# B.A/B.sc - I<sup>st</sup> Semester (Geography)

## FLP-II

## (Physical Geography-I<sup>st</sup>)

Unit-I<sup>st</sup>.

Q.1. Explain the Big-Bang Hypothesis Origine of the Earth.

Unit-II :-

Q.2. What are earth movement? Discuss the various Topographical Features resulting From Faulting and Folding movements.

Unit-III

Q.3. Describe the Igneous rocks according to the mode of Occurrence.

Unit-IV<sup>th</sup>.

Q.4. List the Factors affecting the erosional work of river. Describe the erosional topographies created by the rivers.

## 2.11 BIG BANG THEORY

The Big Bang Theory postulated in 1950's and 1960's and validated in 1972 (May) through convincing evidences received from COBE (Cosmic Background Explorer) explains the origin of universe and every thing in it including ourselves on the premise that the universe contained many million of gallaxies, each one 'having thousands of millions of stars and each star having numerous planets around them'. According to this theory every thing in the universe emerged from a point known as singularity, 15 billion years ago. The galaxies moved apart from one another as the empty space between them expanded. In the beginning the universe was much smaller as there was less space between the galaxies.

All of the matter in the universe was created in one instant at a fixed moment in time. "As the universe expanded for 15 billion years, the hot radiation in the original fireball also expanded with it, and cooled as a result." It may be summerized that there was a single fireball some 15 billion years ago. 'There were already wispy clouds of matter stretching across vast distances, upwards 500 million light years across. As those clouds collapsed in upon themselves, pulled together by their own gravity, they would have broken up and formed clusters of galaxies with the galaxies themselves breaking up into stars like those of the Milky Way' (John Gribbin). The stars might have broken up to form their planets as our earth.

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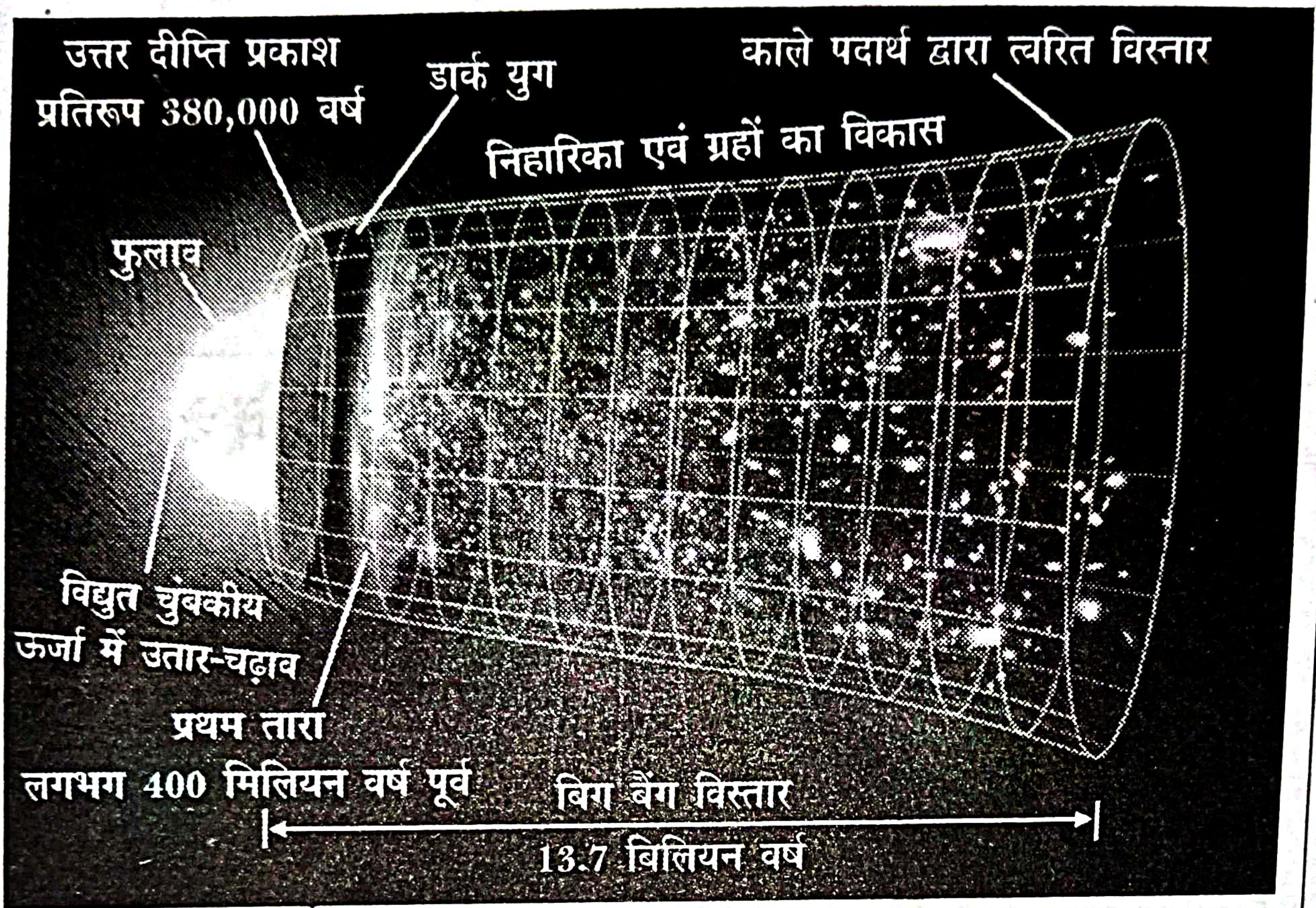

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Q·2.

