. 5.8. Downcutting at the head waters of the river, lengthening the course of the river by its backward extension (shown dotted).

Since the tributaries of the given river will also develop in the same fashion by headward erosion, certain interesting things may sometimes happen under favourable circumstances. Such an interesting thing may happen when a newly headward eroding tributary of the newly developing river *B* may happen to join a major stream of some other old river *A*. When this happens, the steeper gradient developed by erosion in this newly forming tributary, may divert the flow of the old major stream and that of the old river *A*, upstream to the major stream. This interesting phenomenon is called **river piracy** and is shown in Fig. 5.9.

(*iii*) *Valley Widening.* River valleys, as pointed out earlier, are generally formed by deep cutting in the upper mountainous regions, and are, therefore, *very deep and narrow* (having V shapes), called **gorges** or **canyons**. Refer Fig. 5.10. In the plains, however, the ultimately developed river valleys are generally *shallow and wide* in section. The width goes on increasing with time. This large scale widening is done, partly by the lateral erosion caused by the running water through the processes like meandering, and partly by the secondary processes like weathering of banks, rainwash, creep, land

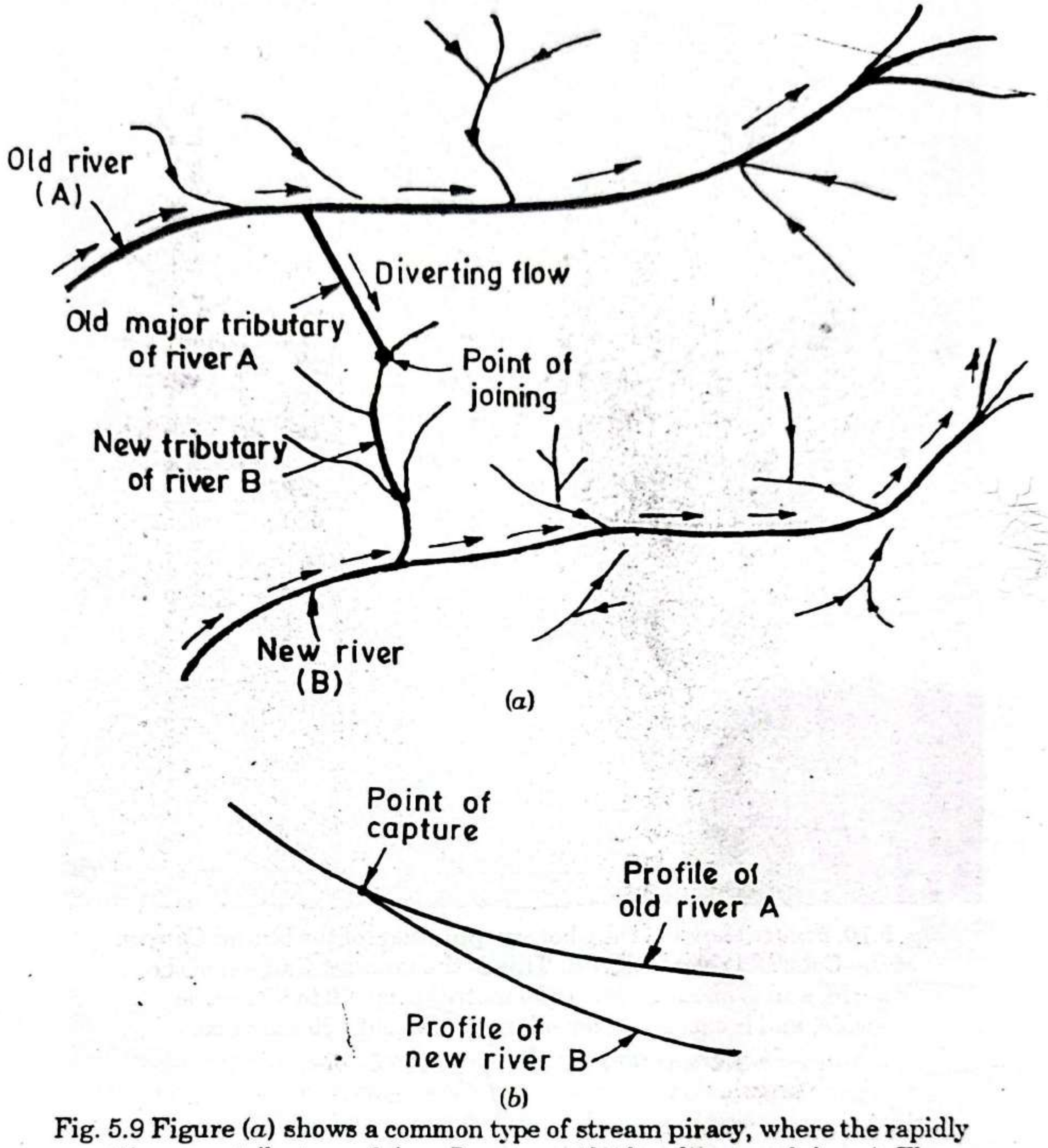



Fig. 5.9 Figure (*a*) shows a common type of stream piracy, where the rapidly cutting new tributary of river *B* captures the head water of river A. The favourable gradients of two rivers are shown in lower diagram (*b*).

slides, etc ; taking place from the sides of the valley. These secondary processes are, however, also helped by the running water in the sense that as and when such downslope movements take place, the resulting debris are removed and transported by this running water, thus paving the way for further slides and consequent large scale widening of the river valley. Moreover, while removing the debris, through the process called **sheetwash**, the running water may itself cause some accompanying erosion on the river sides.

In this way, valleys may be formed, which may become wider and wider and shallower and shallower with the passage of time as shown in Figs. 5.11 (*a*) to (*d*) ; untill finally near the sea in its deltaic region, the river starts flowing on the flat ground.

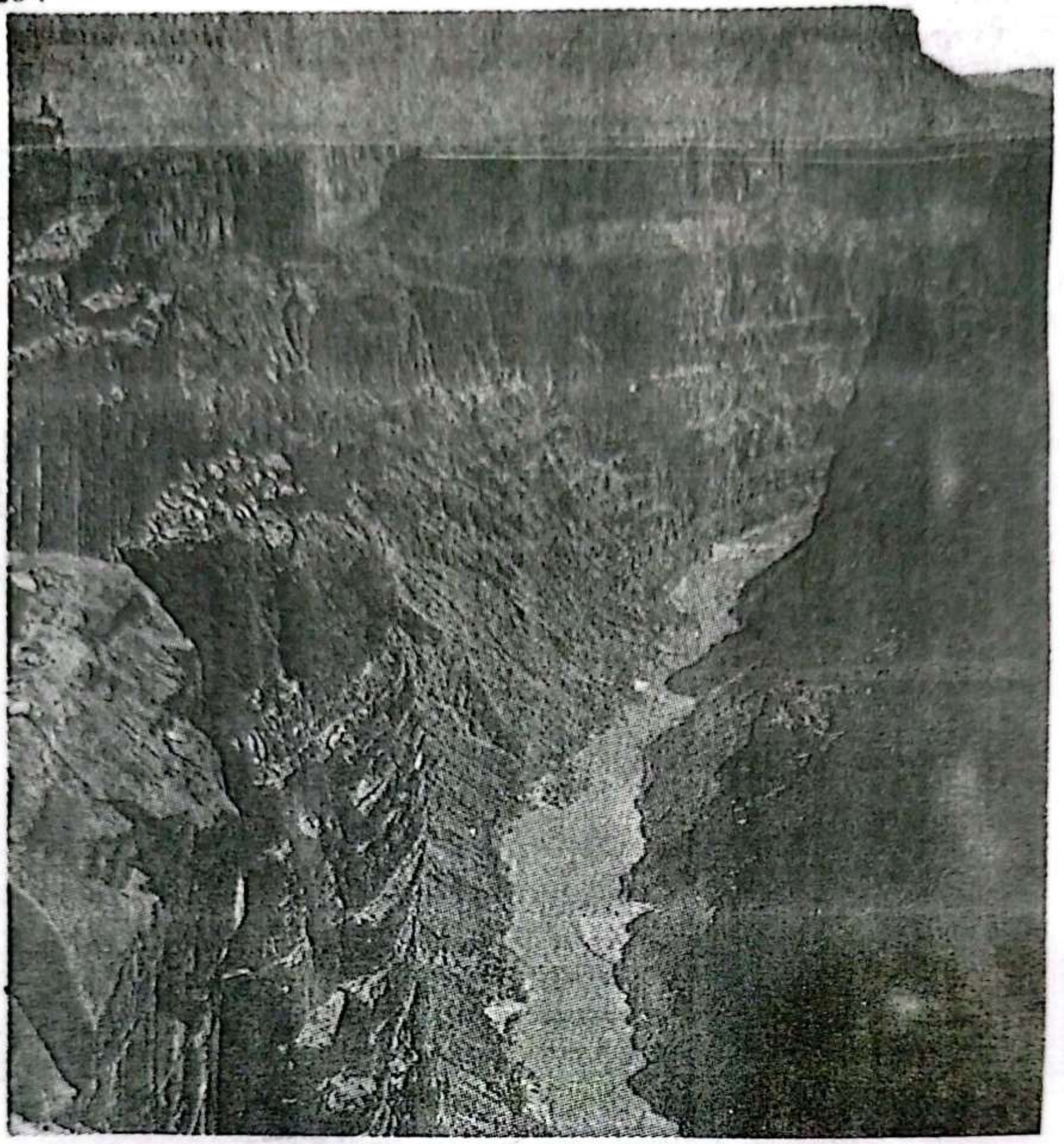
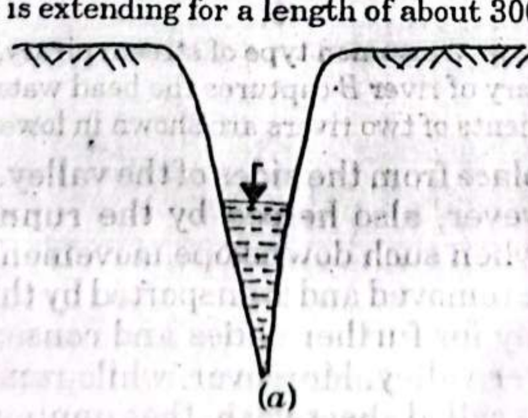
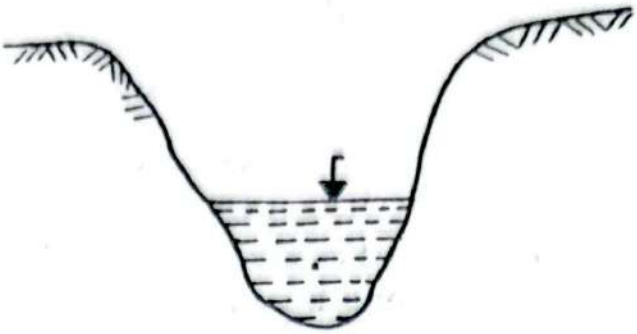


Fig. 5.10. Figure showing the photographic view of the Grand Canyon of the Colorado river of U.S.A. This is the greatest Canyon of the world, and is about 900 to 1800 metres deep, 60 to 90 metres wide, and is extending for a length of about 300 km or so.

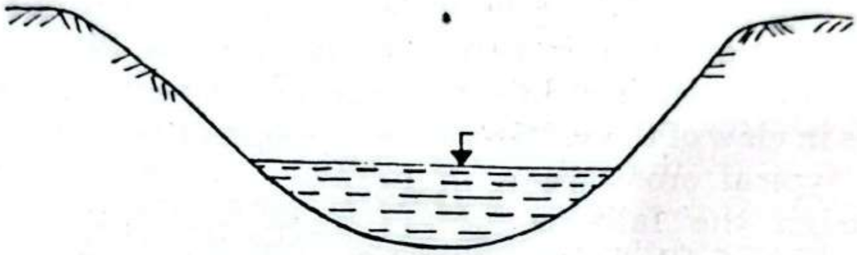


(a)

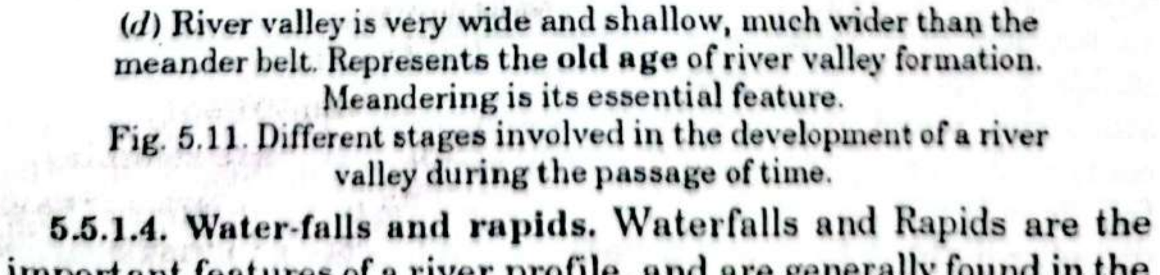
**Very deep and narrow, sharp V-shaped valley. Represents the exteme youth stage of a ri/er-valley formation The river has cut down rapidly so that the downslope movements for the valley sides responsible for widening cannot keep pace with the downcutting. Rapids and water falls, and in some case, lakes, are their accompanying features.**



(*b*) Comparatively less deep and narrow valleys, May be V or U shaped. Represents the **youth stage** of a river valley formation. Rapids and water falls and sometimes lakes, may be their accompanying features.



(*c*) River valley is somewhat wider than the river channel. Represents the **maturity stage** of the river valley formation. River has no waterfalls or lakes. River is no longer rapidly downcutting and is beginning to widen the valley. Meanders, where present, occupy most of the valley bottom.




(*d*) River valley is very wide and shallow, much wider than the meander belt. Represents the **old age** of river valley formation. Meandering is its essential feature.

Fig. 5.11. Different stages involved in the development of a river valley during the passage of time.

**5.5.1.4. Water-falls and rapids.** Waterfalls and Rapids are the important features of a river profile, and are generally found in the mountaineous reaches of the river. A *waterfall* indicates the vertical fall of water through some height, which may vary from a few metres to many metres. The velocity at the foot of the fall will obviously be high, due to the conversion of potential energy into kinetic energy. The river water, after travelling some distance downstream of the fall, will again start travelling with its normal flow at normal gradient.

If instead of a vertical fall, the river bed becomes extremely steep like a glacie, so that the water flows at an excessive slope, then the fall is called a **rapid**.

Waterfalls and Rapids are generally formed due to unequal erosion of different types of bed rocks encountered along the river path. Thus, if we have a hard stratum outcropping in the bed of a river, with softer and weaker beds below it ; the greater wear of the latter will develope sufficient inequality of bed levels, so as to produce rapids. With progressive erosion and increasing steepness of the stream bed, the rapids change into vertical falls. These vertical falls go on receeding upstream with the passage of time, due to further erosion.

The famous *Niagara falls* of U.S.A. can be quoted as the best examples of a water fall ; where the Niagara river drops over the Niagara escarpment* into two water falls, about 50 m high and world famous for their majestic beauty and of peculiar interest to engineers in view of the water-power developments associated with them. A typical cross-section through the falls is shown in Fig. 5.12. From this cross-section, it can be seen that above the falls, the river flows over an outcrop of Limestone, a relatively harder rock, below which occurs Shale. This Shale is affected by the action of water more rapidly than is the Limestone ; thus even under the lip of the fall, it is generally eroded. This will eventually result in the left over of an unstable projection of Limestone bed, which will break off subsequently. This process when continued over a passage of time will result in the recession of the fall. This is of course true, as the site is migrating upstream by a distance of about 1 metre per year ; and it has been established by geological studies that the present day falls were infact situated originally at several kilometres below the present site. This has resulted in the formation of a great gorge, which is a vivid reminder of the potentialities of rivers as a cause of erosion.

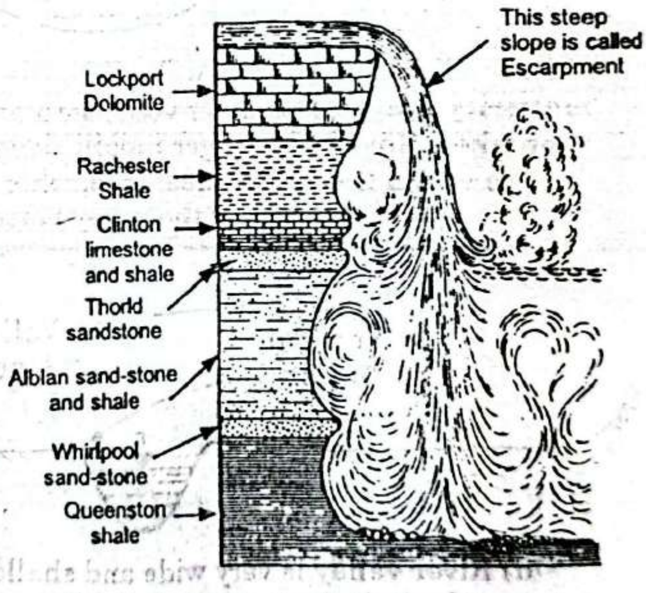
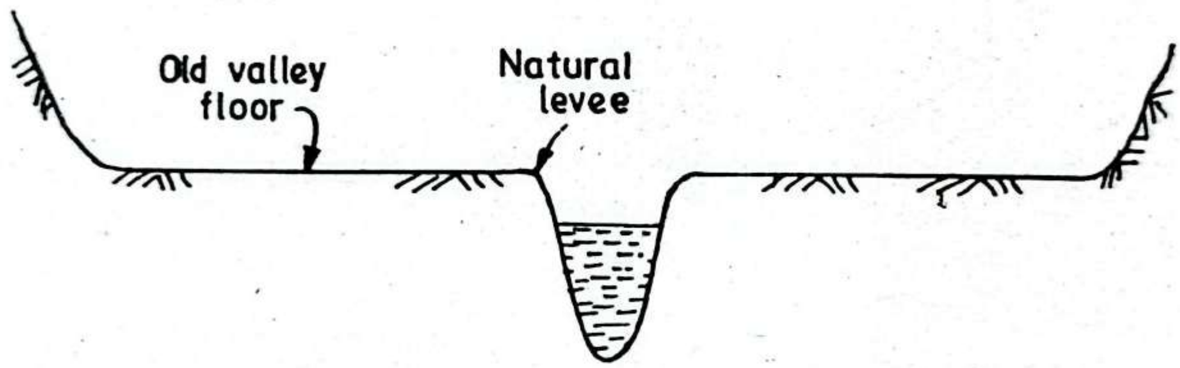


**Fig. 5.12.** Geological section through Niagara falls.

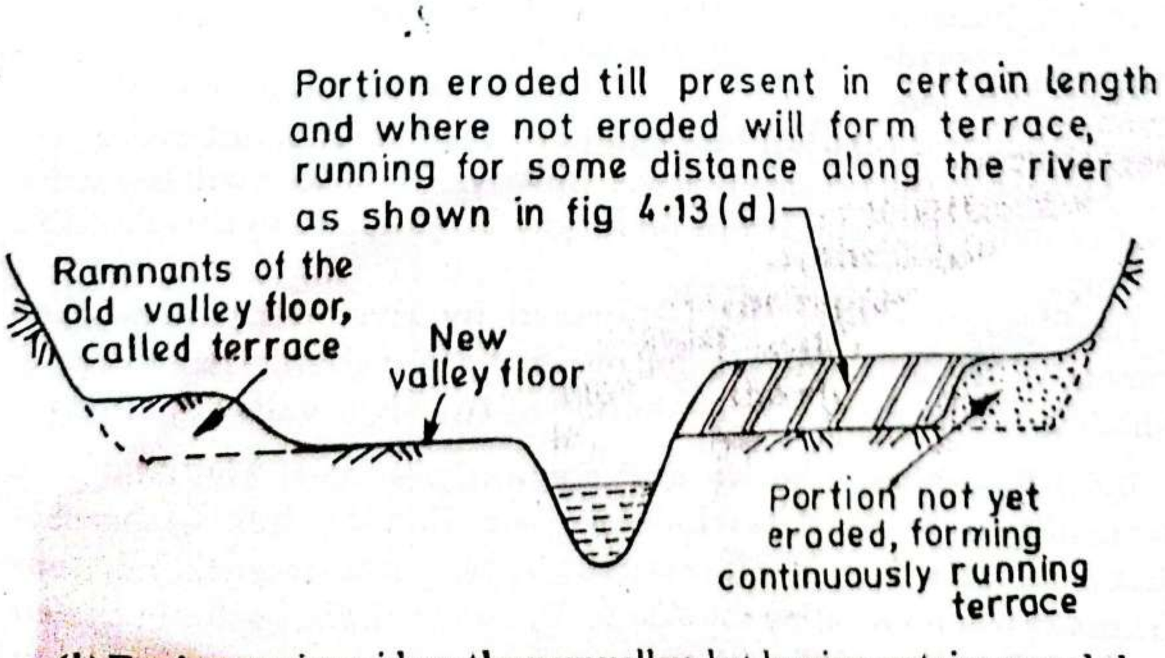
**5.5.1.5. River terraces.** Terraces are the remnants of the old valley floors, found on the present floor of a velley. They are characterised

*The steep slopes formed between the top hard bed and lower softer bed, due of greater erosion of the softer bed, are called the escarpments. (Refer Fig. 5.12.)

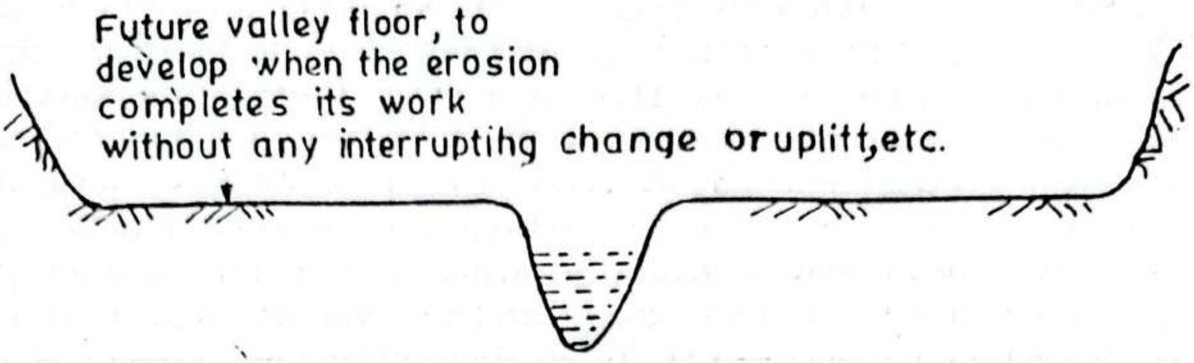
by bench or platform like structures, running parallel to the river for some considerable distances, as shown in Fig. 5.13 (*b*) and (*d*). One or several of these terraces, may be present, and form benches on one side or on both sides of the river valley. These terraces, infact, represent a transitional stage of river erosion, and they will ultimately be washed away by river erosion. So long as they are present however, they can be used to interpret geological history, as their presence indicates that the earlier river of equilibrium has undergone some recent change, which has *rejuvenated* the old river valley section, so as to start fresh downcutting and erosion. This change could be due to an *uplift*, a climatic change or an increase in the flow of the river. Under such a change, the channel will first down-cut and become V-shaped, though present in a wide valley [Fig. 5.13 (*a*)], and will continue to erode. During this process of erosion, the nearby valley sides *i.e.*, flood plains, will be first eroded, leaving terraces on farther sides or at other places along with the



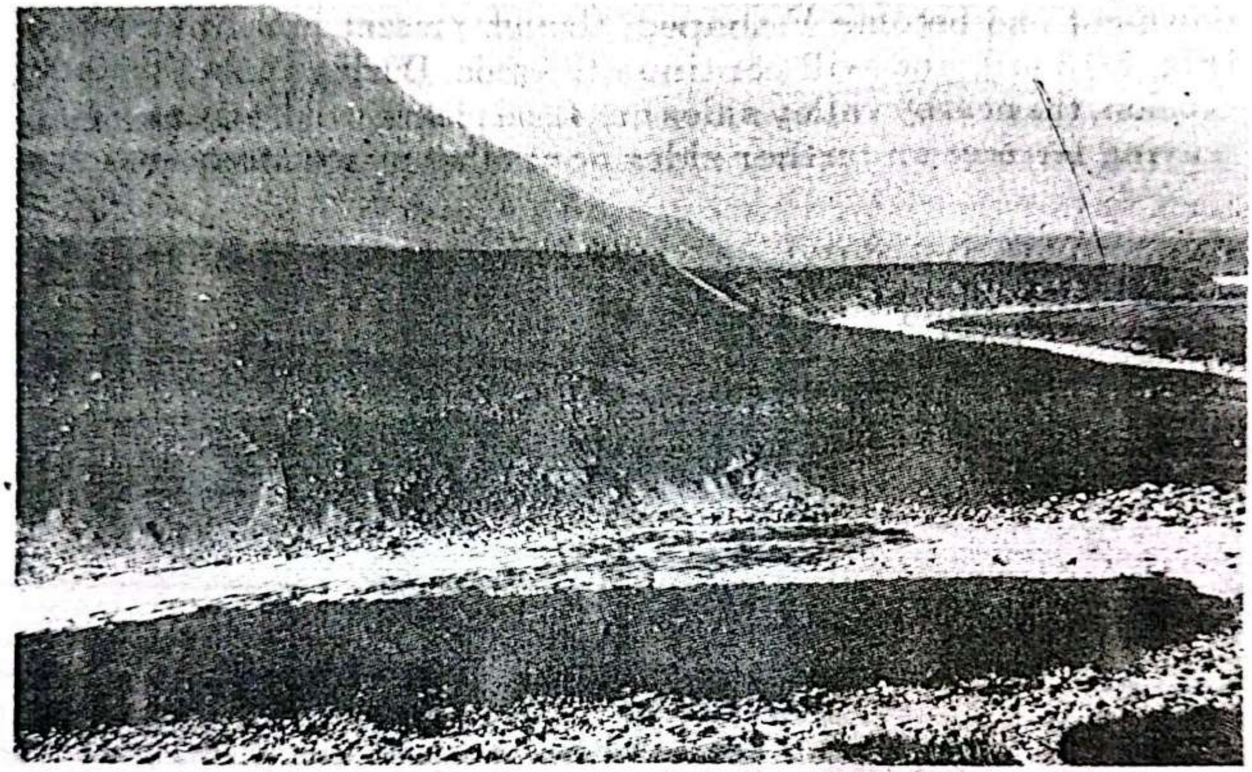

(*a*) An uplift caused the river (initially in a broad valley) to downcut, forming a V-shaped valley.




(*b*) Further erosion widens the new valley, but leaving certain uneroded benches, called terraces. This represents transitional zone of erosion.




(*c*) Finally the erosion removes all the terraces, developing a new unterraced section.



(*d*) Photographic view of successive river terraces formed along the river by unequal erosion along the valley length.

Fig. 5.13. Figure showing formation and removal of River Terraces.

river [Refer Fig. 5.13 (*b*)] where hard strata has encountered. In the final phase of the erosion process, however, terraces will be eroded away completely, and it will no longer be possible to decipher this history.

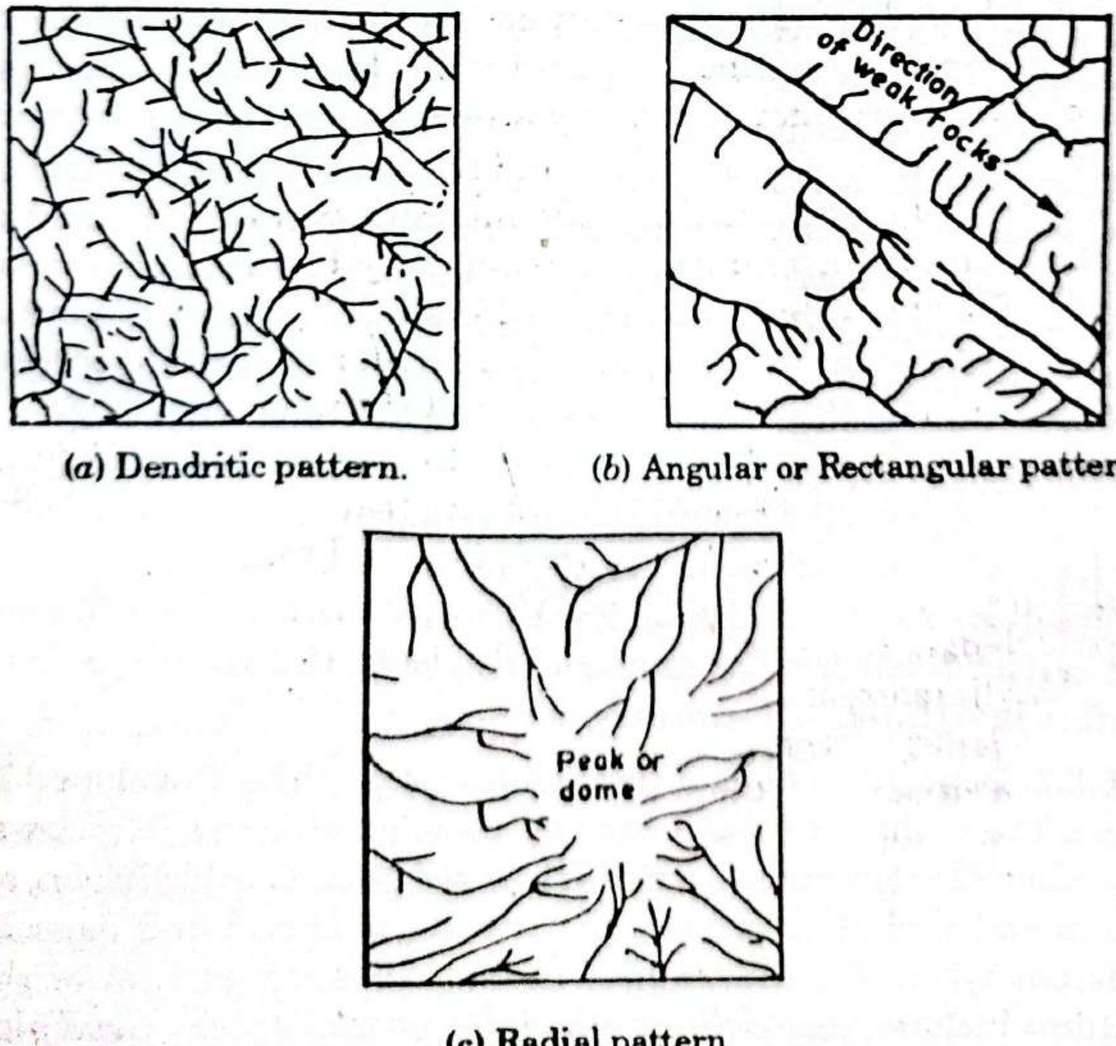
Such terraces may also be formed by river deposition, when instead of an uplift, a depression or some other change has occurred, which has necessitated rejuvenation of the river valley by silting.

**5.5.1.6. Drainage basins and stream patterns.** The land area drained by a river and its tributaries is called the drainage basin of that particular river. The line of damaracation between the adjacent drainage basins is called the *divide*. Both the drainage basin as well as the divide have different orders of magnitude, depending on the size of the river under consideration.

The plan view or the map of a drainage basin shows the arrangement of the tributary streams, and is called the *stream pattern* or *drainage pattern*. The development of the drainage pattern of the whole drainage basin is an important part of erosion.

The different types of stream patterns can, to some extent, indicate the arrangement of the zeological materials through which the streams are flowing. Thus for example, *horizontal massive rocks* effer uniform resistance to stream erosion, and are therefore characterised by the development of a *random* or *dendritic* drainage pattern, so named because of its similarity to the veins on a leaf [Refer Fig. 5.14 (*a*)].

Tilted or folded rocks (*i.e.*, alternating hard and soft rocks) are characterised by *angular* or *rectangular* drainage pattern, because the upturned edges of the different strata have varying resistances to stream erosion. The major drainage lines tend to follow the weak strata, whereas, the tributaries flowing through the more resistant layers tend to enter the trunk streams at right angles, as shown in Fig. 5.14 (*b*).




(*a*) Dendritic pattern. (*b*) Angular or Rectangular pattern.

(*c*) Radial pattern.

**Fig. 5.14. Different types of Drainage patterns.**

A third type of *radial* drainage pattern may develope in hilly regions, at the top of a dome or a peak, where the drainage lines radiate in all directions from the high point, as shown in Fig. 5.14 (*c*).

Different variations of all these three types of drainage patterns may exist, especially where the geology is complex.

**5.5.2. Transportation of Material by a River.** A river carries enormous amount of soil and rock material, which it receives by continued erosion from itself as well as from the downslope movements, as discussed earlier. The river tributaries also contribute a lot of sediment material to it. This sediment material flowing in a river is called *its load* and may be considered in three parts, as

(*i*) *dissolved load* ; (*ii*) *bed load* ; *and*
(*iii*) *suspended load*.

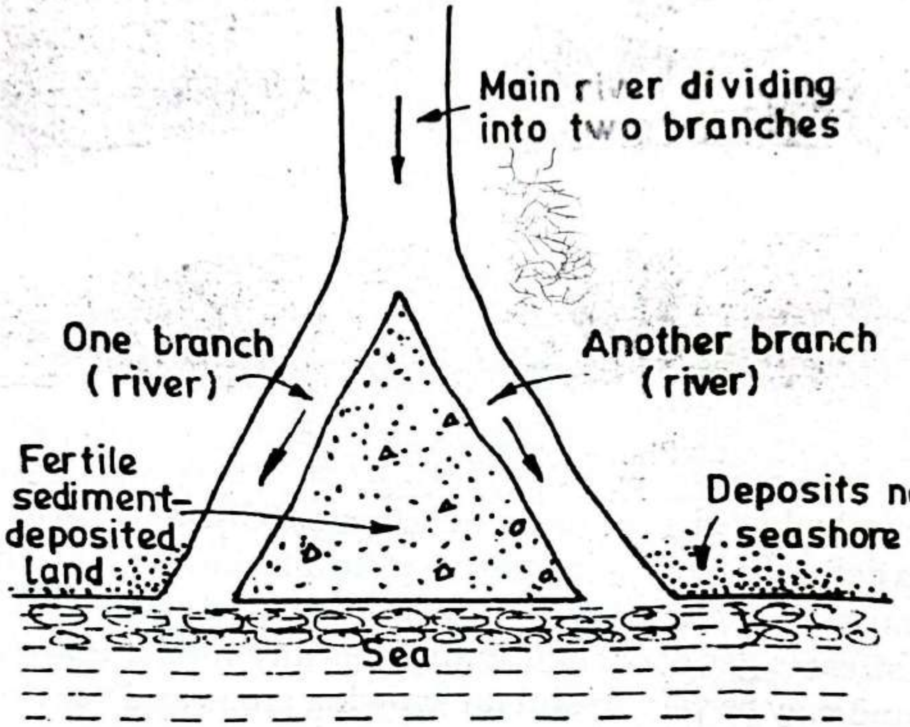
The **dissolved load** is the water soluble material and its presence has no effect on the regime of the river. The **bed load** is that heavier material which moves along the bed of the river with occasional jumps. The **suspended load** consists of finer material which is kept in suspension by the turbulence of the flowing water, and is therefore carried easily over long distances. As the velocity of the river increases, some of the finer bed load will also become suspended load, so that the distinction can be made only at a given movement.

Clay particles settle very slowly and so are carried, generally, as suspended load. Slit particles, settle much more rapidly, and they will, therefore, be carried in suspension, only by turbulent waters having sufficient velocity and upward eddies to keep the silt free from settling. Since, clay is thus carried farther than silt, sorting of sediments will result. The suspended load is thus sorted by rivers. On the similar analogy, the bed load is also sorted, but in addition, the bed load particles are also worn during transportation. The bed load, infact, moves along the bed by sliding and rolling.

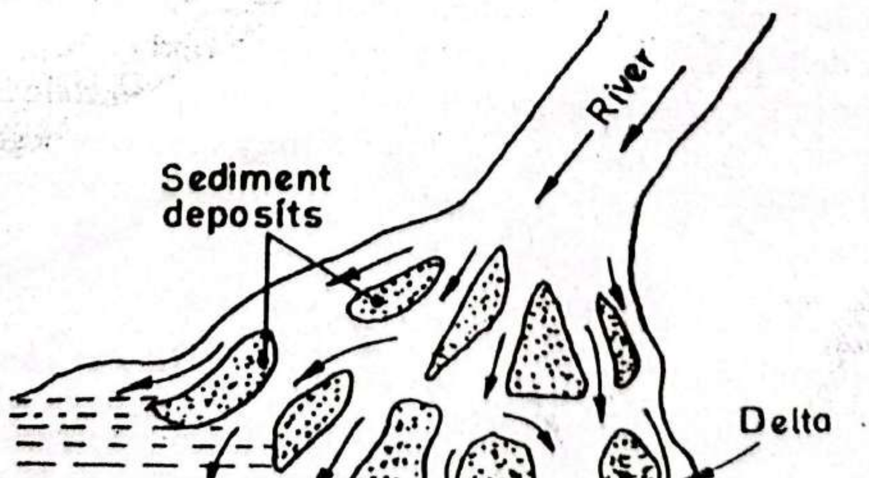
The dissolved, load, although not affecting the regimen of a river, but carries thousands of tonnes of soluble salts from the Earth's surface into the seas and oceans.

**5.5.3. Deposition of the River Material and the Developed Features.** The sediment load carried by a river tends to settle down as and when the flow velocity of the river reduces. Depending on, as to where and when the river sediments are dropped and deposited, different types of features may develop. The important of these features include *river deltas* ; *alluvial fans* and *cones* ; *flood plains* and *natural levees* ; *terraces* ; etc. All these features are briefly described below except *terraces* which have earlier been deseribed :

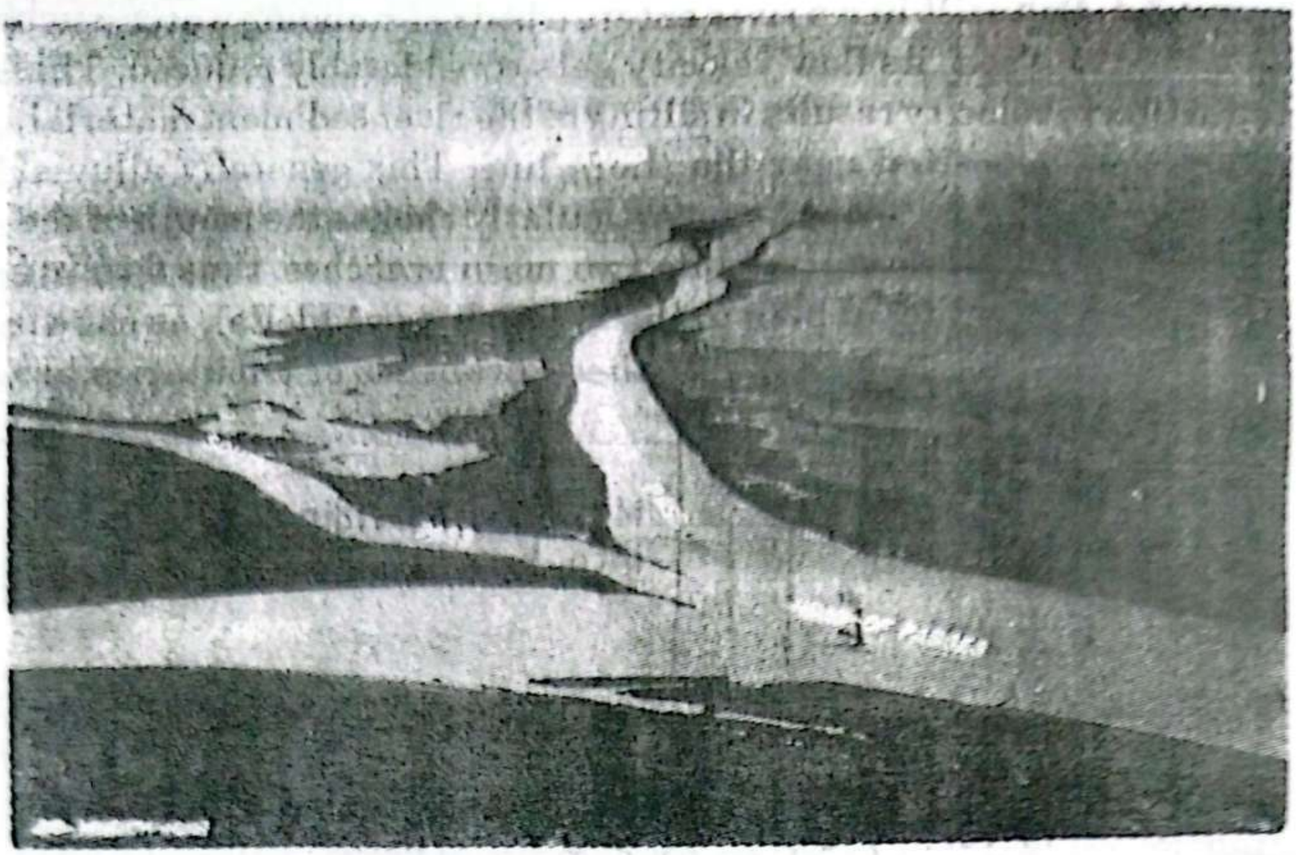
**5.5.3.1. Deltas.** When a river enter: dy of standing water, such as a lake or a sea, its flow velocity g nsiderably reduced. This reduction in velocity results in silting e river sediment material, which gets deposited near the shore . This generally alluvial deposition near the shore line, partic y chokes the mouth of the stream and divides the river into two n branches, thus forming a feature resembling in plan to the G letter Δ (delta), as shown in Fig. 5.15 (*a*). Similarly, when the anches or tributaries are




(*a*) Initial development of a delta.




(*b*) Final development of a delta.

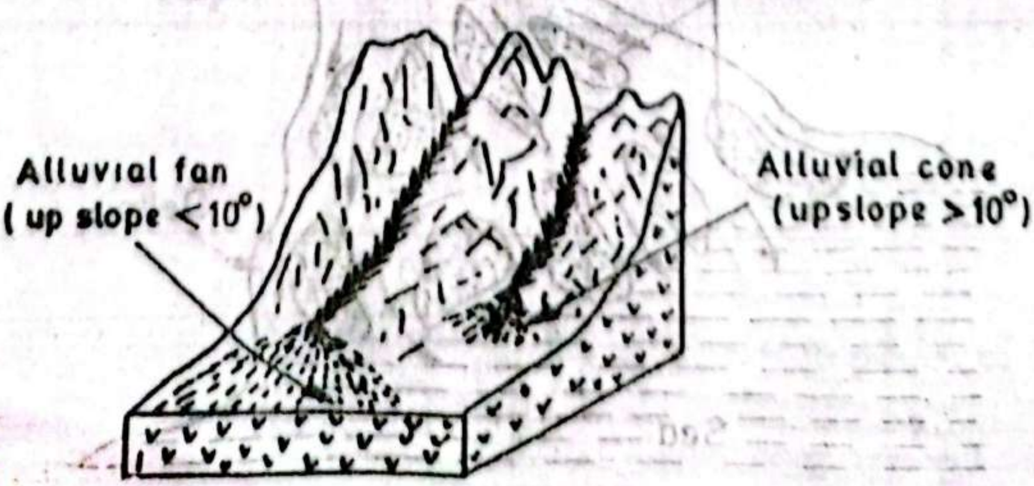


(c) Photographic view of a delta.