# EARTH'S MOVEMENTS

## (Endogenetic and Exogenetic Forces)

### 7.1 INTRODUCTION

The study of forces affecting the crust of the earth or geological processes is of paramount significance because these forces and resultant movements are involved in the creation, destruction, recreation and maintenance of geomaterials and numerous types of relief features of varying magnitudes. These forces very often affect and change the earth's surface. In fact, the change is law of nature. The geological changes are generally of two types e.g. (i) long-period changes and (ii) short-period changes. Long-period changes occur so slow that man is unable to notice such changes during his life period. On the other hand, short-period changes take place so suddenly that these are noticed within few seconds to few hours, e.g. seismic events, volcanic eruptions etc. The forces, which affect the crust of the earth, are divided into two broad categories on the basis of their sources of origin e.g (1) endogenetic forces and (ii) exogenetic forces (fig. 7.1).

### 7.2 ENDOGENETIC FORCES

The forces coming from within the earth are called as endogenetic forces which cause two types of movements in the earth viz. (1) **horizontal movements** and (ii) **vertical movements.** These movements motored by the endogenetic forces introduce various types of vertical irregularities which give birth to numerous varieties of relief features on the earth's surface (e.g. mountains, plateaux, plains, lakes, faults, folds etc.). Volcanic eruptions and seismic events are also the expressions of endogenetic forces. Such movements are called **sudden movements** and the forces responsible for their origin are called **sudden forces**. We do not know precisely the mode of origin of the endogenetic forces and movement because these are related to the interior of the earth about which our scientific knowledge is still limited. On an average the origin of endogenetic forces is related to thermal conditions of the interior of the earth.

Generally, the endogenetic forces and related horizontal and vertical movements are caused due to contraction and expansion of rocks because of varying thermal conditions and temperature changes inside the earth. The displacement and readjustment of geomaterials some times take place so rapidly that earth movements are caused below the crust. The endogenetic forces and movements are divided, on the basis of intensity, into two major categories viz.

(1) diastrophic forces and (2) sudden forces.

#### 1. Sudden Forces and Movements

Sudden movements, caused by sudden endogenetic forces coming from deep within the earth, cause such sudden and rapid events that these cause massive destructions at and below the earth's surface. Such events, like volcanic eruptions and earthquakes, are called **'extreme events'** and become disastrous hazards when they occur in densely populated localities. 'These forces work very quickly and their results are seen within minutes. It is important to note that these forces are the result of long period preparation deep within the earth. Only their cumulative effects on the earth's surface are quick and sudden' (Savindra Singh, 2001, Environmental Geography, p. 68). Geologically, these sudden forces are termed as **'constructive forces'** because these create certain relief features on the earth's surface. For example, volcanic

**tensional force** when it operates in opposite directions. Such types of force and movement are also called as **divergent forces** and **movements**. Thus, tensional forces create rupture, cracks, fracture and faults in the crustal parts of the earth. The force, when operates face to face, is called **compressional force** or **convergent force**. Compressional force causes crustal bending leading to the formation of folds or crustal warping leading to local rise or subsidence of crustal parts.

**Crustal bending**—When horizontal forces work face to face the crustal rocks are bent due to resultant compressional and tangential force. In other words, when crustal parts move towards each other under the influence of horizontal or convergent forces and movements, the crustal rocks undergo the process of 'crustal bending' in two ways e.g. (i) **warping** and (ii) **folding**. The process of crustal warping affects larger areas of the crust wherein the crustal parts are either warped (raised) upward or downward. The upward rise of the crustal part due to compressive force resulting from convergent horizontal movement is called **upwarping** while the bending of the crustal part downward in the form of a basin or depression is called **downwarping**. When the processes of upwarping or downwarping of crustal rocks affect larger areas, the resultant mechanism is called **broad warping**. When the compressive horizontal forces or convergent forces and resultant movements cause buckling and squeezing of crustal rocks, the resultant mechanism is called folding which causes several types of folds.

## 7.3 FOLDS

Wave-like bends are formed in the crustal rocks due to tangential compressive force resulting from horizontal movement caused by the endogenetic force originating deep within the earth. Such bends are called

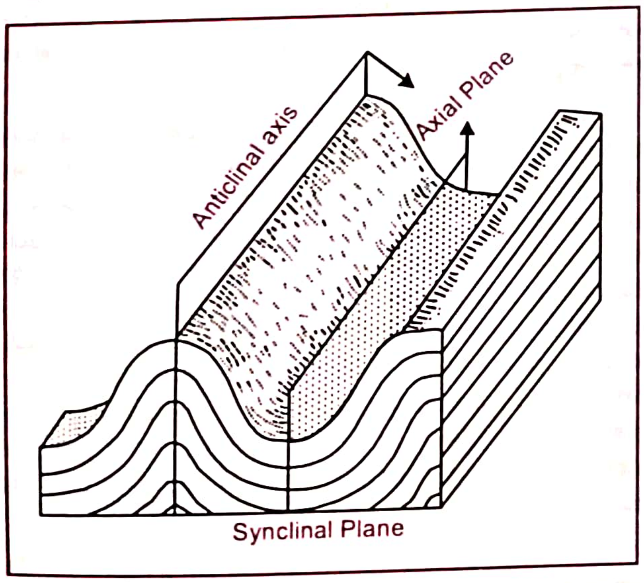


*Fig. 7.2 : Different components of a fold.*

**folds** wherein some parts are bent up and some parts are bent down. The upfolded rock strata in arch-like form are called **anticlines** while the down folded structure forming trough-like feature is called **syncline** (fig. 7.3). In fact folds are minor forms of broad warping. The two sides of a fold are called **limbs** of the fold. The limb which is shared between an anticline and its companion syncline is called **middle limb**. The plane which bisects the angle between two limbs of the anticline or middle limb of the syncline is called the **axis of fold** or **axial plane** (fig. 7.2). On the basis of anticline and syncline these axial planes are called as **axis of anticline** and **axis of syncline** respectively.