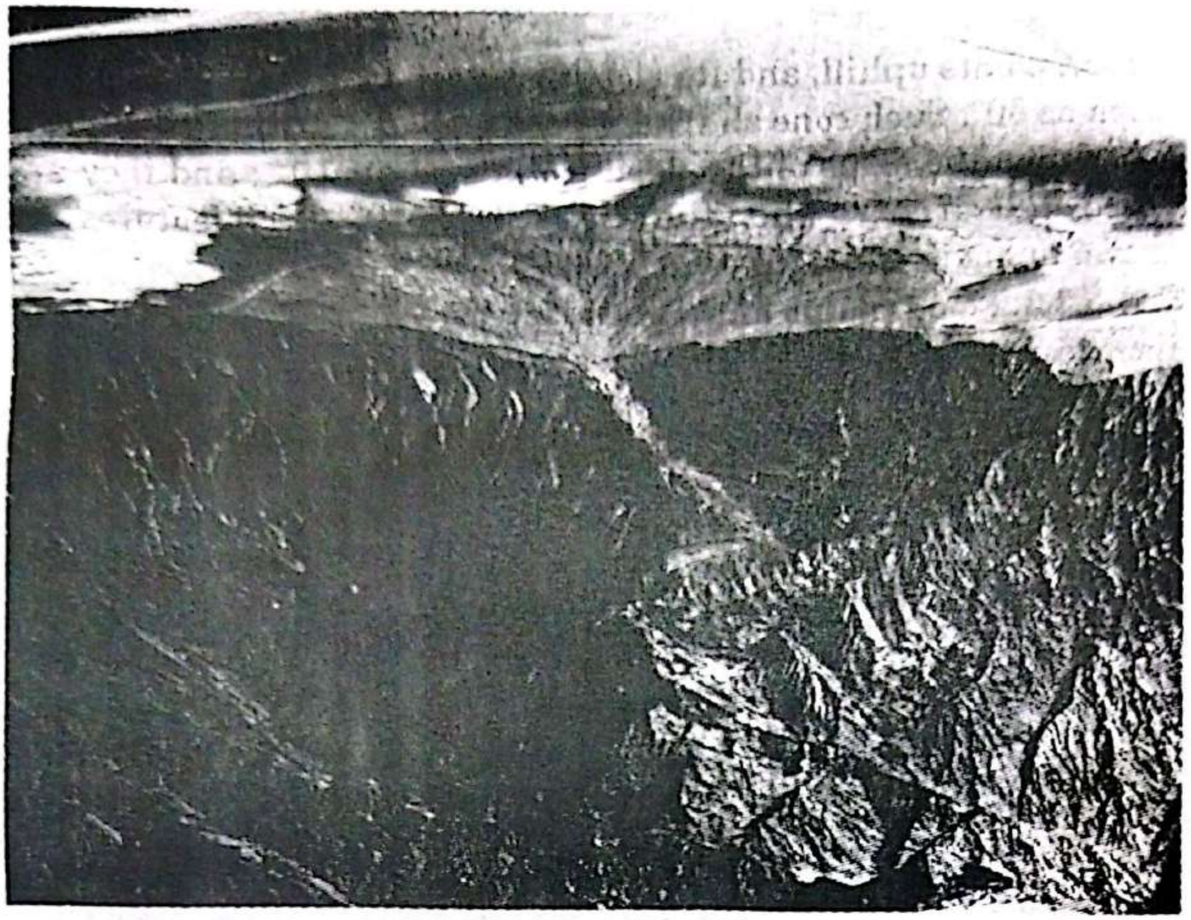
Fig. 5.15. River Delta.

also partially choked, they may be further subdivided into branches. Hence, a delta of a river is indicative of its bifurcation into a number of streams near its outfall point into the sea. The land between these branch streams get deposited with generally fertile alluvial sediments, and may be very useful for growing crops and vegetation. A river delta can thus, play an important role in the economy of a country.

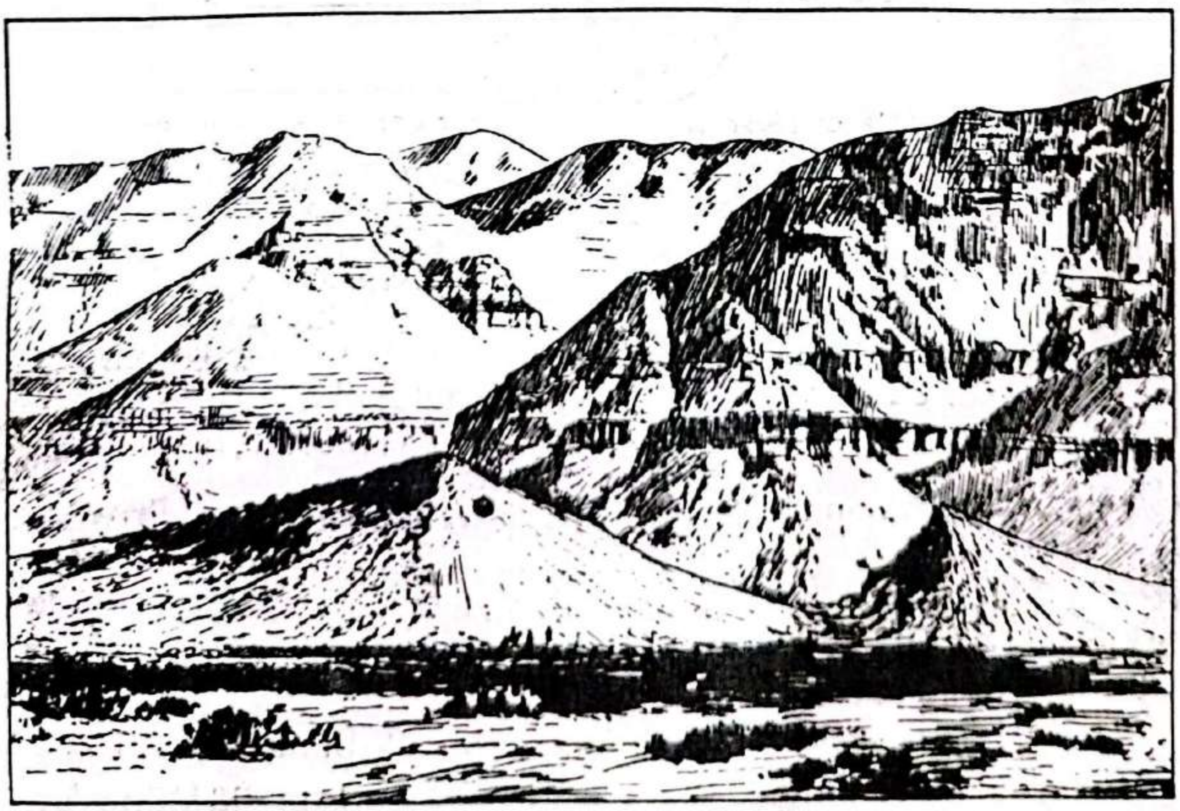
**5.5.3.2. Alluvial fans and cones.** Alluvial cones and fans are deposits of stream sediments, somewhat similar to the ones formed in a river delta, and may be formed where, the stream flows out of mountains into a broad valley in plains, resulting in the reduction in its velocity. Similar deposit features may also develop as and when a mountaineous stream joins a river. The apex of such a




(a) Diagram of fans and cones.



(*b*) Photoview of an alluvial fan on eastern side of Death Valley in California.



(*c*) Perspective view of an alluvial cone at the mouths of canyons in southerh Utaha.
Fig. 5.16. Alluvial Fans and Cones.

deposit points uphill, and its slope may vary from almost flat to as much as 50°. Such cone shaped deposit features are called *alluvial fans*, when the slope of the deposit is less than 10° ; and they are called *alluvial cones* when the slope exceeds 10°. Such features are shown in Fig. 5.16.

**5.5.3.3. Flood plains and natural levees.** When the flow of water increases in a river during flood season, the water level will first fill the river channel up to its top, and then cause flooding in the adjoining valley. Due to this sudden spread of water, the flow velocity is considerably reduced, causing maximum deposition near the top edge of the channel, as shown in Fig. 5.17. Such deposits are called *Levees (or natural levees*, so as differentiate them from man made levees built for flood protection), and they serve as the banks of the river channel.

Although these levees help to keep the river within its banks, but when they are over-topped by higher floods, the area between the levees and the sides of valley will also get submerged, resulting in

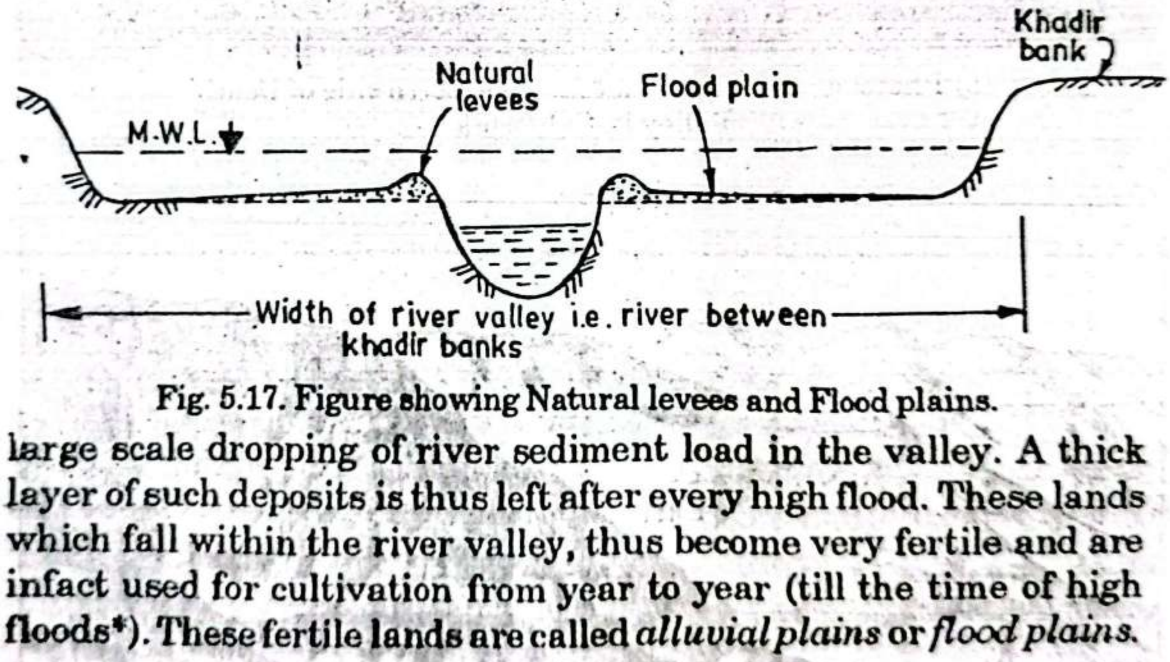



Fig. 5.17. Figure showing Natural levees and Flood plains.

large scale dropping of river sediment load in the valley. A thick layer of such deposits is thus left after every high flood. These lands which fall within the river valley, thus become very fertile and are infact used for cultivation from year to year (till the time of high floods*). These fertile lands are called *alluvial plains* or *flood plains.*

**5.5.4. Development of Overall Landscape and Cycle of Erosion.** In understanding the details of how running water does this or that, so far discussed, one is likely to loose sight of the overall geological accomplishments of stream erosion, which is more or less represented by the *cycle of erosion.*

The term 'cycle of erosion' was given by Mr. William Morris Davis of Hervard, who visualised that every landscape is going through a series of changes from initial uplift, to complete levelling by

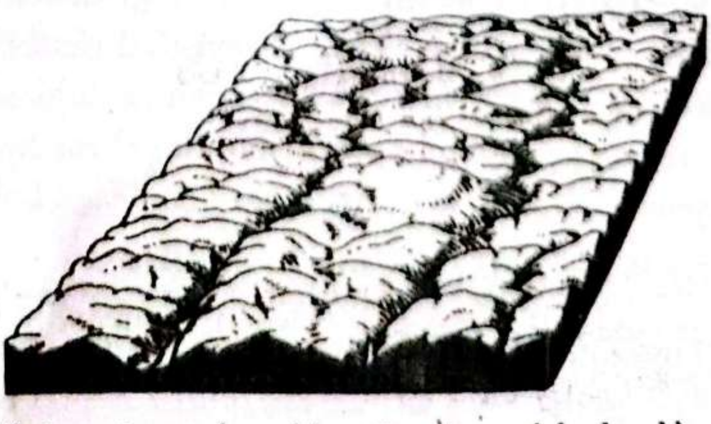
*The cultivation and cultivators are evacuated every year before the onset of major floods weathering and erosion. He, therefore, defined the '*cycle of erosion*' as the total time involved in the reduction of a land area to the *base level*, the lowest level to which streams could reduce a region, if all factors remained constant except time. This entire period or 'cycle of erosion' was divided by him into three stages *i.e.*

(*i*) *youthful stage*,
(*ii*) *mature stage* ; and
(*iii*) *old age stage.*

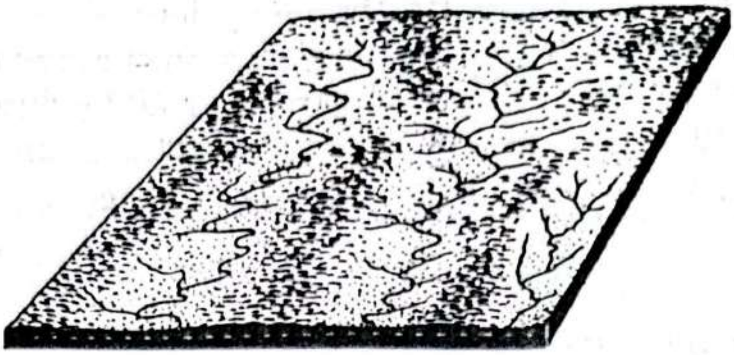
In the **youthful stage**, a newly uplifted area is relatively flat with deeply entrenched streams [Refer Fig. 5.18 (*a*)]. As erosion proceeds, the interstream areas are reduced in size due to the downcutting by the streams and widening of the valleys by downslope movement of the material. When no flat interstream area exists, the stage is said to have progressed to **maturity stage** [Refer Fig. 5.18 (*b*)]. This is the stage of maximum relief or geological features. With further erosion, when the interstream areas are rounded and lowered, it is said to have reached the **old age stage** [Refer Fig. 5.18 (*c*)]. In the *ultimate* stage, when even these gentle interstream areas are worn down to almost flat low levelled ground, the area is called a **peneplain**.

Ideally, a peneplain represents the end stage in the erosion cycle, and would be characterised by sluggish meandering streams ; and the only feature of positive relief would be isolated erosional rem-

(*a*) *Youthfull stage*, parts of initial surface survive.



(*b*) ***Mature stage***, when old surface is vanished and landscape is mainly apart from valley floors.



(c) *Old agè stage,* when landscape becomes subdued and gently undulating, rising only to residual hills, representing the divides between adjoining drainage basins.

Fig. 5.18. Stages in the Cycle of Erosion started on newly uplifted land surface.

nants, called **monadnocks**, which are rounded rock masses uncon-sumed by erosional process, and standing above the general level of peneplain. But in actual practical life, peneplains are the rare features of the Earth's surface. This may be probably due to the reason that an area rarely goes through the complete cycle of erosion, but the cycle is generally interrupted and started afresh, by some new uplift, etc.

**WIND EROSION AND GEOLOGICAL WORK OF WIND**

The Earth, as you know, is surround by an envelop of gases, called the *atmosphere*. The movement of the atmosphere in a direction parallel to the Earth's surface, is *wind* ; whereas the vertical movements of the atmosphere are termed as *air-currents*. The causes of wind formation is the subject of a science called *Meteorology*, and is beyond the scope of this book. We under Geology, are mainly concerned with the geological work done by wind, in the form of erosion and consequent deposition of the eroded material

Like water, wind is also an agent of erosion, transportation, as well as deposition. It is quite an effective agent of erosion in deserts and arid dry areas. While eroding the Earth's surface by mechanical action alone, it produces certain typical geological features ; and similarly, it does so while depositing the eroded material at some other place after its tranportation. The entire geological work per-formed by wind can, therefore, be studied under three headings ; *i.e.* erosion, transportation, and deposition, as discussed below :

## 5.6. Erosion by Wind and Developed Features

Wind erosion is generally caused by two main erosion processes ; *viz.*

(i) *Deflation* ; and
(ii) *Abrasion* ; as explained below :

**5.6.1. Deflation.** Deflation is the process of simply removing the loose *sand* and *dust* sized particles from an area, by fast moving winds. Such a removal of loose fine particles, may at certain places, leave a denuded surface, consisting mostly of hard rocks or coarse material like gravel, and is called *lag gravel*. This gravel layer prevents further deflation. At some other places, where the surface material contains no coarse particles like gravel or pebbles, such as in deserts, deflation may result in the formation of depressions or hollows, called **blow-outs** or **blow holes.** Blow outs represent shallow depressions, generally a few metres deep, and several hectares in area. They may be recognised by their concave shape that could not have been produced by water erosion. These depressions may sometimes become so deep as to expose the ground water-table to the surface ; they are then called **Oases** (Refer Fig. 5.19). An oasis is the most likely place in a desert where vegetation can grow. There are numerous oases with depths of 15 to 30 m in Egyptian deserts ; with *Quattara depression* of Western Egypt providing an extreme example with its 300 km length, 140 km width and 125 m depth (below sea level).

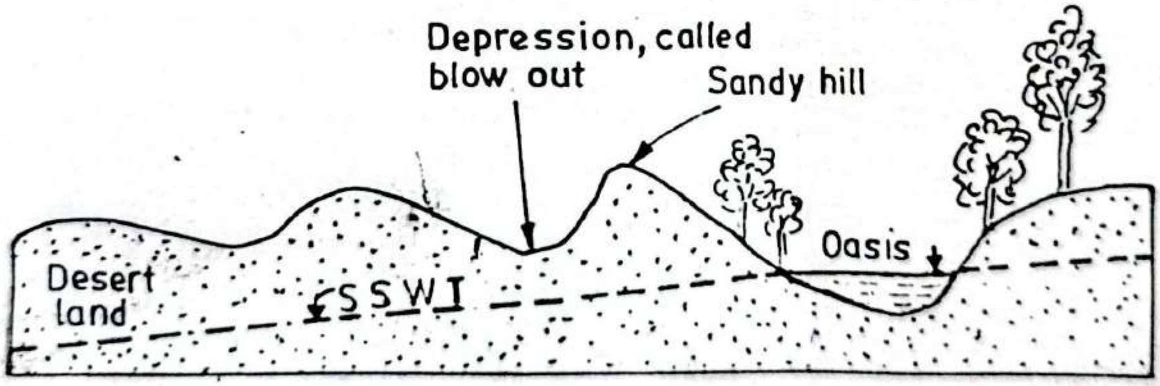
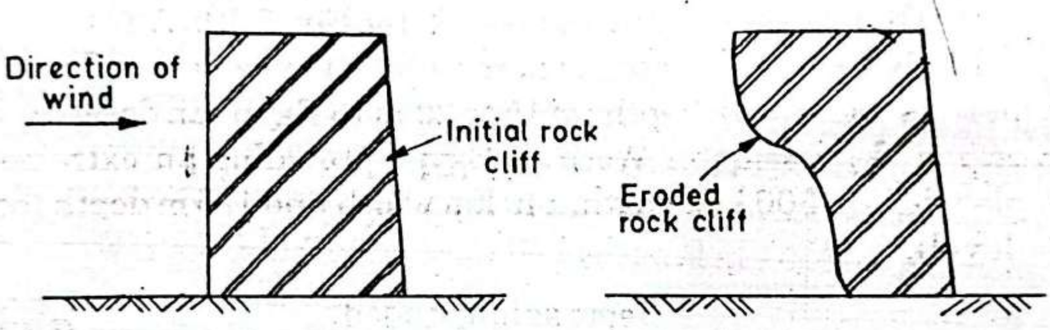



Fig. 5.19. Blow out and Oasis, produced in a desert (vertical scale shown enlarged).

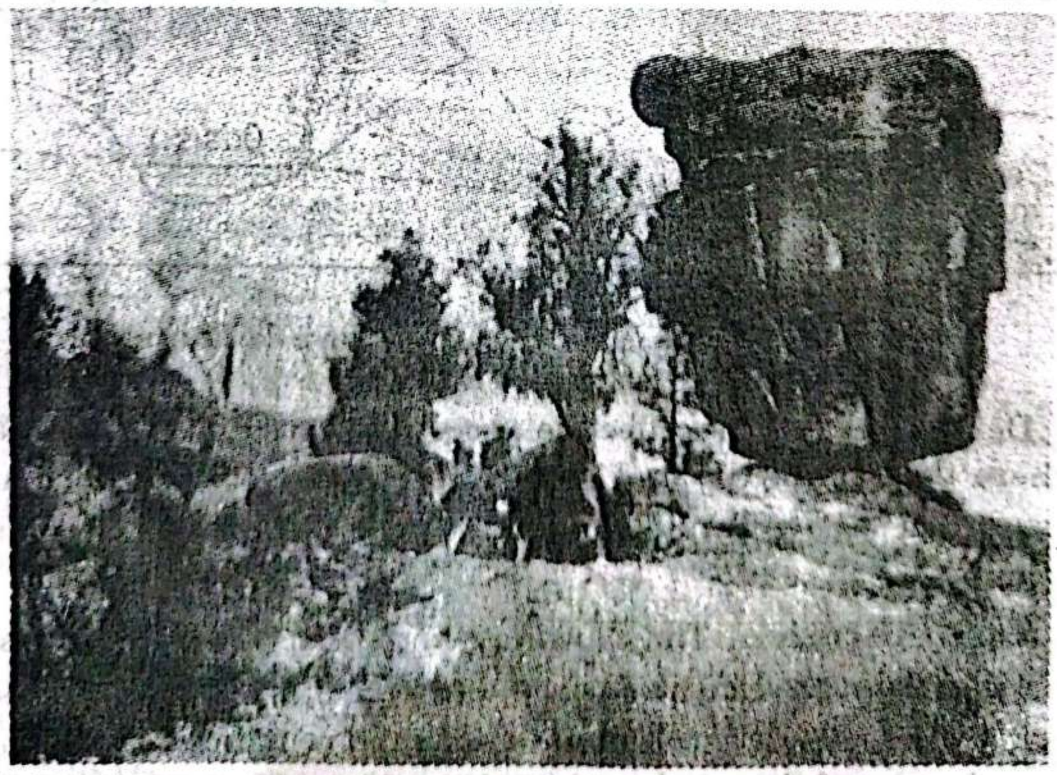
Deflation is a very effective process of wind erosion at places where the land is dry and devoid of vegetative covers, such as in deserts of agricultural lands subjected to extended periods of drought.

**5.6.2. Abrasion.** The blowing winds generally pick up sand particles from the Earth's surface, and then move with them as sand laiden winds. Most of this quantity of sand remains confined to the lower layers of the wind, within about 30 to 60 cm of the surface, and when sand laiden winds strike the prutending rocks or other structures in their way, they will cause them to erode by the rubbing and grinding action of the moving sand particles. This natural abrasion process is similar to artificial *sandblasting*, a process adopted for cleaning and polishing stones, and for etching glass.

This abrasive action of winds is, however, most pronounced on objects standing very close to the Earth's surface (*i.e.* within 30 to 60 cm), due to the maximum concentration of sand load within this small distance. Hence, abrasion will not cause any appreciable erosion of the upper parts of the projecting obstructions, but will cause maximum erosion of the lower parts of the same obstruction. Due to this reason, the cliffs or other rocks, standing on the Earth's surface, are eroded or undercut at the bottom, as shown in Fig. 5.20 (*a*) and (*b*). Such rocks are somewhat similar to pedestal rocks, found near sea shores and formed by waves or water erosion.




(*a*) *Sectional view*, showing abrasion when wind blows from one direction.



(*b*) *Photographic view* showing general abrasion by winds.

**Fig. 5.20.** Figure illustrating the under-cutting or erosion caused by winds due to abrasion.

Stones or boulders lying on the ground surface will also be largely subjected to this abrasive action of winds ; and will get smoothened and polished if they are fine grained ; and pitted or etched if they consist of coarse crystals of unequal hardness. Such wind abraded stones are called **ventifacts**, and they usually occur in association with lag gravels.

### 5.7. Transportation of Eroded Sediment by Wind

The total sediment load carried by a wind can be divided into two parts ; *viz*

(*a*) *bed load* ; and

(*b*) *suspended load*

The larger and heavier particles, such as sands or gravels, which are moved by the winds, but not lifted more than 30 to 60 cm of the Earth's surface, constitute the *bed load*. Whereas, the finer clay or dust particles which are lifted by the moving winds by a distance of hundreds of metres above the Earth's surface, constitute the *suspended load*. The size of the wind blown material seldom exceeds 1 mm, with the average as $\frac{1}{4}$ mm ; and all the material finer than 1/16 mm is considered as dust or suspended load.

Evidently, the bed load produces *sand storms,* and suspended load produces *dust storms.* Moreover, with this, you can easily imagine that *sand storms are associated with dust storms,* but *dust storms may occur without sand storms* ; so in general, dust is moved much farther than sand.

The mechanism behind the movement of bed load (or sand) is attributed to the bouncing or jumping motion of the particles, caused by a process called **saltation method**. If begins, when grain under the wind action, falls into another grain, or is momentarily lifted and then falls over another grain, thus hitting it with some force. This force will then cause the second grain to move and bounce up, carried upto some distance. and finally falling again, hitting some other grain or grains. The Process continues as long as the wind velocity is sufficiently high to keep the sand particles moving. [Refer Fig. 5.21]. It has been estimated that a velocity of about 20 km/hr. is necessary for keeping the fine sand (*i.e.* $\frac{1}{4}$ mm or below in size) in motion.

Sand grain 1 is momentarily lifted by wind and falls back hitting grain 4 and 5, which are again lifted. Similarly, grain 2 rolls over, under wind action, and hits grain 3, which is again lifted. The process continues.

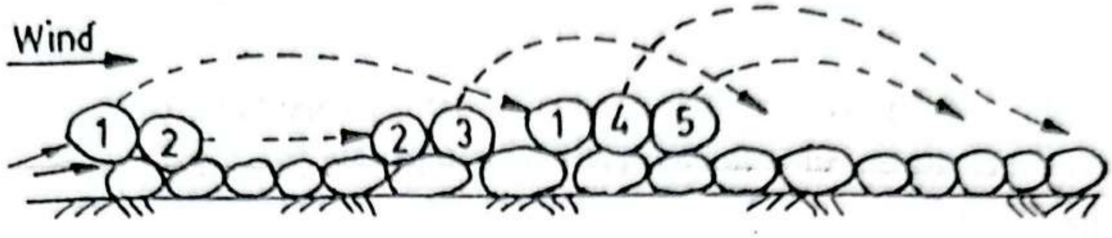



Fig. 5.21. Saltation method of movement of sand grains by wind (grains shown exaggerated in the figure).

The movement of suspended load is easy, and no technicalities are involved. It remains in suspension by the turbulence of the wind, and is moved along with the wind to far off distances, before it is brought down to the Earth's surface by rains, etc.

## 5.8. Deposition of Sediment by Wind and the Developed Features

When the velocity of a fast blowing sediment laiden wind is checked by some obstruction or otherwise, the sediments get dropped and deposited, forming what are known as *aeolian deposits*. The factors which may cause a check in the velocity of the winds and the consequent formation of such deposits, may include : prominent obstructions like hills, mountains and forests ; sudden change in climate and fall of precipitation ; etc. Water bodies like lakes, rivers and oceans may also check the movement of winds moving very close to the ground surface, thus trapping large amounts of bed loads.

There are two important types of aeolian deposits ; *viz*

(1) *Sand dunes* ; and

(2) *Loess.*

*Sand dunes* are formed by the deposition of bed load from sand storms, and the *Loess* are formed by the deposition of suspended load from the dust storms. These two types of important geological features are further described below :

**5.8.1. Sand Dunes.** Sand dunes are the huge heaps of sand formed by the natural deposition of wind blown sand. Such heaps are generally having defined shapes, each having a crest or a definite summit.

The formation of most of the sand dunes probably starts in the lee of an obstacle, as shown in Fig. 5.22. The sand is dropped around such an obstruction, as the velocity of the sand laiden wind is

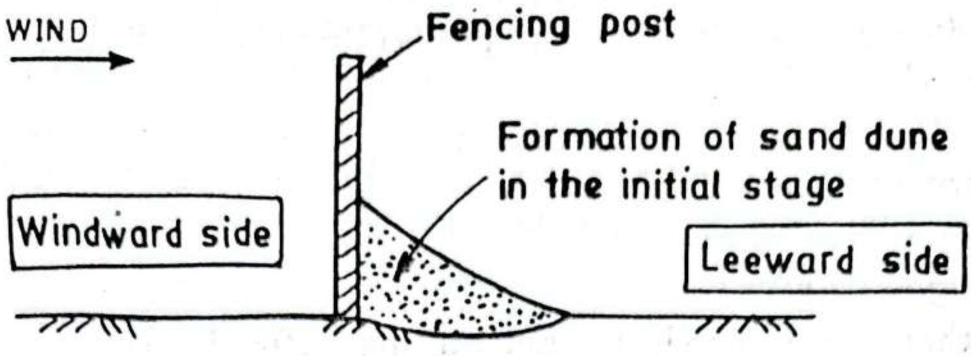



Fig. 5.22. Accumulation of sand in lee of a fence post in the initial stages of a dune formation.

partially checked by the obstruction offered by such an obstacle. When this process of deposition of sand continues for some sufficient time, the accumulated sand takes the form of a heap, which itself then starts acting as a wind barrier, causing further accelerated deposition, and resulting in the formation of different types of sand dunes. Unless they have become *fixed or stabilised* by the vegetation grown over them, most of the sand dunes move slowly across the desert (Refer Fig. 5.23), and are called *active dunes*.

A typical active sand dune is generally characterised by a shape which is triangular in section, having a gentle windward slope and a steeper leeward slope, as shown in Fig. 5.23. Depending upon the variations of winds (their directions, and chances of occurrence) and the climatic variations or possibilities of vegetation growth over a

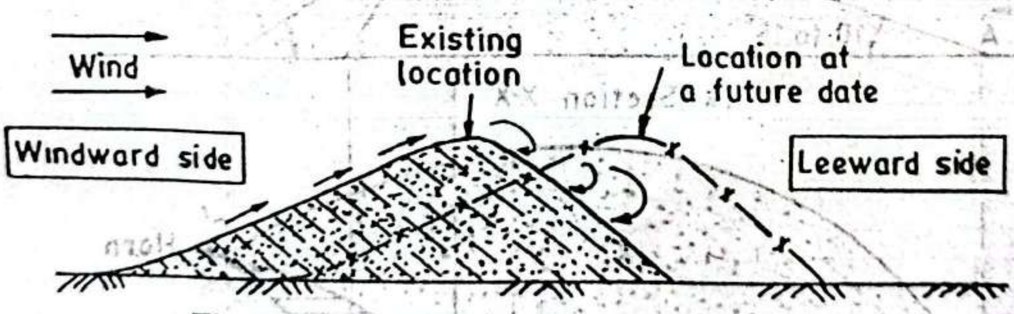



Fig. 5.23. The drifting movement of an *active* (or *unstabilised*) *sand dune* with time.

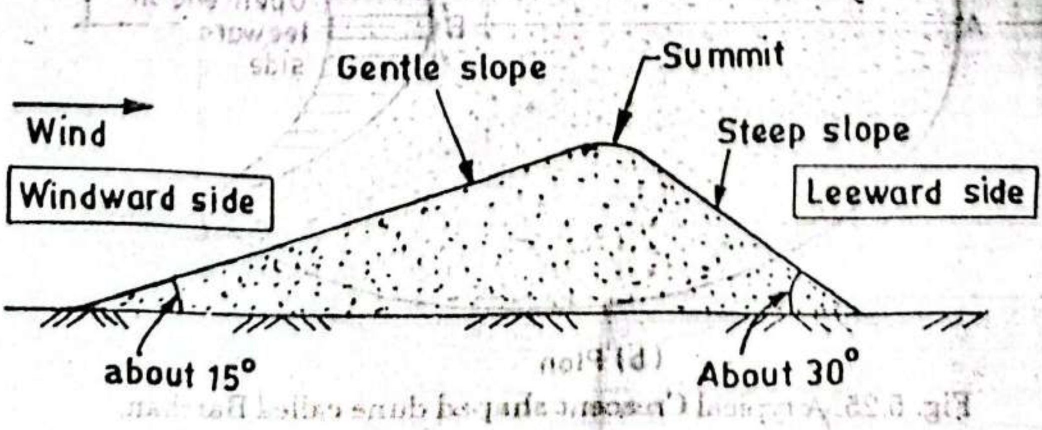



Fig. 5.24. The appearance of a typical sand dune in section.

dune, the sand dunes may acquire different shapes and sizes. The shapes of the *stablished dunes* are generally different from those of the *active dunes*.

The **active dunes** can be divided into the following three types :

(*i*) *barchans* or *crescent* shaped* dunes ;

(*ii*) *transverse* dunes ; and

(*iii*) *longitudinal* dunes.

All other dunes which are not having defined shapes may be called complex irregular dunes.

The most common form of **stabilised dunes** is the *U-shaped dune*, often called a *parabolic dune*. These different types of dunes are briefly discussed below :

(*i*) **Barchans or Crescent shaped dunes.** These dunes which look line a new moon in plan, are of most common occurrence. They are triangular in section with the steep side facing away from the wind direction and inclined at an angle of about 30 to 33° to the horizontal. The gently sloping side lies on the windward side, and makes an angle of about 10 to 15° with the horizontal, as shown in Fig. 5.25. They may have variable sizes, with a generally maximum height of

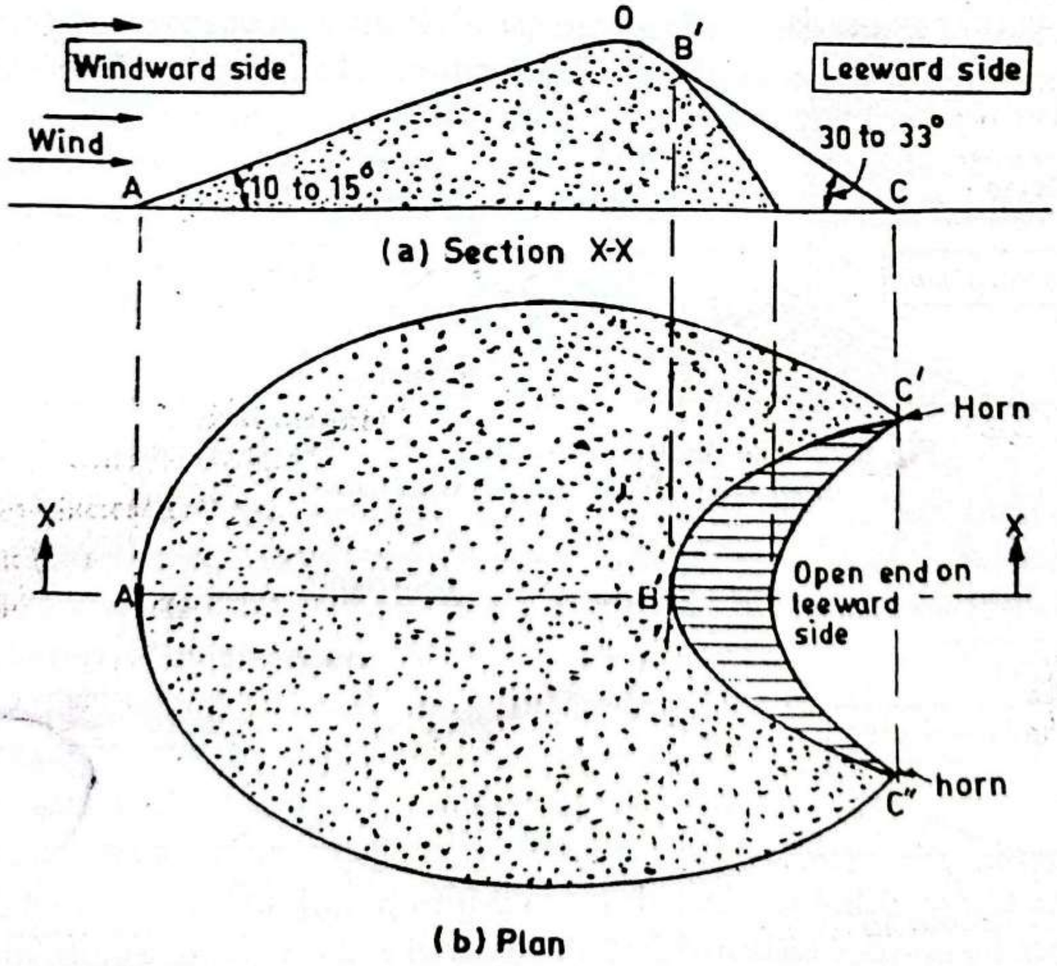



Fig. 5.25. A typical Crescent shaped dune called Barchan.

*New moon like shape.

about 35 metres, and horn to horn width of say 350 metres.

They are generally found to occur in groups in areas of constant wind direction, although isolated units are also found. They may drift or migrate longitudinally at a rate of about 8 to 15 metres per year.

(*ii*) **Transverse dunes.** A transverse dune is similar to a barchan in section ; but in plan, it is not curved like barchan and is such that its longer axis is broadly transverse to the direction of the prevailing winds, as shown in Fig. 5.26.

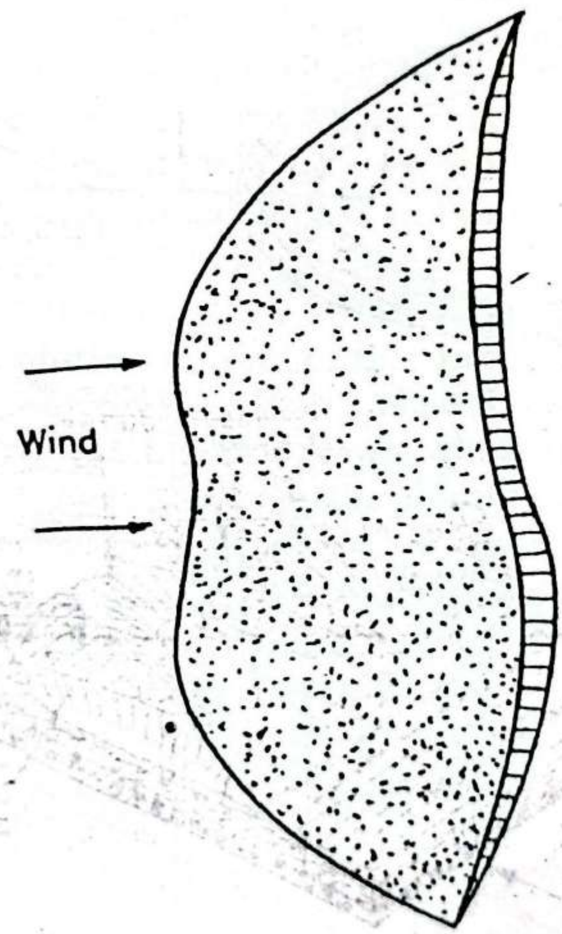



**Fig. 5.26. Plan of a Transverse dune.**

Transverse dunes generally occur in areas with strong winds and where more sand is available.

(*iii*) **Longitudinal dunes or Selfs.** Longitudinal dunes are the elongated ridges of sand with their linger axis broadly parallel to the direction of the prevailing winds. [Refer Fig. 5.27]. When seen

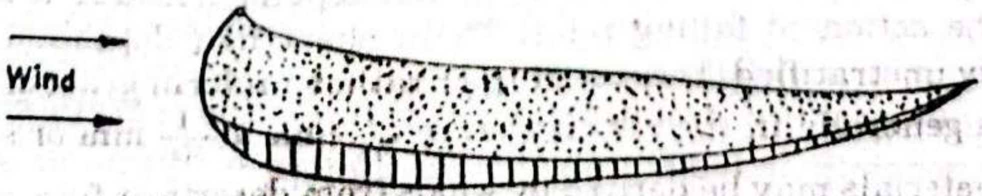
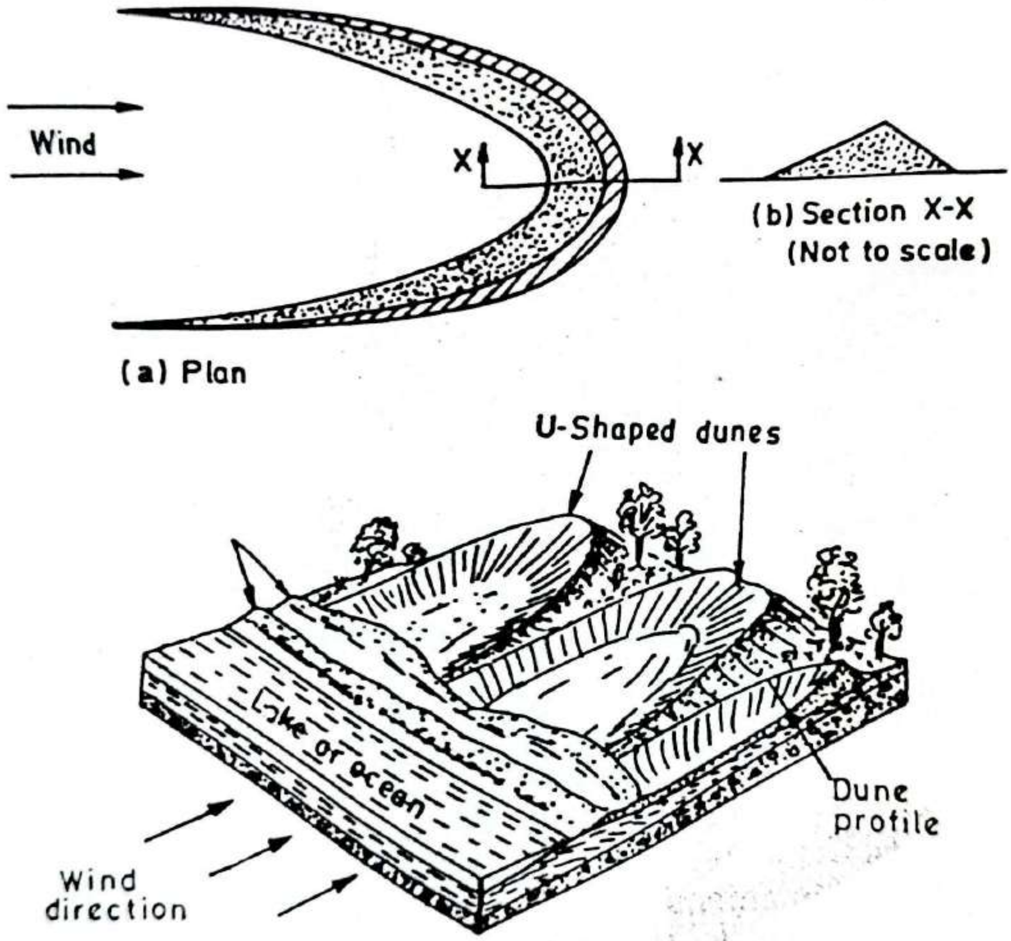



**Fig. 5.27. Longitudinal dunes (Plan view).**

in the side view, they will appear to be triangular. They occur in areas of somewhat high and variable winds, and where small amount of sand is available. On an average, they may be 3 metres high and 200 metres long, although in extreme cases, they may be a high as 90 metres and as ling as 100 kilometres.