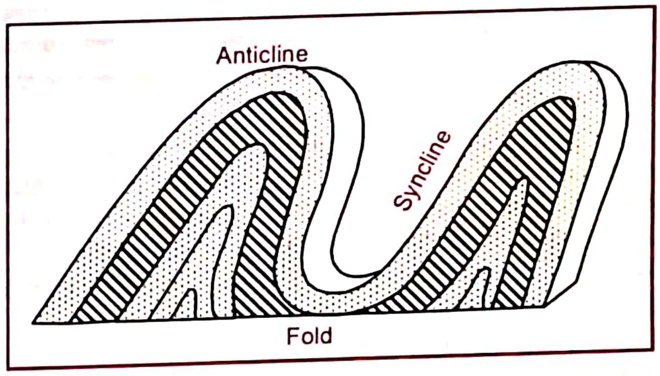


*Fig. 7.3 : Anticlines and synclines.*

It is desirable to explain the characteristics of **dip** and **strike** as it becomes absolutely necessary to understand them in order to understand the structural form. The inclination of rock beds with respect to horizontal plane is termed as 'dip' (fig. 7.4). It is apparent that we derive two information about the dip e.g. (i) the direction of maximum slope down a

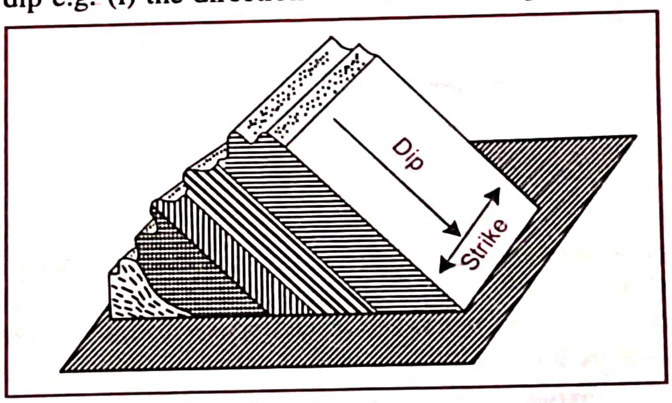


*Fig. 7.4 : Dip and Strike .*

bedding plane and (ii) the angle between the maximum slope and the horizontal plane. The direction of dip is measured by its true bearing in relation to east or west or north e.g., $60^0$ N.E.; while the angle of dip is measured with an instrument called clinometer. For example, if any rockbed is inclined at the angle of $60^0$ with respect to horizontal plane and the direction of slope is N then the dip would be expressed as $60^0$ N. 'The strike of an inclined bed is the direction of any horizontal line along a bedding plane' (A. Holmes and D.L. Holmes). The direction of dip is always at right angle to the strike (fig. 7.4).

**Anticlines**—The upfolded rock beds are called anticlines. In simple fold the rock strata of both the limbs dip in opposite directions. Some times, folding becomes so acute that the dip angle of the anticline is accentuated and the fold becomes almost vertical. When the slopes of both the limbs or sides of an anticline are uniform, the anticline is called as **symmetrical anticline** but when the slopes are unequal, the anticline is called as **asymmetrical anticline**. Anticlines are divided into two types on the basis of dip angle e.g. (i) gentle anticline when the dip angle is less than $40^0$, some times $1^0$ or $2^0$ and (ii) steep anticline when the dip angle ranges between $40^0$ and $90^0$.

**Synclines**—Downfolded rock beds due to compressive forces caused by horizontal tangential forces are called synclines. These are, in fact, trough-like form in which beds on either side 'incline together' towards the middle part. If folded intensely, the syncline assumes the form of a canoe.

**Anticlinorium**—Anticlinorium refers to those folded structures in the regions of folded mountains where there are a series of minor anticlines and synclines within one extensive anticline (fig. 7.5). Anticlinorium is formed when the horizontal

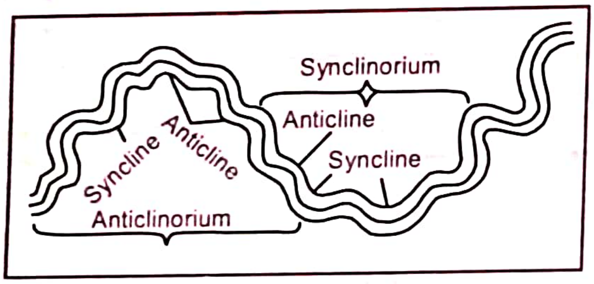


*Fig. 7.5 : Illustration of anticlinorium and synclinorium.*

compressive tangential forces do not work regularly. Consequently, due to difference in the intensity of compressive forces such structures are formed. Such type of folded structure is also called as fan fold.

**Synclinorium** represents such a folded structure which includes an extensive syncline having numerous minor anticlines and synclines. Such structure is formed due to irregular folding consequent upon irregular compressive forces (fig. 7.5).

## Types of Folds

The nature of folds depends on several factors e.g. the nature of rocks, the nature and intensity of compressive forces, duration of the operation of compressive forces etc. The elasticity of rocks largely affects the nature and the magnitude of folding process. The softer and more elastic rocks are subjected to intense folding while rigid and less elastic rocks are only moderately folded. The difference in the intensity and magnitude of compressive forces also causes variations in the characteristics of folds. Normally, both the limbs of a simple fold are more or less of equal inclination but in most of the cases of different folds the inclinations of both the limbs are different. Thus, based on the inclination of the limbs, folds are divided into 5 types (fig. 7.6).

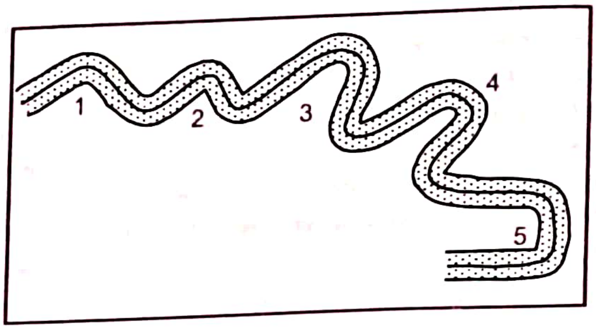


*Fig. 7.6 : Types of folds—1. symmetrical folds, 2. asymmetrical folds. 3. monoclinal folds. 4. isoclinal folds and 5. recumbent folds.*

(1) **Symmetrical folds** are simple folds, the limbs (both) of which incline uniformly. These folds are an example of open fold. Symmetrical folds are formed when compressive forces work regularly but with moderate intensity. In fact, symmetrical folds are very rarely found in the field.

(2) **Asymmetrical folds** are characterized by unequal and irregular limbs. Both the limbs incline at different angles.One limb is relatively larger and the inclination is moderate and regular while the other limb is relatively shorter with steep inclination. Thus, both the limbs are asymmetrical in terms of inclination and length.

(3) **Monoclinal folds** are those in which one limb inclines moderately with regular slope while the other limb linclines steeply at right angle and the slope is almost vertical. It may be pointed out that vertical force and movement are held responsible for the formation of monoclinal folds. There is every possibility for the splitting of the limbs of such folds because of intense folding. Splitting of limbs gives birth to the formation of faults. It is also opined that monoclinal folds are also formed due to unequal horizontal compressive forces coming from both the sides.

(4) **Isoclinal folds** are formed when the compressive forces are so strong that both the limbs of the fold become parallel but not horizontal.

**(5) Recumbent folds** are formed when the compressive forces are so strong that both the limbs of the fold become parallel as well as horizontal.

**(6) Overturned folds** are those folds in which one limb of the fold is thrust upon another fold due to intense compressive forces.Limbs are seldom horizontal.

**7. Plunge folds** are formed when the axis of the fold instead of being parallel to the horizontal plane becomes tilted and forms plunge angle which is the angle between the axis and the horizontal plane.

**8. Fan folds** represent an extensive and broad fold consisting of several minor anticlines and synclines. Such fold resembles a fan. Such feature is also called as anticlinorium or synclinorium (fig. 7.5).

**(9) Open folds** are those in which the angle between the two limbs of the fold is more than $90^0$ but less than $180^0$ (i.e. obtuse angle between the two limbs of a fold). Such open folds are formed due to wave-like folding because of moderate nature of compressive force (fig. 7.7).

**(10) Closed folds** are those folds in which the angle between the two limbs of a fold is acute angle. Such folds are formed because of intense compressive force.

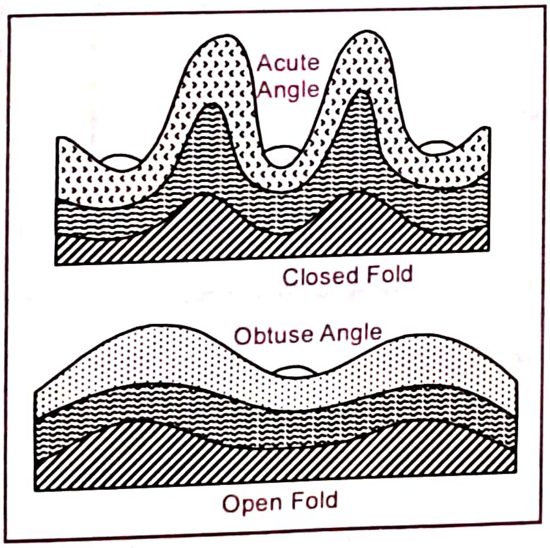


*Fig. 7.7 : (A) closed folds and (B) open folds.*

### Nappes

Nappes are the result of complex folding mechanism caused by intense horizontal movement and resultant compressive force.Both the limbs of a recumbent fold are parallel and horizontal. Due to further increase in the continued compressive force one limb of the recumbent folds slides forward and overrides the other fold. This process is called **thrust** and the plane along which one part of the fold is thrust is called **thrust plane** . The upthrust part of the fold is called 'overthrust fold'. When the compressive force becomes so actute that it crosses the limit of the elasticity of the rock beds, the limbs of the fold are so acutely folded that these break at the axis of the fold and the lower rock beds come upward. Thus, the resultant structure becomes reverse to the normal sructure. Due to continued horizontal movement and compressive force the broken limb of the folds is thrown several kilometres away from its original place and overrides the rock beds of the distant place. Such type of structure becomes unconformal to the original structure of the place where the broken limb of the fold of the other place overrides the rock beds. Such broken limb of the fold is called **nappe** (fig. 7.8).