*(iv)* **U-shaped or Parabolic dunes.** They are the extremely curved shaped dunes (in plan), more curvilinear than barchans, and look like an open parabola in plan. However, unlike, barchans, they have their open end facing towards the wind, as shown in Fig. 5.28.




(c) Perspective view.
Fig. 5.28. Parabolic or U-shaped dune.

The height of such dunes is generally limited to about 30 metres. They occur in areas of moderate winds and some vegetation, such as in coastal areas near the sea shores.

**5.8.2. Loess.** *Loess* are the blanket deposits of silt and clay formed by the deposition of such material from the suspended load of winds, under the action of falling rains. These sheet like deposits are relatively unstratified, because of their rather uniform grain size, which is generally in the silt size range ($\frac{1}{16}$ mm to $\frac{1}{500}$ mm or so). These materials may be derived by winds from deserts or from the flood plains of rivers.

Initially, these deposits are porous and friable, but with the passage of time, they become stronger due to the protective grip of the grasses that grow over them.

200 to 300 metres thick loess deposits of North China provide an excellent example of such deposits. They are believed to have been formed from the winds coming from the deserts of Central Asia, especially the Gobi desert. There are no such deposits in India, although countries like America, Sudan, Nigeria, etc. are having some good enough loess deposits. Loess deposits have been tried for the manufacture of bricks, but the product is not so satisfactory.

**5.8.3. Engineering Problems Posed by Sand Dunes and Loess.** The biggest engineering problem posed by sand dunes is their migration and movement of sand. The sand is sometimes flown away by the violent winds from the unstabilised dunes, and may get deposited over any valuable land and property, causing enormous losses and disasters. The migration of a sand dune itself will make it impossible to carry out any kind of construction on it.

The best solution to combat this problem of sand dunes is to stabilise them by covering their surface by vegetative covers. First of all, some grasses should be grown, which can be replaced later by suitable forest trees. Moroever, the plantation should be done in the beginning on the windward side of the dune.

Loess deposits offer engineering problems in two ways. Firstly, they are likely to settle on wetting or when loaded by construction of engineering structures, against which their safety must be examined. Secondly, in cold countries, they pose problems in highway or air-field constructions, because they are highly susceptible to frost heaving. The only remedy in such cases is to remove the loess to a depth below the level of frost penetration, and replace it with coarse material.

## EROSION BY MOVING ICE AND GEOLOGICAL WORK OF GLACIERS

A *glacier* is a mass of moving ice*, which causes erosion of the surface over which it moves. The eroded material is carried in an embedded state by the glacier over some distance ; and then deposited at some place (s), as and when the sediment load gets separated out due to over-loading or sudden disturbance or melting of glacier itself. A glacier, like water and wind, thus act as an agent of erosion, transportation, as well as deposition.

About 10% of our present land of the globe is covered by glaciers. They are slow erosive agents, much less effective than water, as far

*Moving naturally under the action of gravity, of course.

as the overall erosion is concerned. However, in areas of excessive snowfalls, such as in mountain tops and solar regions, they become quite effective over a period of time, and are thus believed to have developed many land forms (*i.e.*, geological features) of the world.

The activity of the glaciers, and the way they have changed, or are changing the land beneath them, will now be discussed in the following pages under this sub-chapter.

## 5.9. Growth and Movement of Glaciers

A glacier, as defined earlier, is a mass of moving ice. It is formed by the crystallisation of the accumulated snow in high altitude snowhill areas, called snowfields* In such areas, where annual snowfall is more than the snow melted or wasted, snow layers will go on accumulating year after year, until a sizable thickness is reached. When buried beneath the upper layers of older snow layers (initially light and loosely packed flakes with sp. gravity = 0.05) get compressed by the overburden. Due to the successively increasing overburden pressure, the snow undergoes a series of changes, similar to low temperature metamorphic changes ; and finally recrystallises to form pure air-free ice (a dense coarsely crystalline mass with specific gravity = 0.9). An intermediate product formed in the process, is called neve or **firn**, which is a granular mass of impure ice with sp. gravity = 0.8. This *neve*, on further compaction and crystallisation, becomes pure crystalline solid ice. When the amount of ice formed in this way, becomes large enough (of the order of 30 to 50 m in depth), it begins to flow as a *plastic solid* under its own weight, thus giving birth to a **glacier**.

The mechanics of a glacier flow is not clearly understood, but the velocity of glacier movement can be measured on the *glacier surface*, by driving a series of stakes and by surveying their displacements over a certain period of time. On such surveys, the glaciers have been found differing in their movement rates, from a few cm per day to as much as 20 metres per day under extreme conditions. The velocities, deep below the glacier surface, are difficult to be evaluated even with the help of bore holes. It is however, generally believed that the *rate of glacier flow increases with depth*, but some minimum movement does occur at the base of the glacier, as confirmed by the evidence of glacier erosion found on the rock surfaces formerly covered by glacier ice.

*The areas situated at a level above the *snow* line are called *snow fields*. *Snow line* is the arbitrary altitude line in a region representing the level up to which snow melts in summer. Hence above this level, the areas will always be covered permanently with ice, forming permanent snow fields.

## 5.10. Types of Glaciers

Glaciers are of the following two types :

(1) *Valley glacier* or *Mountain glacier* ; and

(2) *Continental glacier* or *Ice sheets* or *Ice caps*.

**Valley glaciers** are literally rivers of ice flowing between valley walls, and extending from a neve in the mountains, down into the valley. They may also emerge from the edge of an ice sheet. In the former case, they are called *alpine glaciers** ; and in the latter case, *polar glaciers* or *ice tongues*.

**Ice sheets** are those, forming huge sheets of ice, covering a large part of the continent. They cover broad areas, and flow outward in all directions from the zone of accumulation.

Another name, called **Piedmont glacier**, is given when a number of valley glaciers join and spread out at the foot of a mountain range.

## 5.11. Valley Glaciers and their Characteristics

The valley glaciers, often called *mountain glaciers*, may be defined as the rivers of ice, developed in previously formed stream valleys. Such pre-existing river valleys, because of their being at lower level than the surrounding country, become accumulation sites for snow, which with the passage of time gets converted into ice, as explained earlier. When sufficient ice has formed, the glacier begins to move down the valley.

A glacier, thus, moves down the valley under the influence of increasing accumulation of snow. This will happen when snowfall exceeds the snow wasted or melted. But as the glacier moves down the valley, the rate of wastage or melting increases due to the warmer climates of the lower altitude regions. Thus, at certain point in the valley, say several hundred metres below the snow line, a position may reach when a balance is established between : (*i*) The *snow accumulation* mostly in the upper regions) and the consequent movement of the glacier, and (*ii*) The *snow melted* (mostly in the lower levels).

**Under such a condition of equilibrium, the toe (*snout*) of the glacier will become fixed at a certain point in the valley. The glacier is then said to be in equilibrium.**

**However, if the rate of snow accumulation decreases due to lesser snowfall, or wastage increases due to warming up of climate, then naturally the glacier's toe will melt back, and the glacier is said to be retreating.** Conversly also, if the rate of snowfall increases or the

*The name given on the name of Alpine valley where such glaciers occur in abundance.

climate becomes cooler, causing less melting, the **glacier's snout** (toe) will move further down the valley, and the glacier is said to be **advancing**.

It may also be pointed out here that 'the change of climate' or 'the change in the rate of accumulation of snow', considered above, are not the instantaneous changes, but are the changes over a period of number of years. Hence, the advance or the retreat of the glacier's snout (toe) gives some information on the long term climatic changes. Most of the glaciers of the world today are retreating in response to a general world wide climatic warming. Another point which needs emphasis is that the glacial ice is always moving (flowing) down the valley, even if the toe of the glacier is retreating (the retreat being the net result of actual forward movement of the glacier and the backward movement by melting).

Of the two types of the glaciers, the valley glaciers are the most common. They may be a few hundred metres in width and many kilometres in length. The are largely found developed in numerous valleys of Alpine, Himalayas, Caucasus and Karkoram mountain ranges. Smaller sized valley glaciers are found in the Zanskar range of the Kashmir Himalayas also.

The surface of a valley glacier usually contains rock debris eroded from the valley walls. These debris found embedded in the glacial ice, forms *longitudinal visible dark bands*, called **moraines**. These *moraines* can be seen on aerial photographs of a glacier. After a glacier becomes extinct, these debris are left behind on the valley floor as deposits, and they are then also called as *moraines*. The details of the different types of moraines will, therefore, be discussed as 'deposit features' a little later, and not here.

Besides these visible bands, the surface of a glacier also contains open cracks or *crevasses*. These crevasses may be quite deep upto 30—60 m, and may be developed due to the difference in the rate of flow of the top and bottom layers in the upper brittle portion of the glacier ice. Sometimes, these crevasses get filled up with blowing snow, which hides their presence. Extreme care is, therefore, needed while traversing such hidden crevassed zones. Fatal accidents have befallen many mountain climbers, who failed to appreciate the dangers associated with such covered hidden crevasses.

## 5.12. Zeological Work of Valley Glaciers

A valley glacier further *erodes* its pre-existing stream valley, *transports* the eroded material, and finally *deposits* the same at some places downstream. While doing so, it produces numerous land forms, called geological features. The entire geological work performed by valley glaciers is discussed below in this article.

**5.12.1. Glacial Erosion.** Erosion by glaciers is generally caused in two ways, *i.e.*

(*i*) by *plucking* ; and

(*ii*) by *abrasion*.

**Plucking** or *Quarrying* is the process of loosening a rock mass and then pulling out blocks after blocks from the loosened bed rock. This natural erosion process taking place in a glacial stream-valley is started by the melt water that flows into the joints in the bed rock and later freezes to the main mass of ice. The moving glacial ice thus develops a firm hold or attachment with that portion of the rock mass into which it has crept in. Now, when the glacial body moves down the valley, it exerts sufficient pressure over the gripped rock, and thereby tearing some of the rock blocks out of its place. An irregular surface is thus created in the rock mass which facilitates further plucking. Thus, blocks after blocks are torn out of position, and moved away, leaving behind a rough and rugged surface.

The **abrasion** (*i.e.* rubbing and scratching) action now plays the secondary roll. The plucked angular rock pieces and the debris that fall on the glacier from the valley sides, help the moving ice mass to cause grinding on the sides and bottom by abrasion. These rock fragments act like teeths in the rock mass, and do the grinding work. The bigger fragments sometimes cut the rock, producing *grooves* in it ; the fine sharp pointed fragments leave *scratches* on the rock surface ; and sand and silt does the *polishing* job. These *grooves, scratches,* and *polishing* due to erosion infact, provide good geological features of a glacial river, and thus helping in its recognition.

As far as the overall erosion is concerned, it can be said that *plucking* probably does most of the erosion ; whereas, the *abrasion* generally smooths and even polishes the resulting form.

Glacial erosion greatly modifies the shape of that portion of the river valley which was occupied by the glacier. A glacial valley generally differs from a river valley in the sense that *it is deepened and side slopes are steepened so that its cross-section is changed from V-shaped to* **U-shaped** (Refer Fig. 5.29).

The deepening of a glacial valley will be more, if the glacial ice is more, or the glacier size is large. The tributary valleys occupied by smaller glaciers are, therefore, less deeply eroded than the main valley, and hence, are left *hanging* above the trunk valley. Such a valley is called a **hanging valley,** and it makes a fascinating geological work done by glaciers. With the disappearance of the glaciers,

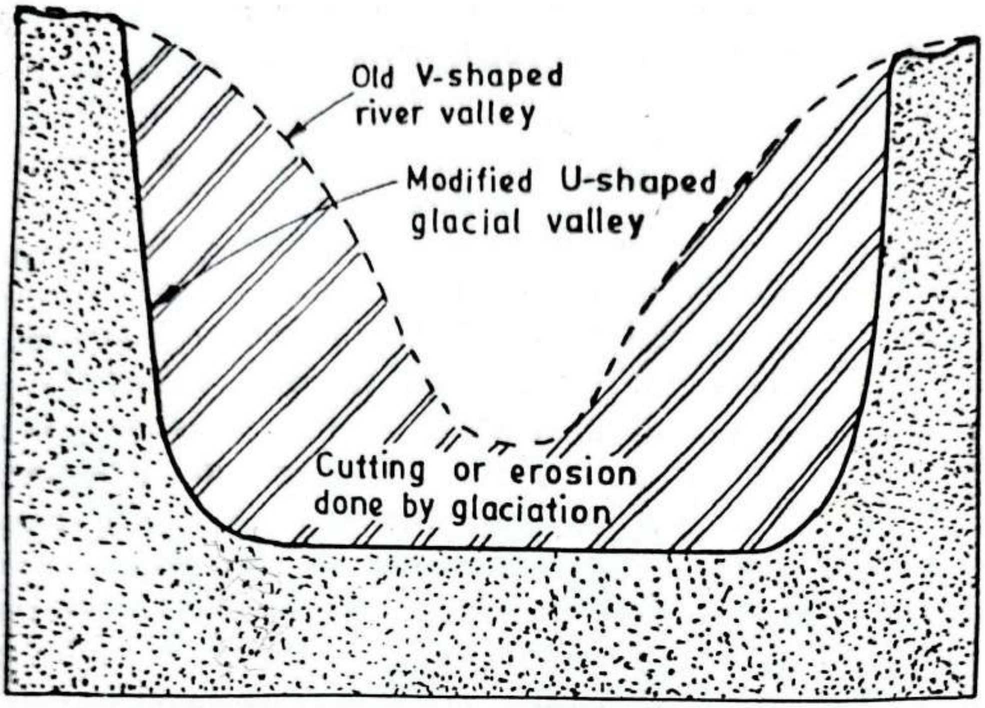



Fig. 5.29. Formation of U-shaped valley cross-section from the old V-shaped ; modification done by glacier erosion.

the hanging valleys are reoccupied by water streams, which discharge into the main valley *via* water falls. [Refer Fig. 5.30].

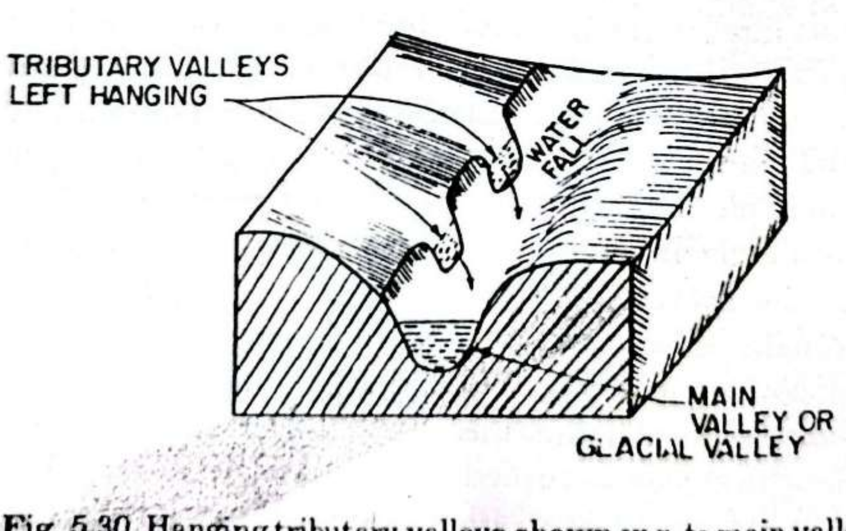



Fig. 5.30. Hanging tributary valleys shown w.r. to main valley.

Besides such changes imposed in the valley cross-sections, the glaciation also produces changes in their longitudinal profiles, due to unequal erosion along their lengths. This glacial erosion is most active near the head of the glacier. In the upper reaches, therefore, more deepening will occur, which flattens the gradient of the valley. This deepening together with the steepening of the sides, at the head of the valley, produces a semi-circular or half bowl-shaped* depression, within an otherwise uniform valley shape. This amphi-theature like form is called cirque (Refer Fig. 5.31). Downstream of this

*A tea-cup cut vertically in half.

cirque, steps may be developed in the river profile at places where more resistant rocks, crop out. Such *bed rock basins* may contain lakes (Refer Fig. 5.31).

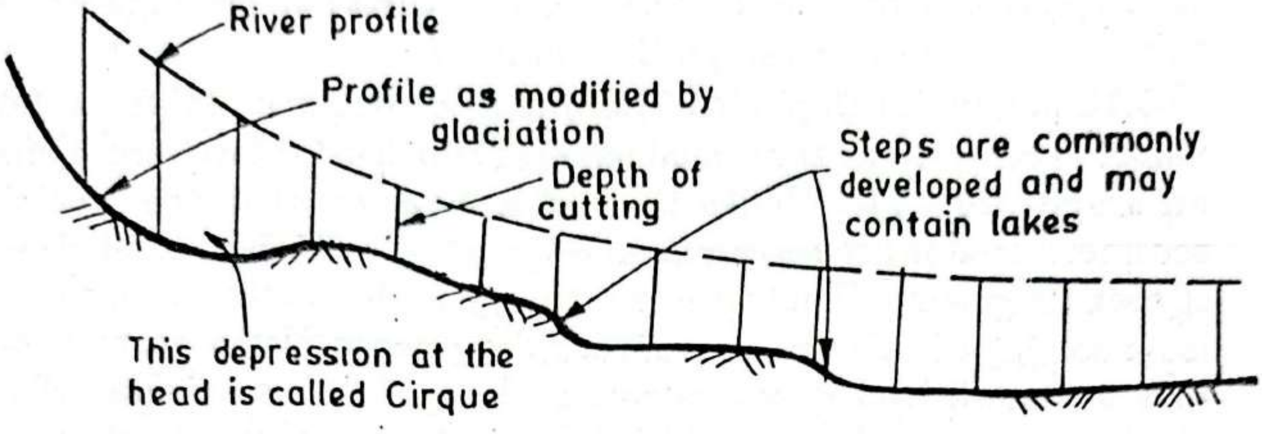



Fig. 5.31. Formation of Cirque and Steps. The figure shows the longitudinal profiles of a river valley and that modified by glaciation.

Besides developing such important erosional features like U-shape, cirque, steps, hanging valleys, etc., a few more changes are produced by glacial erosion. For example, the originally existing small hills or knobs in the river valley, are over-ridden by the glaciers ; and are rounded and smoothened by abrasion on up side, and are steepened by plucking on the down or leeward side, as shown in Fig. 5.32. Such residual hillocks are called **whaleback forms or roches mountonnes.**

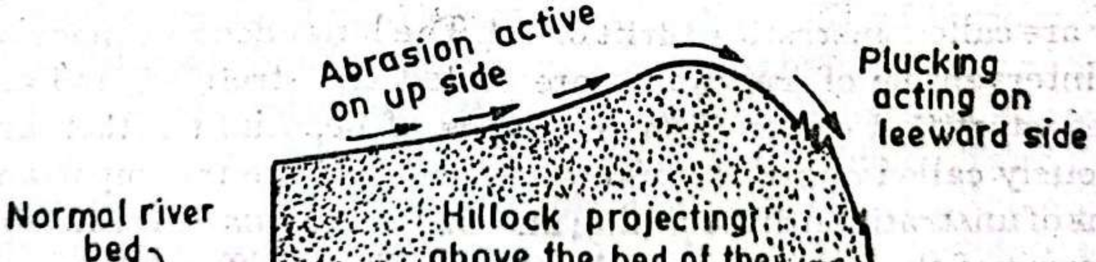



Fig. 5.32. Roches mountonne (*i.e.* Residual hillock left by glaciations).

Also, a glacier tries to *straighten the original curvilinear path of the river valley,* as it cannot turn like water. This will remove the spurs or ridges on the insides of the curves of the stream valley.

Besides producing such changes in the main valley through which the glacier actually moves, certain changes are produced even in the higher parts of the mountain range that is above the level of glaciers. What happens there is that due to the presence of glaciers, the frost action in the nearby higher mountains increases, which produces narrow, jagged ridges extending up the peaks. Moreover, the peaks develop pointed pyramidal shapes, called **horns**, that are largely due to headward erosion by cirque development.