Several examples of nappes are traceable in the present folded mountains. The nappes of the Alps have

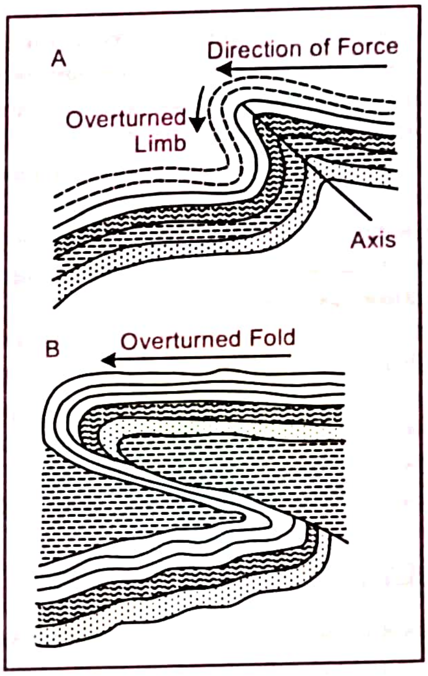


*Fig. 7.8 : Formation of nappe : (A) stage of overturned fold, (B) overriding of one limb of the fold on the other limb.*

been more systematically studied. Four major nappes have been identified in the Alps mountains. The structure has become very much complex because of superimposition of one nappe upon another nappe. The four major groups of Alpine nappes from below upward are (i) Helvetic nappe, (ii) Pennine nappe, (iii) Austride nappe and (iv) Dinaride nappe. In fact, these nappes are located like a series of earth-waves. In most of the localities the overriding nappes have been eroded away because of dynamic wheels of denudational processes and thus burried basic structure has been exposed. When the portion of lower nappe is seen because of denudation of overriding nappe, the resultant open structure is called **structural window**. Several examples of **complete window** have been discovered in eastern Alps.

A few examples of nappes have also been traced out in the Himalayas. The existence of nappes has been discovered by Wadia from Kashmir Himalaya, by Pilgrim from Simla Himalaya, by Auden from Garhwal Himalaya and by Heim and Gansser from Kumaun Himalaya. It is desirable to mention some facts about nappe structure. When the broken limb of a fold overrides the other fold near to the broken fold, the resultant nappe is called **autochthonous nappe**. On the other hand, when the limb of a fold, after being broken, overrides the other fold at a distant place (several kilometres away), the resultant nappe is called **exotic nappe**.

### CRUSTAL FRACTURE

Crustal fracture refers to displacement of rocks along a plane due to tensional and compressional forces acting either horizontally or vertically or some times even in both ways. Crustal fracture depends on the strength of rocks and intesity of tensional forces. The crustal rocks suffer only cracks when the tensional force is moderate but when the rocks are subjected to intense tensional force, the rock beds are subjected to dislocation and displacement resulting into the formation of faults. Generally fractures are divided into (i) **joints** and (ii) **faults**. A joint is defined as a fracture in the crustal rocks wherein no appreciable movement of rock takes place, whereas a fracture becomes fault when there is appreciable displacement of the rocks on both sides of a fracture and parallel to it.

## 7.4 FAULTS

A fault is a fracture in the crustal rocks wherein the rocks are displaced along a plane called as **fault plane**. In other words when the crustal rocks are displaced, due to tensional movement caused by the endogenetic forces, along a plane the resultant structure is called a **fault**. The plane along which the rock blocks are displaced is called **fault plane**. In fact, there is real movement along the fault plane due to which a fault is formed (fig. 7.9). A fault plane may be vertical, or inclined, or horizontal, or curved or of any type and form. The movement responsible for the formation of a fault may operate in vertical or horizontal or in any direction. During the formation of a fault the vertical displacement of rock blocks may occur upto several hundred metres and horizontally the rock blocks may be displaced upto several kilometres but it does not mean that the total displacement occurs at a single time. In fact, fault-movement or the displacement of rocks occurs only upto a few metres only at a time. Fault, in fact, represents weaker zones of the earth where crustal movements become operative for longer duration. A few terms regarding an ideal fault should be understood before going into the details of the mode of formation of various types of faults.

(1) **Fault plane** is that plane along which the rock blocks are displaced by tensional and compressional forces acting vertically and horizontally to form a fault. A fault plane may be vertical, inclined, horizontal, curved or of any other form.

(2) **Fault dip** is the angle between the fault plane and horizontal plane (fig. 7.9).

(3) **Upthrown side** represents the upper most block of a fault.

(4) **Downthrown side** represents the lowermost block of a fault. Some times it becomes difficult to find out, which block has really moved along the fault plane?

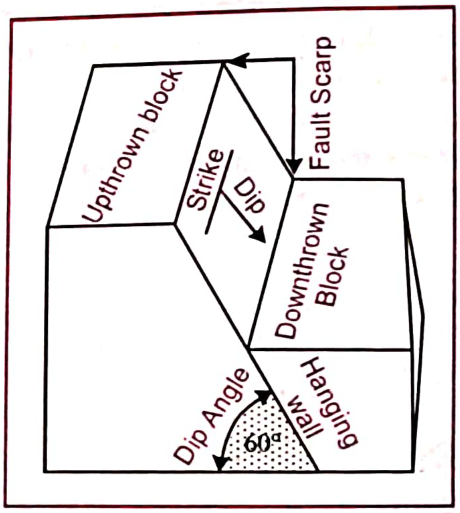


*Fig. 7.9 : Different components of a fault.*

(5) **Hanging wall** is the upper wall of a fault.

(6) **Foot wall** represents the lower wall of a fault.

(7) **Fault scarp** is the steep wall-like slope caused by faulting of the crustal rocks. Some times the fault scrap is so steep that it resembles a cliff. It may be pointed out that scarps are not always formed due to faulting alone, rather these are also formed due to erosion, but whenever these are formed by faulting (tectonic forces), these are called 'fault-scarpts.

### Types of Faults

The different types of faulting of the crustal rocks are determined by the direction of motion along the fracture plane. Generally, the relative movement or displacement of the rock blocks or the slip of the rock blocks occurs approximately in two directions viz. (i) either to the direction of the dip or (ii) to the direction of the strike of the fault plane. Thus, the displacement or movement of rock blocks may be distinguished as (a) **dip slip movements** and (b) **strike slip movements.** Thus, on the basis of the direction of slip or displacement faults are divided into (i) **dip-slip faults** and (ii) **strike-slip faults.** Again, the displacement of rock block-mainly upper blocks may be either down the direction of the dip (then the resultant fault is called **normal fault**) or up the dip (the resultant fault becomes **reverse** or **thrust fault**). In the case of strike-slip movement and fault, the relative displacement of the rock blocks may be either to the right (then the resultant fault will be **right-lateral** or **dextral fault**) or to the left-side (the resultant fault becomes **left-lateral** or **sinistral fault**). Strike slip faults are also called as **wrench faults, tear faults** or **transcurrent faults.** The combinations of normal and wrench faults or reverse and wrench faults are called as **oblique slip faults.**

(i) **Normal faults** are formed due to the displacement of both the rock blocks in opposite directions due to fracture consequent upon greatest stress. The fault plane is usually between $45^0$ and the vertical. The steep scarp resulting from normal faults is called fault-scarp or fault-line scarp the height of which ranges between a few metres to hundreds of metres. It may be mentioned that it becomes very difficult to find out the exact height of the fault-scarps in the field because the height is remarkably reduced due to continued denudation (fig. 7.10).

(ii) **Reverse faults** are formed due to the movement of both the fractured rock blocks towards each other. The fault plane, in a reverse fault, is usually inclined at an angle between 40 degree and the horizontal (0 degree). The vertical stress is minimum while the horizontal stress is maximum. It may be mentioned that in a reverse fault the rock beds on the upper side are displaced up the fault plane relative to the rock

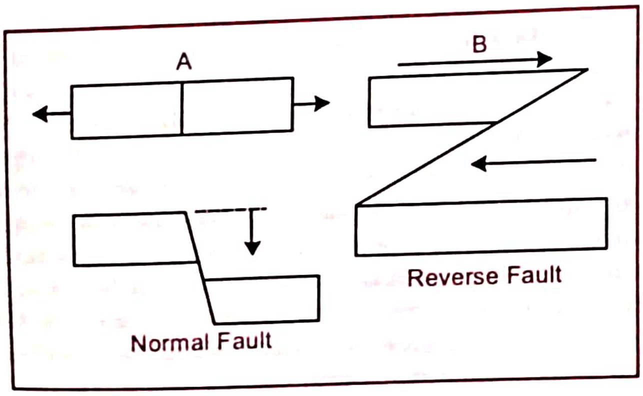


*Fig. 7.10 : (A) Normal fault and (B) reverse fault.*

beds below. It is apparent that reverse faulting results in the shortening of the faulted area while normal faults cause extension of the faulted area. It is, thus, also obvious that some sort of compression is also involved in the formation of reverse faults. Reverse faults are also called as **thrust faults.** Since the reverse fault is formed due to compressive force resulting from horizontal movement and hence this is also called as **compressional fault**. When the compressive force exceeds the strength of the rocks, one block of the fault overrides the other block and the resultant fault is called as **overthrust fault** wherein the fault plane becomes almost horizontal.

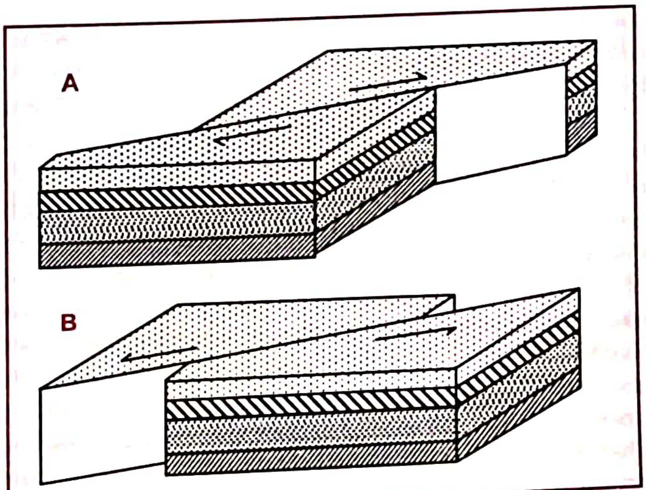


*Fig. 7.11 : Formation of strike-slip or transcurrent faults : (A) right-lateral or dextral fault and (B) left-lateral or sinistral fault (after A. Holmes and D.L. Holmes, 1978).*

(iii) **Lateral or strike-slip faults** are formed when the rock blocks are displaced horizontally along the fault plane due to horizontal movement. These are called **left-lateral** or **sinistral faults** when the displacement of the rock blocks occur to the left on the far side of the fault and **right-lateral** or **dextral faults** when the displacement of rock blocks takes place to the right on the far side of the fault (fig. 7.11). In majority of the cases there are no scarps in such faults, if they occur at all, they are very low in height..