**5.12.2. Glacial Deposits.** The entire eroded material from the valley is collected by the glacial ice and *transported* downstream in an embedded state. Unlike that of a river or wind, the glacial sediment load is *heterogeneous* in character, and contains all sizes of rock fragments. What we mean to say is that in this case, there is no sorting of different sizes of rock fragments. Moreover, most of this sediment load is concentrated along the base or sides of a glacier, and is called *sub glacial load.* A part of this load may, however, be scattered over the upper surface of the glacier, especially along the sides, and forms what is known as *supper-glacial load.*

All the glacial load moves ahead at the same rate. The sediment load will, therefore, continue to move along with the glacier till the glacier reaches the *end* or *terminal point.* When this end point or toe of the glacier starts melting or retreating, a lot of sediment will get dropped and deposited at the end point, forming what is known as the *end moraine.* Similarly, when the entire glacial ice becomes extinct due to melting, then we will find various deposits of the sediment at various places on the valley floor. These sediment deposits may be formed simply by extinction of ice and dropping of sediment wherever it happens to be in the glacial body, or may be transported by the melt water before their final deposition. The former ice deposited sediments are unsorted and unstratified, and they are called **unstratified drift** or **till.** The latter deposits made by the intervention of melt water, are sorted and stratified, and are called **stratified drifts.** Both the types of deposits together are obviously called *drifts. Moraine* and *Drumlins* are the important forms of unstratified drifts or tills ; and *Outwash, Kames,* and *Eskers* are some of the forms of stratified drifts. These different types of deposits are defined below :

**(1) Moraines.** The unsorted and unstratified ice deposited sediments found at various places on the valley floor, are called *moraines.* Depending upon the position of such debris w.r. to place of deposition in the valley, we may have the following four types or moraines.

(*a*) *End moraine.* The unsorted and unstratified debris deposited at the end or terminal point of a glacier is called **end moraine** [Refer Fig. 5.33]. Thus, end moraine marks the point of farthest advance of a glacier, and is formed when the toe of the glacier remains stationary for several years. Because the toe of a glacier is curved, the end moraine is characteristically curved.

(b) *Lateral moraines.* The heterogeneous unstratified collection of debris along the sides of a valley are called **lateral moraines**. The lateral moraines develope in much the same manner, as the terminal moraines, as a result of melting of slow moving ice at the valley sides. [Refer Fig. 5.33].

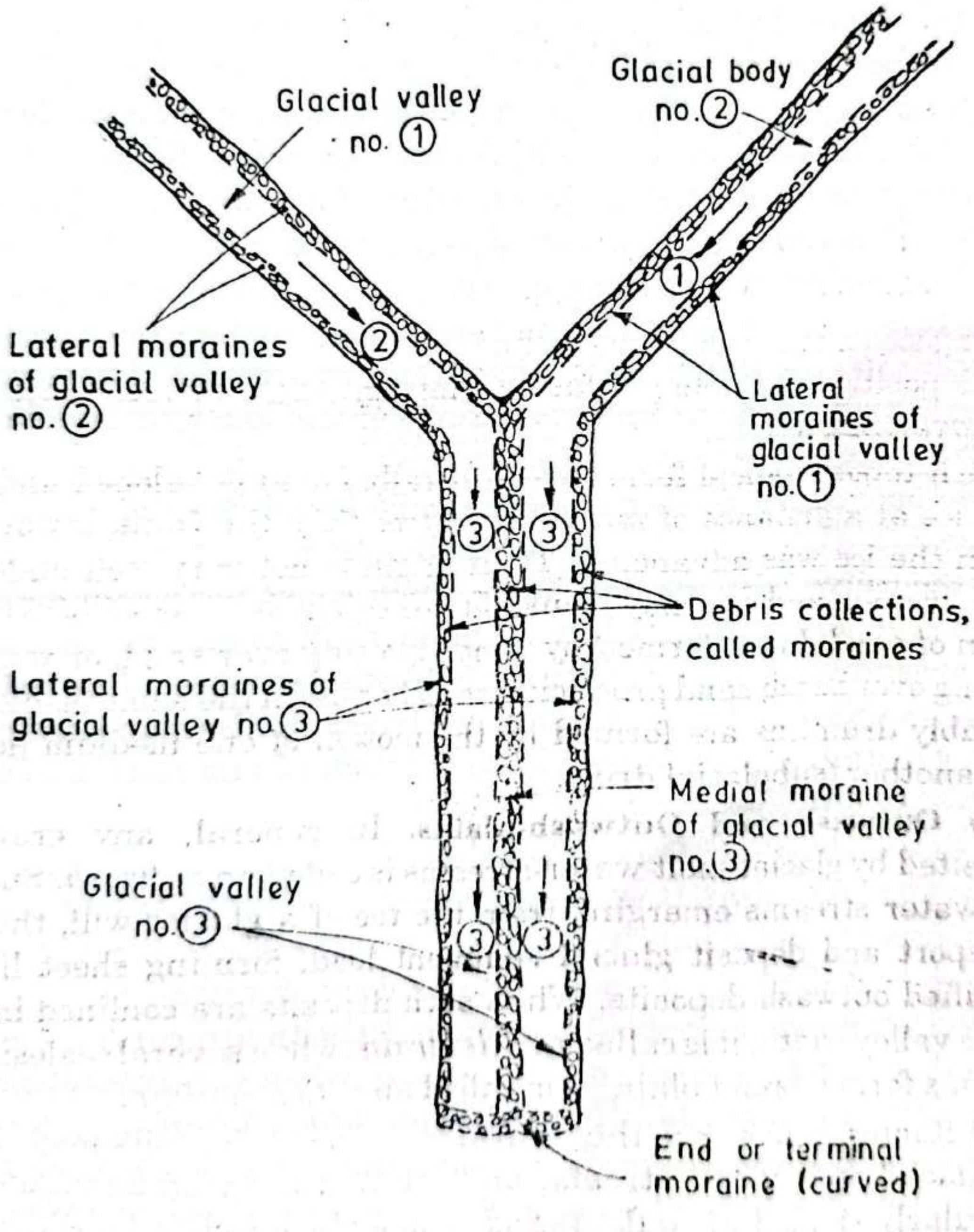



Fig. 5.33. Plan view of glacial valley, showing moraines.

(c) *Medial moraines.* When two body glaciers and their valleys join together, their inner lateral moraines will also merge together to form a comparatively thick layer of debris, running longitudinally through the central regions of the new composite glaciated valley. These medial ridges of heterogeneous unstratified deposits are called **medial moraines** [Refer Fig. 5.33].

(*d*) *Ground moraine*. When a glacier melts, the sediment load embedded along the glacier will get dropped on the valley floor, wherever it happens to be, thus forming a *ground moraine*. This heterogeneous unstratified deposits of boulders, sand, silt etc. may at certain places acquire some good enough thickness.

(2) **Drumlins.** Drumlins are the typical land forms made up of whale shaped streamlined ridges. These mounds are made of sand or clay or both, and look like an inverted bowl of tea-spoon, as shown in Fig. 5.34. These somewhat elliptical shaped ridges (in plan) have their longer axis parallel to the direction of motion of the glacier, and the end facing upstream is relatively broad and blunt, compared with the tapering at downstream end or tail, a typical stream-lined shape. This streamlined shape implies that the surface between the moving ice and the subglacial sediment load was moulded by erosion and deposition, so as to produce a shape giving least resistance to the advancing ice.

Such topographical forms are generally found developed under deep ice at a distance of many kilometres from the front, towards which the ice was advancing. Their origin is not very well understood or seen, and one may think of their origin as analogous to the origin of sand dunes formed by winds blowing over sand, or water flowing over beach sand producing sand banks. In the same fashion, probably drumlins are formed by the motion of one medium (ice) over another (subglacial drift).

(3) **Outwash and Outwash-plains.** In general, any gravel deposited by glacial-melt water-streams is called an *outwash*. Such meltwater streams emerging from the toe of a glacier will, thus, transport and deposit glacial sediment load, forming sheet like stratified outwash deposits. When such deposits are confined in a single valley width, it is called a *valley train* ; when several coalesing streams form a broad plain, it is called an *outwash plain*.

(4) **Kames.** Kames are the stratified sediment deposits made by the glacial melt water stream, and are characterised as isolated irregularly shaped mounds, found commonly associated with end moraines.

(5) **Eskers.** Eskers are like kames placed together in a series, thus forming long narrow winding ridges. They represent poorly stratified glacial-melt-water deposits, generally formed by sub-

Fig. 5.34. A typical landscape of drumlins.

glacial-streams in ice tunnels. In height, they may be as low as 2 m, and in length they may extend for many kilometres, trending roughly parallel to the flow of extinct glacier.

### 5.13. Continent Glaciers and their Geological Works

The continent glaciers, often called *ice sheets* or *ice caps*, consists of extensively large masses of glacial ice, covering enormous area of the existing topography. They are often so thick that all surface features except the high peaks stand buried under them. These protruding visible peaks surrounded by glacier ice are called **nunataks**.

There are only two major ice sheets in existence today in the world. These two ice sheets are :

(*i*) The *Greenland ice sheet* ; and

(*ii*) The *Antarctic ice sheet.*

Besides these, many smaller ice sheets, called **ice caps**, occur in small plateaux and plains ; and are characterised by a radial outward movement of numerous glacial streams.

The *Greenland ice sheet* is broadly dome-like in appearance, and is spread over more than 80 percent area of Greenland. It is about 2400 km from north to south, and about 960 km wide at its greatest width, with an overall area of about 1.7 million sq. km. The maximum thickness of the ice is about 3000 metres. The ice flows towards the margin, where it either spills through valleys as *outlet glaciers,* or debouches directly into the sea where massive portions of the glacier break off and become *icebergs* (*i.e.* huge blocks of ice floating in sea).

The other important *ice sheet of the Antarctic* is the world's largest ice sheet, covering about 14 million sq. km. *i.e.* about 90 percent of the area of the Antarctic continent, which is about twice the size of U.S.A.

The **geological work of continent glaciers** is very similar to that of valley glaciers. However, their *erosive effects* are much less, and are generally limited to rounding the topography, and scrapping off much of the soil and over-burden. Their *sediment deposits* are also like those of valley glaciers, but are more extensive. One type of deposit that helps in the recognition of continental glaciation is the *erratic boulders.* **Erratic boulders,** some of which are quite large, are those boulders, which are foreign to their present location. Thus, a huge block of Granite rock, lying freely in a valley made up of Limestone rocks, is an erratic block, which must have been brought here from some distant source ; possibly by a glacier, as rivers or winds cannot transport huge and heavy boulders. Such erratic blocks are often found in glaciated regions, and are transported over as long distances as 1200 metres or so. In some areas, occurrences of distinctive erratic boulders can be traced back to their origin, thus indicating the path of a glacier.

## 5.14. Engineering Problems Posed by Glaciated Regions

Generally speaking, no construction site should be selected on a glacier, or in the path of a glacier, or at a place where glacial load is deposited. However, sometimes, areas through which glaciers had moved in the past, or are covered with glacial sediment deposits, may have to the chosen for taking up the construction of an engineering project. *In all such cases, suspicion and caution are of utmost tmportance.* This is so, because the glacial deposits are among the most heterogeneous types of materials, as far as their engineering properties are concerned. All such deposits should therefore be thoroughly examined for ascertaining the true nature of the material for determining the reasonably safe depth of the foundations for engineering structures. Sands and gravels, although constitute good materials, yet may contain some compressible clay layers ; which if gone undetected, may endanger the foundations, of heavy structures. Some high reliable values of 'factor of safety' should generally be considered in the designs of engineering projects to be located in such regions.

## MARINE EROSION AND GEOLOGICAL WORK OF SEA

## 5.15. Definition of Sea and Other Marine Bodies

A sea may be defined as an enormously large continuous body of water, formed over the depressed parts of the Earth's surface. Exceptionally deep seas, generally with an average depth of more than 4 km, are known as oceans. A sea is thus, a part of an ocean, which is close to the continental land. A small and a broad inland extension of sea water is called a bay ; which when extending much deeper into the land is called a gulf. The border land all along the margin of oceans or seas, is known as coast. Whereas, the area immediately close to the sea, and which is frequently invaded by sea water by waves during tides, is called *sea-shore*. Sea water will not normally cross beyond the sea shore, and such a demarcation between land and sea is called *shore line* of the area.

Nearly 71% of the surface of the Earth is covered by ocean basins. *Pacific* ocean, *Atlantic* ocean, *Indian* ocean, *Mediterranean* ocean, *Arctic* ocean, and *Antarctic* ocean, are the six well known oceans of the world. The Pacific ocean which is the biggest and the deepest ocean is spread over almost half of the Earth's surface with an average depth of 4.2 km. A point which we may like to clarify here is that all these different seas and oceans are no separate bodies, but are the part of a single closed continuous body of water. The different names given are based on the areas or the continents covered by such a body with arbitrary dividing lines.

Since all the rivers flowing through the land surface, drain into this body of oceans, huge amounts of salts are continuously added to this body, which make the ocean's water (termed as marine water) highly saltish, with increasing salt concentrations over the passage of time. The present salt concentration of marine water has been estimated to be 3.5 per cent by weight. Besides salts, rivers also bring huge quantities of sediments and dump that in the oceans. The oceans thus, act as giant reservoirs of water and sediments. In addition to this, there exists an abundant *Plant and animal life* in the oceans, which makes them a separate world in themselves.

### 5.16. Sea Waves and Sea Currents

The otherwise calm water of oceans develops mighty waves and currents under the influence of *winds* and *tides*, and sometimes earthquakes. The **tidal action**, which is caused mainly by the gravitational attraction of the moon and partly by that of the sun, causes the marine water level to rise and fall periodically (every 12 hrs 26 minutes).

Periodical tides are essentially caused by the rotation of the Earth around its own axis, once in every 24 hours or so. The ocean water facing the moon, is pulled by the moon by more force than it exerts on the Earth's centre, causing the water to go up, producing a *high tide*. When this happens, water is drawn away from an ocean which is 90° apart from the ocean having a high tide, which results in a *low tide* there. The effect of Sun is similar to that of the moon, but considerably less powerful because of its far-off distance from the Earth. The Sun will assist the moon, when Sun, Earth and moon all fall along the same straight line, thus producing a tide of maximum range, called **spring tide**. This will happen at the time of new moon or full moon. However, when the Sun and moon are at right angles relative to the Earth, the moon produces high tides, where the Sun produces low tides. These tides are then less high and low than usual, and are called **neap tides**.

In an open ocean, the difference in the level between a high tide and a low tide is only a metre or so. Enclosed basins have still weaker tides (only 30 cm or so in the Mediterranean ocean, and 10 cm in the Black sea). In shallow seas, however, and especially where the tide is concentrated between converging shores, tide ranges of 6 to 9 metres are common, and tidal currents are also generated. Spring tides may reach 12 to 13 metres in height, producing more vigorous currents. Flowing winds during tides may result in the formation of vigorous waves and currents.

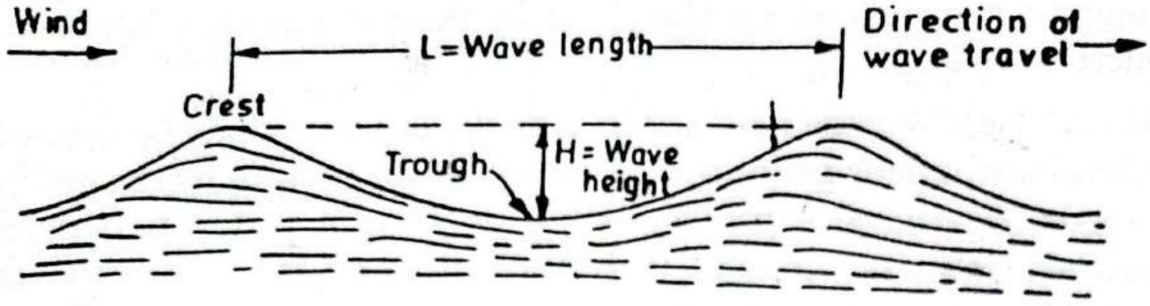
Irregular waves and currents may be produced by blowing winds. All such waves and currents are highly powerful, and bring about numerous changes along the shore by their destructive and constructive work.

**5.16.1. Sea Waves and their Types.** Sea waves may be defined as the disturbances produced on the sea water surface by the action of winds. During the propagation of a wave, a water particle is disturbed from its place of rest, and is thrown into a circular or elliptical or elongated or any other type of orbital motion, before it comes to rest once again. On the basis of the shape of the orbit, we can recognise two principal types of sea waves. The are :

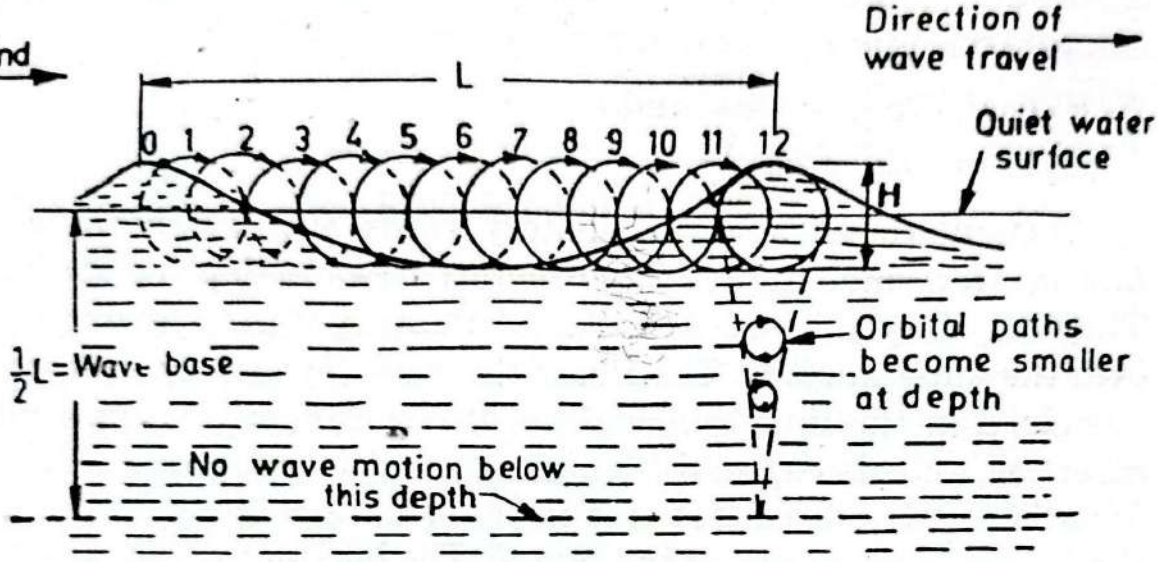
(i) *Oscillatory* waves, and
(ii) *Translatory* waves.

(i) **Oscillatory Waves.** Oscillatory waves, such as shown in Fig. 5.35 (a) are formed in seas. where sufficient water depth is available. They may be produced due to the formation of the blowing winds over the water surface. The size of the wave depends upon the wind velocity; and the time taken by it to blow continuously from a single direction, and also upon the length of the open water over which the wind blows. The highest point on the wave is called the *crest*, and the lowest point is called the *trough*. The horizontal distance from crest to crest, or from trough to trough, is called the *wave length* (L). The difference between the levels of the crest and the trough is called the *wave height* (H). A wave is generally described by the ratio of its length to height (*i.e.* L/H). On an average, the height of sea waves varies between 9 to 12 metres, although individual wave heights up to 20 to 30 metres have been recorded. The usual wave lengths may vary between 150 to 250 metres, while the maximum wave length usually varies between 600 to 900 metres.

These oscillatory waves are formed by the circular oscillatory motion of the individual water particles, as shown in Fig. 5.35 (b). The *wave shape advances in the direction of the wind*. Thus, in these waves, there is only an up and down motion of the water particles, and the *water particles make little or no advance with the wave in the direction of wind.* The orbit of the individual water particles has a dia equal to the wave height. This orbital motion is illustrated by some floating object, such as a cork. The cork may be seen to be at the bottom of its orbit in the trough of the wave, rising to top at the crest of the next wave, and again coming to the bottom of its orbit in the next trough. The *wave period* (T) is the time required for a complete orbit of a water particle, and thus coincides with the time interval required for the advancement of the crest by a distance




(*a*) Cross sectional shape of an oscillatory wave.




(*b*) Cross-sectional shape of an oscillatory wave showing motion of water particles at 12 different points on the surface of the wave. Dark arrows of the dotted circles show the direction and distance travelled by each point as the crest reaches that particular point. The figure also shows how the orbital dia increases with depth.

Fig. 5.35

equal to one wave length. The *velocity (v)* of the wave is then equal to the wave length divided by the wave period $\left( i.e., v = \frac{L}{T} \right)$.

The oscillatory wave motion diminishes rapidly with depth, since the orbital path of the water particles become smaller and smaller, as shown in Fig. 5.35 (*b*). This motion dies out completely at a depth equal to half the wave length. This lowest level at a depth of 'half the wave length' below the quiet water surface is called the *wave base*, and represents the level below which winds can cause no water motion. This is the reason which explains as to why a submarine can easily ride out a storm when submerged, while a surface vessel of the same size is wildly tossed about.

(*ii*) **Translatory Waves.** A translatory wave is defined as the one in which the water particles experience a forward movement with the wave, and do not return to their original position, as happens in oscillatory waves. Moreover, although the movement of the individual water particles themselves may be short, but since the impulse is transmitted, the wave shape often travels considerable distance in the direction of wind.

Such translatory waves are formed in coastal areas where the available water depth is very less. They are essentially formed after the oscillatory waves *break* during their movement towards the shore.

In such sea shore areas, where the water is shallow, the incoming oscillatory waves undergo marked change in shape due to the effect of sea bottom. The wave height increases and the length becomes shorter, but the period remains more or less the same. Eventually, the wave becomes so high that the crest topples over, and the wave is *said to break*. It is, infact, the energy of such breaking waves, which crashes on the shore, producing erosional geological changes on almost all shorelines.