(iv) **Step faults :** When a series of faults occur in any area in such a way that the slopes of all the fault

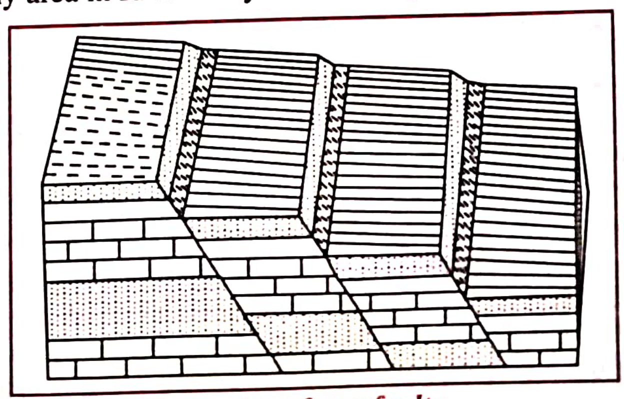

*Fig. 7.12 : Illustration of step faults.*

sedimentary rocks provided that there is no disintegration of pre-existing rocks, e.g. slate, quartzite, marble etc.

## 8.3 IGNEOUS ROCKS

The word igneous has been derived form a Latin word **'ignis'**,meaning thereby fire. It does not mean that the origin of igneous rocks is associated with fire in any way. In fact, the igneous rocks are formed due to cooling, solidification and crystallization of hot and molten materials known as magmas and lavas. Since the magmas and lavas are so hot that they look like the red pieces of fire and hence there is a confusion of fire but this is not the case. Igneous rocks are also called as **primary rocks** because these were originated first of all the rocks during the formation of upper crust of the earth on cooling, solidification and crystallization of hot and liquid magmas after the origin of the earth. Thus, all the subsequent rocks were formed, whether directly or indirectly, from the igneous rocks in one way or the other. This is why igneous rocks are also called as **parent rocks.** It is believed that the igneous rocks were formed during each period of the geological history of the earth and these are still being formed.

### Characteristics of Igneous Rocks

(1) In all, the igneous rocks are roughly hard rocks and water percolates with great difficulty along the joints. Some times the rocks become so soft, due to their exposure to environmental conditions for longer duration, that they can be easily dug out by a spade (e.g. basalt).

(2) Igneous rocks are granular or crystalline rocks but there are much variations in the size, form and texture of grains because these properties largely depend upon the rate and place of cooling and solidification of magmas or lavas. For example, when the lavas are quickly cooled down and solidified at the surface of the earth, there is no sufficient time for the development of grains/crystals. Consequently, either there are no crystals in the resultant basaltic rocks or if there are some crystals at all, they are so

minute that they cannot be seen without the help of a microscope. Contrary to this, if magmas are cooled and solidified at a very slow rate inside the earth, there is sufficient time for the full development of grains, and thus the resultant igneous rocks are characterized by coarse grains.

(3) Igneous rocks do not have strata like sedimentary rocks. When lava flows in a region occur in several phases, layers after layers of lavas are deposited and solidified one upon another and thus there is some sort of confusion about the layers or strata but actually these are not strata rather these are layers of lavas. Such examples may be seen anywhere in the Western Ghats where several lava flows during Cretaceous period resulted into the formation of thick basaltic cover having numerous layers of lavas of varying compositions. One can see such lava layers near Khandala or along the deeply entrenched valleys of Koyna river, Krishna river, Saraswati river etc.in and around Mahabaleshwar plateau.

(4) Since water does not penetrate the rocks easily and hence igneous rocks are less affected by chemical weathering but basalts are very easily weathered and eroded away when they come in constant touch with water. Coarse grained igneous rocks are affected by mechanical or physical weathering and thus the rocks are easily disintegrated and decomposed.

(5) Igneous rocks do not contain fossils because (i) when the ancient igneous rocks were formed due to cooling and solidification of molten rock materials at the time of the origin of the earth, there was no life on newly born earth and (ii) since the igneous rocks are formed due to cooling and solidification of very hot and molten materials and hence any remains of plants or animals (fossils) are destroyed because of very high temperature.

(6) The number of joints increases upward in any igneous rock. The joints are formed due to (i) cooling and contraction, (ii) expansion and contraction during mechanical weathering, (iii) decrease in superincumbent load due to removal of materials through denudational processes and (iv) earth movement caused by isostatic disturbances. Whenever these joints are plugged by minerals, the rocks become quite hard and resistant to weathering and erosion.

(7) Igneous rocks are mostly associated with the volcanic activities and thus they are also called as volcanic rocks. Igneous rocks are generally found in the volcanic zones.

## Classification of Igneous Rocks

There are vast variations in the igneous rocks in terms of chemical and mineralogical characteristics, texture of grains, forms and size of grains, mode of origin etc. Thus, the igneous rocks are classified on several grounds in a variety of ways as follows :

(1) The most traditional method of the classification of the igneous rocks is based on the amount of silica (Si $O_2$). Thus, the igneous rocks are devided into two broad categories e.g. (i) **acidic igneous rocks** having more silica, e.g. granites, and (ii) **basic igneous rocks** having lower amount of silica, e.g. gabbro. It may be pointed out that silica content is not a measure of acidity.