**5.16.2. Sea Currents and their Types.** Sea waves are not the only water movements that modify the sea-shores. A variety of currents*, such as, *density currents, salinity currents, river currents, tidal currents, wave currents, undertoe currents, littoral currents, conventional currents,* etc. stir the sea water. Of these various types of currents, the following two are more important from geological point of view :

(*i*) **Undertoe Currents.** Where oscillatory waves break, or translatory waves advance on a sea shore, excess water is pushed landward. This creates a hydraulic head with more head inland, and the surplus water must find an escape. If this escape is along the bottom, a broad outflowing current will be formed, and is called an *undertoe*. Now, if the slope of the beach is sufficiently and moderately steep, the sand particles from the shore will be removed by the undertoe. At some places, these undertoe current are very powerful and they won't let any sand to be left on the beach ; they are than locally called rip **currents.** At such places, the beach may be only of gravel, as out of the sand and gravel both thrown on the beach by the onrushing waters of the breaking oscillatory waves, only sand will be removed by rip **currents.**

*A current may be defined as the actual movement or pushing up of layers of water, in a particular direction.

(*ii*) **Littoral Currents.** Littoral currents are those currents which move along the shore parallel to the shoreline. They are produced by the waves striking obliquely against the shore rocks. The higher the angle of obliquity with which the wave impinges, the more rapid and vigorous will be the resultant *along the shore* or *littoral currents*.

## 5.17. Section of a Sea Basin

A general cross-section of a continent and an adjacent ocean basin was shown in Fig. 2.8 in chapter 2. It was explained therein that whereas a thickness of about 35 km of the Earth's crust exists below the Continents, a thickness of hardly 6 km of Earth's crust exist below an ocean basin, and the bottom of the ocean basin is about 5 km below the sea water level.

The depth of an ocean basin is not achieved abruptly and steeply from the shoreline, but is achieved gradually from the shore to the deep interior. Even inspite of it being highly uneven, making depressions at certain places and projecting islands at others, there exists some general slopes from the land to the deep interior of the sea, as shown in Fig. 5.36.

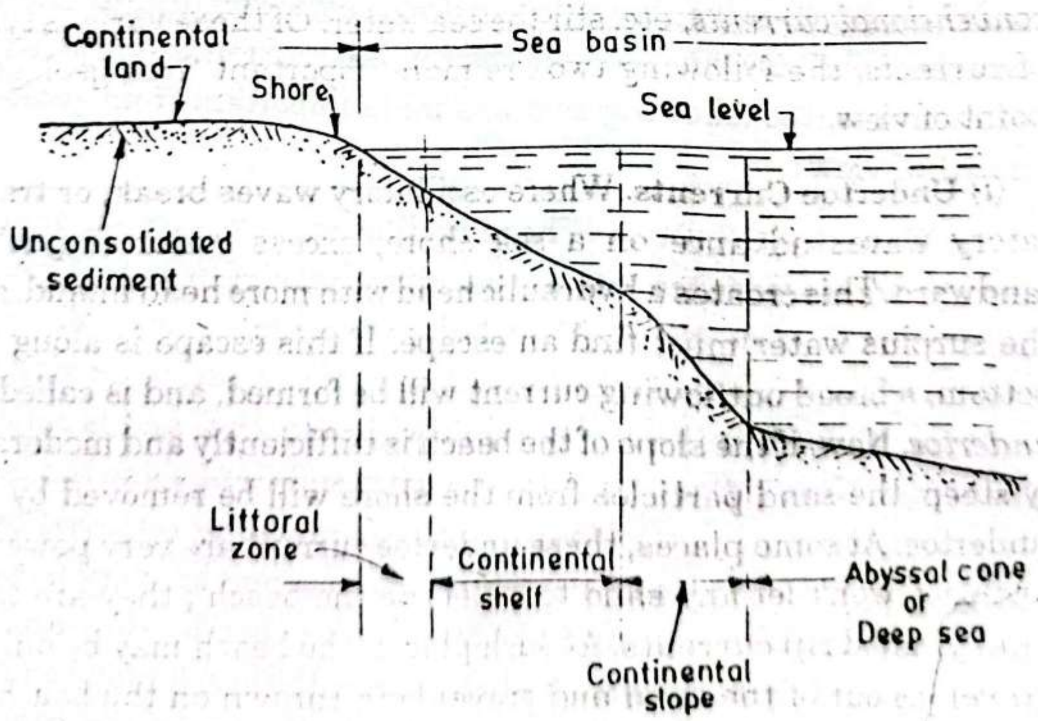



**Fig. 5.36. X-section of a Sea basin showing depth zones (vertical scale shown exaggerated).**

**Starting from the shore towards the deep sea, the following four zones may be recognised in an ocean basin :**

(1) **Littoral Zone.** This zone indicates the area between the high tide and low tide levels. It is also known as *Strand*. The sediments found in this zone are the coarse fragments of the rock waste. The bare sands of this zone make beautiful beaches.

(2) **Continental Shelf.** Below the low tide level, the continental shelf starts. It may extend from the land to a variable distance, say up to about 300 km or so. The maximum depth in this zone is about 180 metres or so. The floor shows a gentle slope. The sediments deposited in this zone are well sorted with coarser particles in the initial shallower zone, and finer particles towards the deeper end portions. The upper part of this zone is liable to be affected by the sun light, seasonal temperature changes, and current and wave action. A major part of sea plant life and animals like molluses grow here in this zone. The lower part shows very little penetration of sun light and is very less affected by temperature changes. It is characterised by the deposition of only fine sediments like muds, etc. The sea animals like *corals* and *brachiopods* grow in this zone.

(3) **Continental Slope.** This zone is represented by a suddenly increased slope, as shown in Fig. 5.36. The depth variation in this zone, from sea level, may be from 180 metres to as much as 900 metres or so. It is characterised by low temperature, almost no penetration of sun light (except the top about 15 metres thick water layers, which may show a very dim light), and deposition of fine coloured muds at the bottom. Fine deposits of micro-organisms called *oozes* are found abundant is this zone.

(4) **Abyssal zone or Deep Sea.** This is the deepest zone marking the deep sea or the ocean floor. It is characterised by the deposition of finest muds of oozes and red clays. The red colour of the fine clays of this zone is primarily due to iron oxidation.

## 5.18. Geological Work of Sea

Although a sea is nothing but a reservoir of water, but by virtue of its enormous dimensions and the consequent generation of waves on its surface, it acts as an ever active agent performing a lot of geological work in the form of land erosion, and deposition of the eroded material into the sea basin. The presence of numerous organisms inside the sea, also plays its own part in the process. The sea, not only acts as the agent of deposition for depositing the rock fragments or sediments eroded by itself, but it also absorbs in itself the sediments brought at its mouth by numerous rivers and glaciers.

The advancing sea waves cause the erosion of the shore land, thus advancing the sea towards the shore line. The eroded sediments are then swept into the sea by retreating waves. The eroded material moves in suspension as well as in solution. The suspended load, when taken into the sea basin for deposition, is very well sorted out by the water, with coarse materials deposited near the shore. and finer particles taken to far off distances inside the sea. A sea basin, thus, acts as an agent of *erosion, transportation,* and *deposition* as well. While causing erosion of the land, or while depositing the sediments, it produces certain important geological features, which are discussed below :

**5.18.1. Marine Erosion and the Developed Geological Features.** Marine water in the form of sea waves and currents, considerably erodes the land near the sea coast, and may cause extensive damage to an unprotected sea shore, or to the man made structures situated near the shore. The wave attack is mainly confined between low tide level and the general highest level reached by water during the formation of such waves. The erosion work by waves is generally accomplished by *abrasion, solution (i.e. corrosion),* or simply by *hydraulic action.*

**Abrasion** is the process of constant rubbing and grinding action of sandy sea water, continuously striking with the loosely packed sediments or rocks existing on the sea shore, thus causing erosion or at least smoothening of the irregularities in the shore rocks. The solvent action of sea water, particularly erodes the rocks, which are soluble or easily attacked by marine water, and this process of erosion is called **corrosion**. The **hydraulic action** is the simple process of breakening or loosening of the weak portions of the coastal rocks under the influence of pressure created by sea waves.

The net result of marine erosion, produced by these *erosional processes*, is to considerably modify the original configuration of the sea shore and to retreat it landward. The extent of damage done to a particular sea coast will depend upon the *composition and strength of coastal rocks, the slope and type of the coast, and the extent and fierceness of the prevalent winds and that of the consequently generated sea waves, in the area*. As is obvious, the weaker the shore rocks, greater will be the erosion. Similarly, the more is the steeply walled coast (*i.e.* precipitous coast), the more erosion will be there, as it will be subjected directly to powerful and unobstructed waves. On the other hand, if the sea is having a generally sloping profile, the waves loose much of their energy while traversing through the shallow marginal waters and thereby causing less erosion. Also, the more fierce are the winds and storms occuring near a particular sea coast, the more erosion will be there due to the fierceness of the waves and currents so developed in the sea.

The important *erosional features developed by the first stage erosion* of a gently sloping sea shore, are given below :

(*i*) **Wave cut cliff.** A wave cut cliff is the steep slope left at the end of a shore line which is retreating landward due to cutting by erosion, and which will ultimately be born down due to continuing erosion by waves [Refer Fig. 5.37]. Such a precipitous cliff will be formed due to undermining by waves of the gently sloping high sea shore near its base.

(*ii*) **Wave cut Platform.** As the cliffs are born back, a wave cut platform is left infront (Fig. 5.37), the upper part of which becomes visible as the rock fore-shore is exposed at low tide level. At the foot of the cliffs, some rock fragments like sand and pebbles may be present, which are, infact, continuously being broken by waves from the cliff, and are used by them for further erosive work, until finally it is ground down to sizes that can be carried away be currents. The platform itself is abraded by the sands and shingles sweeping to and fro across its surface. Since the outer parts of the platform will be subjected to longer scouring than the inner ones, a gentle seaward slope is developed. As the cliff or shoreline retreats, the platform width increases, and the waves will then have to cross a broad expanse of shallow water, so that when they reach the cliff, most of

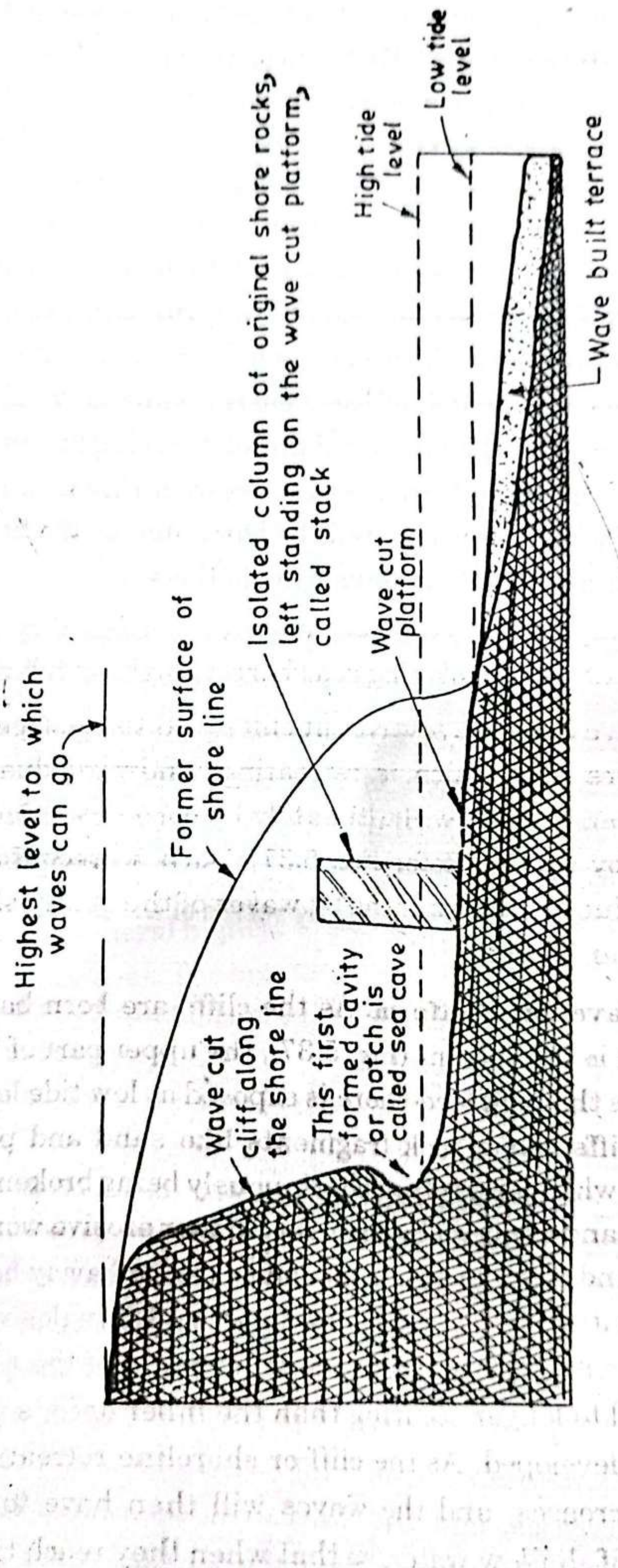



Fig. 5.37. Structural feautres of marine erosion.

their energy has already been used in transporting the abrading sediments. Thus, the rate of coast erosion is automatically reduced.

(*iii*) **Stacks.** During the continued undercutting of shore rocks and the retreat of the cliff, some isolated columns of some resistant rocks may be left standing over the platform. They are called *stacks* [Refer Fig. 5.38].

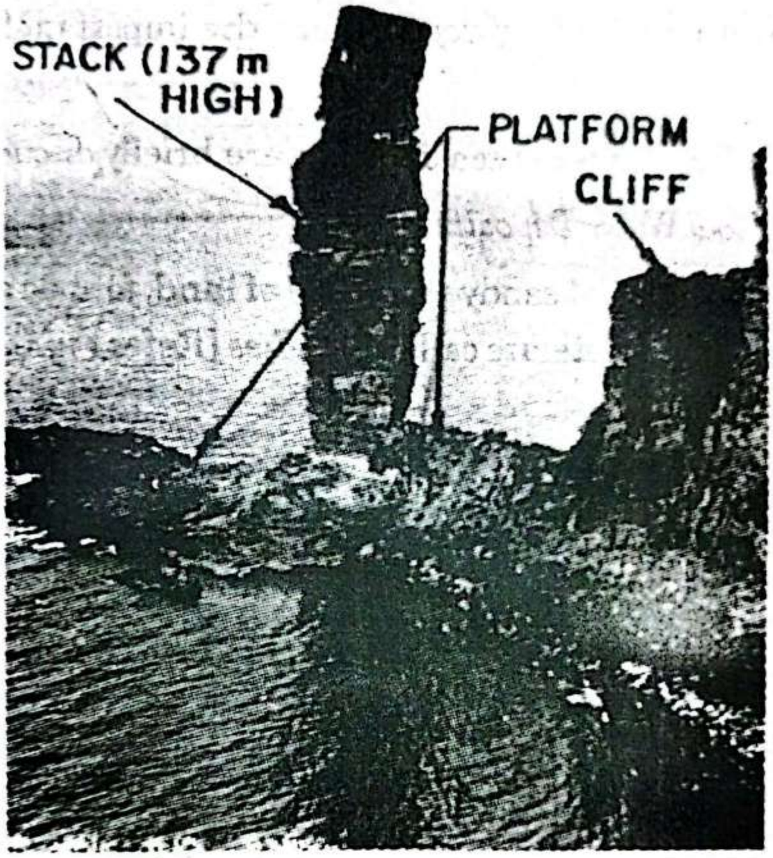



Fig. 5.38. Photo view, showing a Stack and a Cliff.

(*iv*) **Sea Caves.** The cavities or notches formed by under-mining at the base of wave cut cliffs, are called *sea caves*.

**5.18.2. Marine Deposition and Developed Geological Features.** The sediments entering sea water either from rivers or by erosion by sea waves, are carried in suspension by the waves, and are deposited on the floor of the sea at some place or the other. Coarser and heavier sediments are generally left near the coast, and the finer sediments are taken to far off places into the deep sea. The sediments deposited near the shores form certain characteristic features, called *shore deposits* or *shallow water deposits* or *wave deposits*. Such deposits typically include *beaches, spits, and bars*.

Besides these wave deposits, what happens in the deep interior sea is : that the animals, plants, and other organisms living in sea water go on consuming fine muds, minerals, etc. from the sediments entering the sea basin, and thus go on building their shells. Death and decay of these plants and organisms, and the consequent collection of their skeletons, may result in the formation of huge sea deposits. These deposits are called *deep water deposits* or *pelagic deposits*. Coral reefs or *reef deposits* are the important forms of such deposits.

These different types of sea deposits are briefly discussed below :

(A) *Shallow Water Deposits*

(*i*) **Beaches.** The flat sandy stretches of land, formed adjoining the shores at certain coasts, are called *beaches* [Refer Fig. 5.39]. Beaches

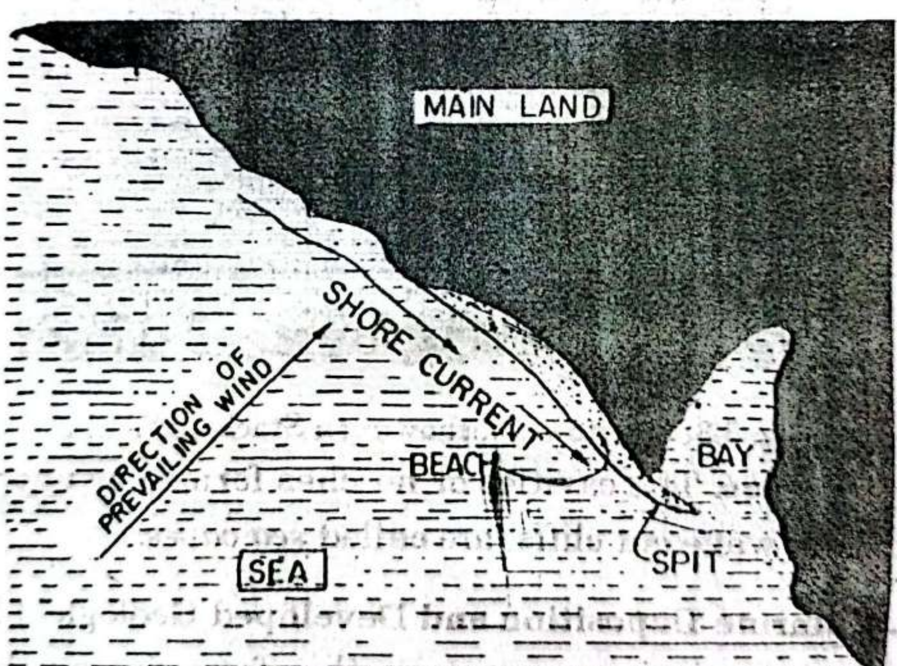



**Fig. 5.39. Figure showing Shoreline deposits.**

are generally formed under the action of sea waves and currents, particularly during the high tides. The material eroded from the sea coast by waves and currents is generally sorted by the retreating waves, which carry the finer sediments away from the shore, leaving coarse sand and shingles on the shore beach. Similarly, the river sediments discharged at some seaward distance from the shore, are carried back to the shore by the waves, and are ultimately deposited on the shore due to reduction in velocity of the waves approaching the shore. The deposition of the coarser sand and gravel on the shore, thus, results in the formation of a *sea beach*.

This process of shifting of the coarser material from the seawards side towards the head land, along the shore, is called **beach drift** or **shore drift**; and is generally assisted by oblique waves, as shown in Fig. 5.40.

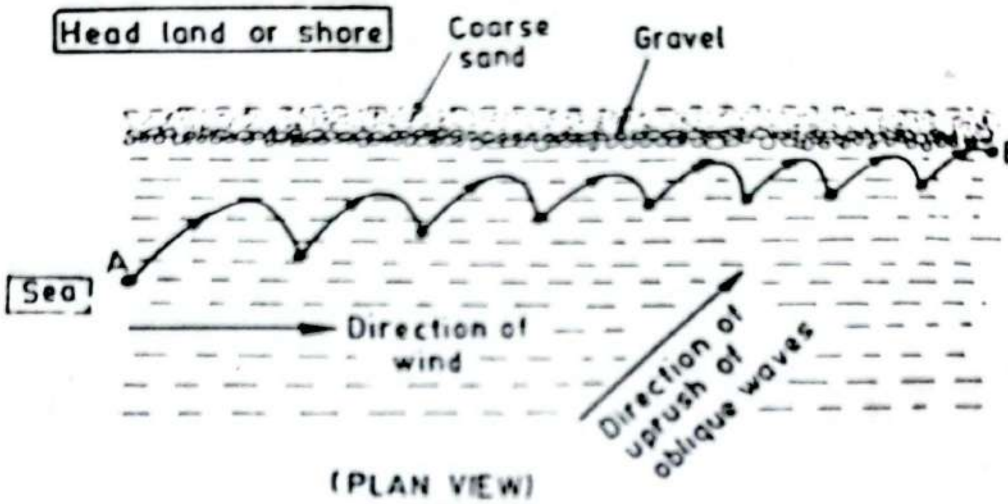



Fig. 5.40. Figure illustrating beach drifting, showing the path followed along a sloping beach, by a gravel or sand grain under the influence of uprush and back wash of successive oblique waves during an advancing tide. Note. The gravel is taken from A to B.

(*ii*) **Spits and Bars.** A spit is a narrow ridge or beach-type sediment that extends from the land into a body of water (Refer Fig. 5.39). Spits are submerged at their open ends, and commonly form from where a beach had been extended into deeper water by longshore currents. Commonly, this takes place at a bend in a shoreline, *i.e.* at the entrance to a bay. Spits tend to curve or hook rather sharply at their outer ends, as shown in Fig. 5.41 (*a*), and may then be called as **hooks.**

When the sand ridges extend across or nearly across the mouth of a bay [as shown in Fig. 5.41 (*b*)], it is called a *bar*. Perhaps, such a bar originated as a spit, and was gradually lengthened.

The **bars** which extend from an island to the mainland ; or from an island to another island, is called a **tombolo**. This feature

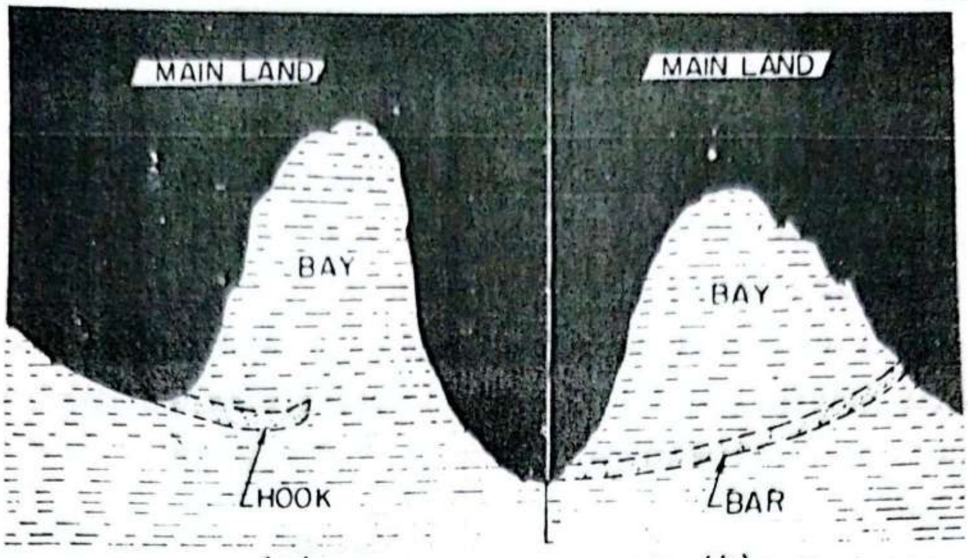



Fig. 5.41. Figure showing the difference between a Hook and Bar.

develops when there are islands nearer to the shore with shallow water.

(B) *Deep Water Deposits*

(*i*) **Coral Reefs or Reef Deposits.** *Corals* (**Colour Photo 5.4**) are tiny sea animals and organisms, living in colonies (groups), and secreting skeletons of lime stone (calcium carbonate) to form reef, after a few years. *Coral reefs* (**Colour Photo 5.5**) are thus defined as the Limestone rock structures found standing in the ocean water, that have been built by certain sea organism and plants, like corals and algae. These deposits are formed by the accumulation of the dead parts of such sea organisms (corals), which form an ever growing pile, as living organisms build upon the remains of the dead. These deposits are thus formed by the deposition of (*i*) *skeletons of corals** ; (*ii*) *shells of other attached organisms* ; and (*iii*) *sediments added by the waves,* which are all cemented together, chiefly by plants known as calcarious algae. This ultimately results in the formation of **porous limestone** rocks within the sea.

These reef deposits may appear in different topographical forms like ridges, platforms, mounds, and many a times, as full fledged islands (atolls). Such deposits are of great significance to man, as they may constitute dangerous underwater hazards to ships at sea, in addition to their being sometimes serving as potential sources of stored petroleum. Coral reefs, however, help in protecting the coast-line against sea erosion by dissipating the energy of weves. They also serve as important breading and nursery grounds to a large

***Corals** are small sea organisms living in groups of millions of them. They are known to live at different depths, temperatures and latitudes in the oceans. However, **reef building corals** are restricted in their environment, *i.e.*, they thrive only in warm shallow relatively clear and normally saline water, that is less than 45 to 60 m deep and at a temperature of 23 to 25°C or above.

number of important fish & shellfish. They provide shelter to Juvinile fish and larvae of may organisms. They are ideal breading places, as eggs laid in them are secure from predators. *Coral reefs constitute the most productive marine ecosystem*.

The three main types of coral reef deposits are :

(*a*) *fringing reefs* ; (*b*) *barrier reefs* ; and (*c*) *atolls*.

The **fringing reefs** consist of Vaneers or platforms of corals, that are formed along the margin of the main land (*i.e.*, along the coast) as shown in Fig. 5.42 or margins of large islands, as shown in Fig. 5.43. They grow in sea-ward direction in the form of platform of corals, and their width may be as large as 800 m or even more. *Because of their growth as fringes along the land mass, they are known as fringing reefs*. At low tides, they may be seen to be in continuity with the shore, or nearly so.

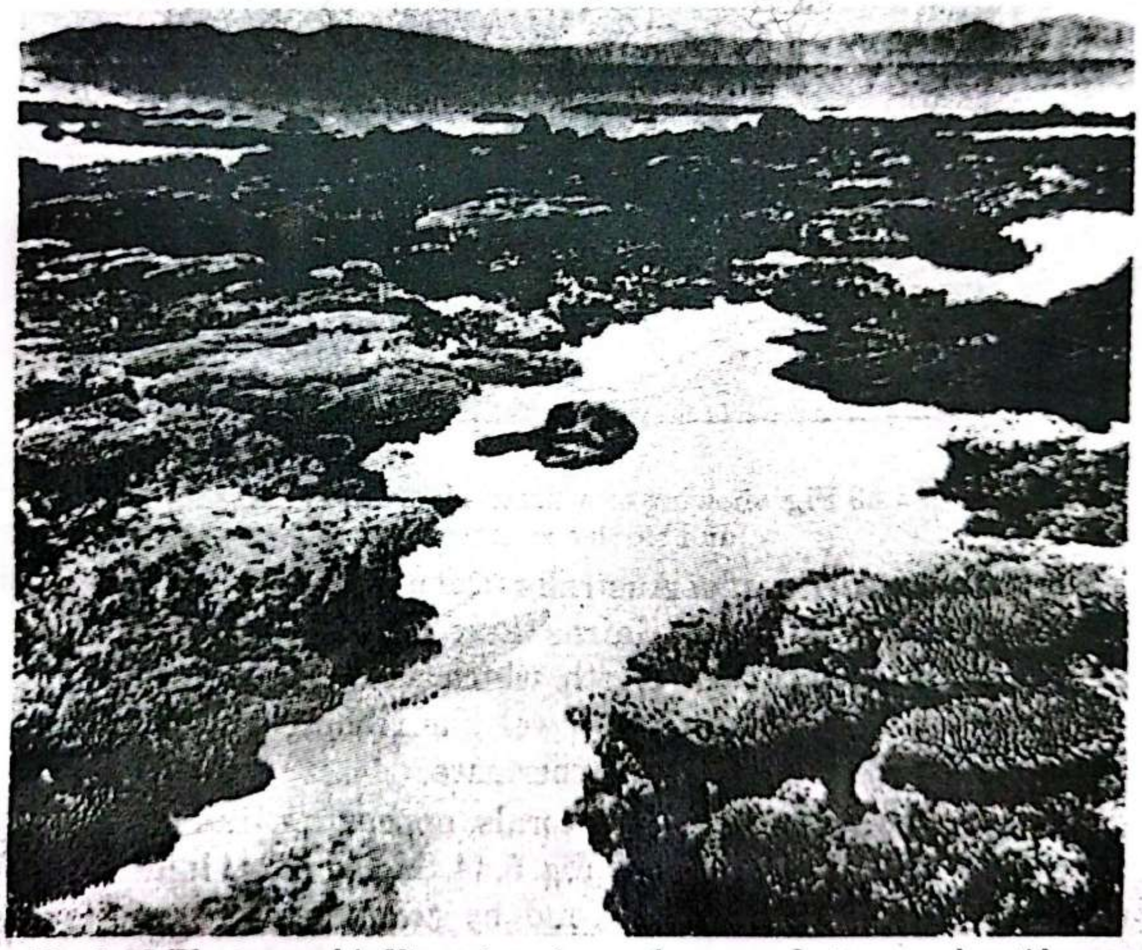


Fig. 5.42 Photographic View of coral growth exposed at a very low tide on a fringing reef off the coast of Queen's land, near Port Denison (USA).

The **barrier reefs** grow as off-shore deposits up to 300 km off the shore. The water enclosed in the lagoon* between the land and the reef remains incontact with the main sea water through the openings in the reef barriers. In the case of islands, such reefs usually grow encircling the entire island, at sufficient distance away from the island, with openings in the reef, as shown in Fig. 5.43.


Fig. 5.43 Fig. showing comparative location of fringing and barrier coral reefs.

The *great barrier reef* of Australia (**Colour Photo 5.6**), approachable from the coastal city of Kairns (near Brisbane or Gold Cast), is the only living structure on Earth, which is visible from Moon, and offers spectacular view of the jewel like ribbon reefs, adding a magical touch to the one's reef experience.

An atoll, is a huge deposit of corals, appearing like a low lying ring shaped island, as shown in Fig. 5.44. Such a coral island can be approached from the main island by crossing the sea (lagoon enclosed between the two islands). Corals shall be fully visible at the fringes or coast of such a coral island.

*Maldives* type of islands in Indian Ocean, which contain about 1300 of such atoll islands, of which about 200 are populated, offer excellent examples of such atoll coral islands.

***A lagoon** is a salt water lake (sea water lake) separated from the main sea by sand banks or coral reefs, etc. (see Fig. 5.43).

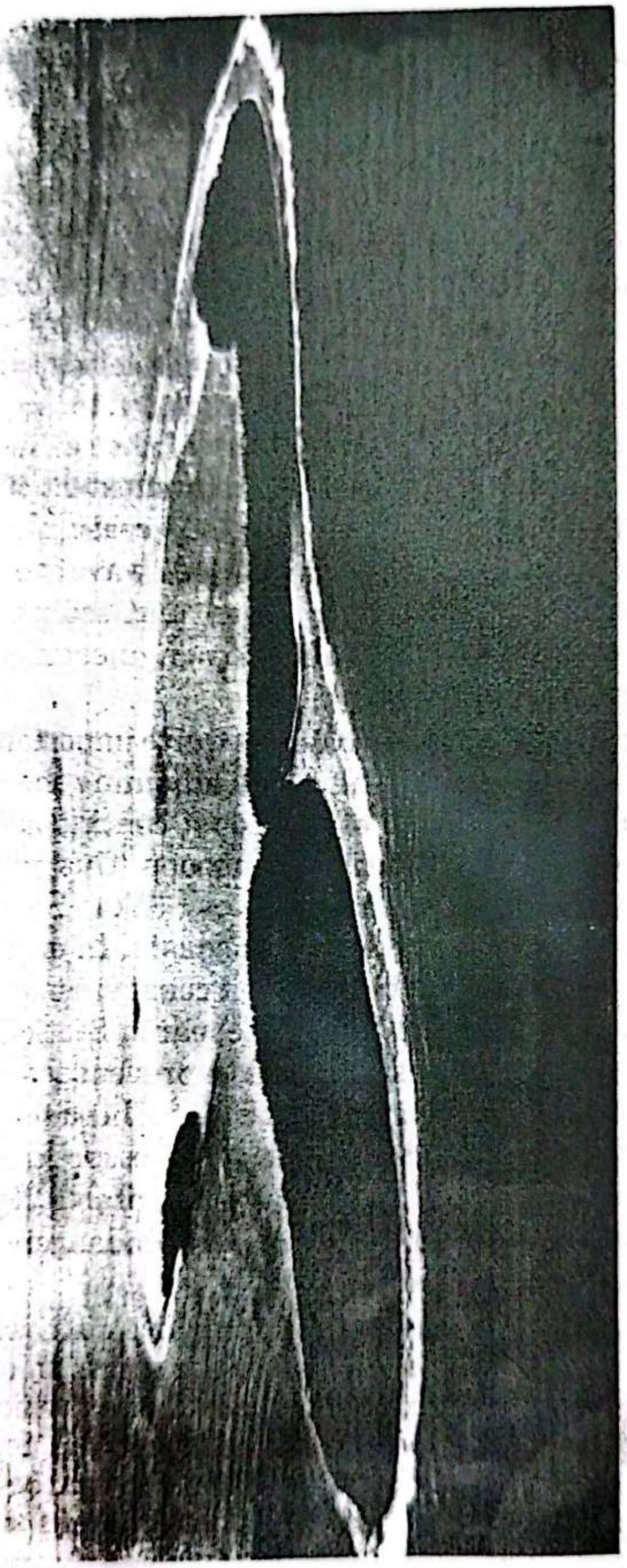


Fig. 5.44. Infaluk Atoll looking West, Western Caroline islands Western Pacific (U.S.).

*Cinque coral island* [Colour Photo 5.7] situated in Indian Ocean, very near to the Port Blair town in Andaman group of islands, offers a senic example of such an atoll (coral island) in our own country, India. To see this island, one needs to visit Portblair, from where you will be taken by a motor boat to the cinque coral island ; at the beach of which, you can easily walk into the corals at a few metres distance from the coast line to enjoy the beauty of the various types of corals.

## 5.19. Engineering Problems Posed by Marine Erosion and Deposition

The problem of sea coast erosion near cities and deposition of silt near harbours are the major problems posed by sea waves and currents. In order to find out proper engineering solutions to both these problems, it is absolutely necessary to acquire sufficient knowledge of the geological behaviour of the sea in question. It is necessary to know not only the nature and extent of the prevailent sea waves, but also the nature of the sea coast. The erosional and depositional capacity of the prevailent sea waves, and the nature of the coast and the coastal rock types and sediments, should be thoroughly studied before planning any engineering solutions in the given region.

The problem of **sea coast erosion** is quite important, especially in a country like India, where the areas adjoining the sea are proportionately large. The erosion of sea-coast continuously takes place, and is particularly severe during monsoons. This may endanger the thickly populated areas and cities (like Bombay, Madras, Trivandrum, etc.) situated near the coasts. In order to find out a suitable solution of the problem of sea coast erosion, investigations were conducted at Central Water Research Station Poona, and it was established the the best method to prevent sea-coast erosion is to construct **sea walls** along the sea coast. These solid gravity walls are known as **groynes and pelisades.** The cost of constructing such walls is enormously high, but they are inevitable, if protection is to be given to the important and costly endangered settlements, situated near the sea coast.

The **silting of harbours** take place quite often when sea waves carry a lot of sediment load towards the shore. In order to control such silting, *barriers* are constructed in the sea, which considerably reduce the velocity of the waves. The sediment is deposited beyond the barriers, and carried back towards the sea, as and when the retreating waves attain sufficient powers to transport the same.

## LAKES AND THEIR GEOLOGICAL WORKS

### 5.20. Definition of Lakes

A lake may be defined as *water-filled depression* or *a hollow of a fairly large size,* existing on the Earth's surface. The size of a lake is somewhere between a pond and a sea. The water of the lake is generally *semi-stagnant*, as it has got a definite source of supply, and generally an outlet. Rivers, melting glaciers, springs, sea, ground water, and rain water may act as regular water supply sources to different lakes. The supply of water to a lake may vary, depending upon the availability of water from its source.

Most of the lakes do have outlets, but certain lakes may not have outlets, and such lakes keep on adding to their salt contents, and ultimately becoming highly saltish or *brackish*. The lakes situated near the sea coasts are generally *saltish* or saline in nature.

## 5.21. Formation of Lakes and their Types

Depending upon the manner in which a *lake basin* (*i.e.* the depression which gets filled up with water) is formed, we may have the following nine types of lakes :

(1) **Tectonic Lakes or Crustal Lakes.** The depressions formed in the Earth's crust by tectonic movements (*i.e.*, displacements) taking place within the Earth's crust, like folding, faulting etc, may result in the formation of basins for such lakes. This type of lakes are generally quite permanent.

India does not have any lake which may be of truely tectonic origin. However, some lakes and particularly those of Kumaon Himalayas (*i.e.*, Nainital and Bhimtal lakes) might be due to the results of differential earth movements, such as faulting, and may, therefore, be classified under this category.

(2) **Barrier Lakes.** These lakes are formed along river valleys by natural obstructions created across their courses. The lakes so formed on the upstream side of the obstruction may be called as a *barrier lake*. The obstruction may be caused by rock slides, or by *alluvial* or *glacial barriers*. The alluvial barriers might be deposited by excessive deposition caused by extinct glaciers or river flows, during the past history. There are many such lakes located in the higher ranges of Himalayas in India and Tibet. Almost all the lakes of Kashmere have probably been formed in this manner by glacial deposition. The examples are : the Pangkong lake, the Tsomoriri lake, the Salt lake, the Wular lake, and the Dal lake.

(3) **Rock-Basins.** These may be defined as the hollows or depressions scooped out by glaciers on the rocky floors of the river valleys during the past geological times. These depressions or lake basins may get their water supply from the melting of glaciers of the upper regions or from rivers and rains. There are many fresh water lakes

located in the higher ranges of Himalayas, and particularly in the Tibetan Himalayas, which are believed to be of such an origin. The largest Koko-Nor lake, the sacred Manasarovar lake—the source of supply to Sutlej, and the Rakas Tal lake, are the important lakes of Tibetan Himalayas.

(4) **Volcanic Lakes or Crater Lakes.** The crater* or caldera* of an extinct volcano may get filled up with water, and thus acting as a lake basin, called *volcanic lake* or *crater lake*. The Gohana lake of Garhwal (India) is believed to have been formed in this manner. The Lonar lake in Buldana district of Berar (Peninsular India) is a deep circular crater like hollow in the basalt plateau of the Deccan. This hollow is believed by some geologists to have been formed by crypto volcanic explosion unaccompained by any lave eruption. On this view, this lake is treated by them as *explosion volcanic lake* or *crater lake*.

(5) **Meteoric Lakes.** Sometimes, the meteorites hit the earth surface with great impact, and as a result, may produce large hollows or depressions on the crust. The lakes formed in such basins may be called as *meteoric lakes*. Such lakes are generally very rare. The Lonar lake basin of Peninsular India in Buldana district of Berar, is believed by certain geologists, to have been formed in this manner.

(6) **Desert Lakes.** In arid regions (deserts), sometimes, the winds may erode down the land surface to such an extent that the water-table is exposed to form an *oasis* (as discussed earlier). The lake so formed at the site of the depression may be called as an **oasis lake**. The Quattara depression of Western Egypt provides an excellent example of such a type of lake basin. It is 300 km long, 140 km wide, and 125 m deep.

The Sambar and other salt lakes of Rajasthan (India), which provide us common salt on a large scale, are of *aeolian origin* ; formed by the rain water getting deposited in the depressions amongst the sand dunes. These lakes are highly salty, because the south-west monsoons and other ordinary winds bring a lot of salt in this area from sea-coast and margins of the Runn of Kutch.

(7) **Deltaic Lakes.** Sometimes, the inland *off-shoots* of a sea may get separated from the main body of the sea by deposition of spits, bars, etc. ; forming a *deltaic lake* on the land margin. The Chilka lake in Orissa offers an Indian example of such a lake. This lake is alternately fresh and saline, and is only a few feet deep.

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*These are the top depressions formed over the conical or dome-shaped volcanoes. For details, please refer chapter 6, Figs. 6.1 and 6.2.

(8) **Ox-bow Lakes.** *Ox-bow lakes* or *Horse-shoe lakes*, explained earlier*, are the bodies of water standing in the deserted loops of a meandering river. Certain geologists believe that some of the lakes of Kashmere-Himalayas are ox-bow lakes instead of rock basins.

(9) **Artifical Lakes.** The lake formed on the upstream side of an artificial dam constructed across a river may be called as an *artificial lake*. Lake Mead of Hoovar dam in U.S.A. and the Govind Sagar lake of Bhakra dam in India, may be quoted as the most important examples of such a lake.

## 5.22. Geological Work of Lakes

The lakes, because of their smaller size (compared to sea or ocean) are not the active agents of geological work. But, large sized lakes can perform the geological work of erosion and deposition just like a sea, although the work will be of much less magnitude. Only in such big sized lakes, the waves, capable of performing erosive work on shore rocks, are generated. These waves perform their erosive work by *hydraulic action* and *abrasion,* as already described under stream and ocean erosion. Their most important work is, however, *deposition*. Most of the lake basins are bodies of standing water, like reservoirs ; and they go on receiving sediments from time to time from the feeding rivers, glaciers, or the winds passing over them. They may also absorb some of the sediments eroded from their shores by waves.

The sediments brought into a lake, are generally very well sorted and screened, particularly in deep lakes. The rate of flow and the amount of sediment brought into a lake are also responsible for the quality of screening. Shallow lakes and lakes filled up rapidly by large quantities of rock-waste, may show poor sorting. In any case, the lake basins get gradually filled up with sediments ; and thus, get vanished over a passage of time, leaving behind ponds, swamps and marshes.

## 5.23. Importance of Lakes

Lakes provide better living conditions and climates in their nearby areas. In particular, they greatly reduce the intensity of hot and dry climates, making it quite tolerable and healthy.

Lakes having connections with rivers, act as important *natural regulators* for such rivers. Such lakes may absorb excess water during flood season, thus, acting as a flood control device. Some large lakes may also supply water into rivers, making them perennial or

*Refer Fig. 5.6 (*e*).