(2) On the basis of the chemistry and mineralogical composition (light and dark minerals) the igneous rocks are classified into two dominant groups e.g. (i) **felsic igneous rocks** composed of the dominant minerals of the light group such as quartz and feldspar having rich content of silica. The word **felsic** has been derived from fell(s), feldspar plus ic., meaning there by the dominance of feldspar mineral (ii) **mafic igneous rocks** composed of the dominant mineral of dark group such as pyroxenes, amphiboles and olivines, all of which have rich contents of magnesium and iron. The word '**mafic**' has been derived from magnesium and f (ferrous) for iron and ic meaning thereby the dominance of magnesium and ferrous (iron), (iii) **ultramafic igneous rocks** are characterised by the abundance of pyroxenes and olivine minerals, examples, peridotite (rich in pyroxene and olivine),and dunite (rich in olivine).

(3) The igneous rocks are also classified on the basis of texture of grains into 5 major groups.

(i) **Pegmatitic igneous rocks** (very coarse-grained igneous rocks) include very large crystals, several metres across. Examples, granites.

(ii) **Phaneritic igenous rocks** (coarse grained igneous rocks). The word phaneritic has been derived from Greek word '**phanero**', meaning thereby visible.

(iii) **Aphanitic igneous rocks** (fine grained igneous rocks). The word aphanitic has been derived from the Greek word '**aphan**', meaning thereby invisible, that is the grains of the aphanites are so minute that they cannot be seen by bare eyes.

(iv) **Glassy igneous rocks** (without grains of any size).

(v) **Porphyritic igneous rocks** (mixgrained igneous rocks).

(4) The igneous rocks are more commonly classified on the basis of the mode of occurrence into two major groups.

(i) **Intrusive igneous rocks**—(a) plutonic igneous rocks, (b) hypabyssal igneous rocks.

(ii) **Extrusive igneous rocks**—(a) explosive type, (b) quiet type.

### 1. Intrusive Igneous Rocks

When the rising magmas during a volcanic activity do not reach the earth's surface rather they are cooled and solidfied below the surface of the earth, the resultant igneous rocks are called intrusive igneous rocks. These rocks are further subdivided into two major groups of plutonic intrusive igneous rocks and hypabyssal intrusive igneous rocks on the basis of the depth of the place of cooling of magmas from the earth's surface. When the magmas are cooled and solidified very deep within the earth, the resultant rocks become plutonic but when the magmas are cooled just below the earth's surface , the rocks are called as hypabyssal igneous rocks.

(i) **Plutonic igneous rocks** are formed due to cooling of magmas very deep inside the earth. Since the rate of cooling of magmas is exceedingly slow because of high temperature prevailing there and hence there is sufficient time for the full development of large grains. Thus, the plutonic igneous rocks are very coarse-grained (pegmatites) rocks. Granite is best representative example of this category.

(ii) **Hypabyssal igneous rocks** are formed due to cooling and solidification of rising magma during volcanic activity in the cracks, pores, crevices, and hollow places just beneath the earth's surface, the resultant rocks are called as hypabyssal igneous rocks. The magmas are solidified in different forms depending upon the hollow places such as batholiths, laccoliths, phacoliths, lopoliths, sills, dikes etc. It should be remembered that these should not be taken as the types of igneous rocks because these are different shapes of solidified magmas.

(A) **Batholiths** are long irregular and undulating forms of solidified intruded magmas. They are usually dome-shaped and their side walls are very steep, almost vertical. The upper portions of batholiths are seen when the superincumbent cover is removed due to continued denudation but their bases are never seen (fig. 8.1) because they are buried deep within the earth. When exposed to the surface they are subjected to intense weathering and erosion and hence their surfaces become highly irregular and corrugated. Numerous batholithic domes were intruded below the Dharwarian sedimentaries in many parts of the peninsular India during pre-Cambrian period. Many of such batholithic domes have now been exposed well above the surface in many parts of the Chotanagpur plateau of India mainly Ranchi plateau where such batholithic domes are called as **Ranchi batholiths**. Murha pahar near Pithauriya village, to the north-west of Ranchi city, is a typical example of exposed Ranchi batholithic domes.

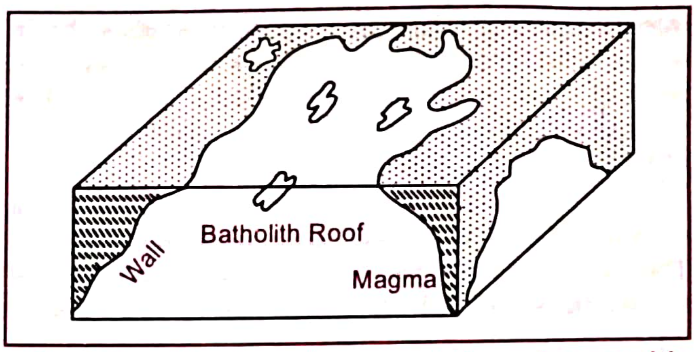


*Fig. 8.1 : Diagramatic presentation of a granitic batholith.*

(B) **Laccoliths**—The world laccolith has been derived from German word, **'laccos'** meaning thereby 'lithos' or rocks. Laccoliths are formed due to injection (intrusion) of magmas along the bedding planes of horizontally bedded sendimentary rocks. Loccoliths are of mushroom shape having convex summital form. The ascending gases during a volcanic eruption force the upper starta of the flat layered sedimentary rocks to arch up in the form of a convex arch or a dome. Consequently, the gap between the arched up or domed upper starta and the horizontal lower starta is injected with magma and other volcanic materials (fig. 8.2).

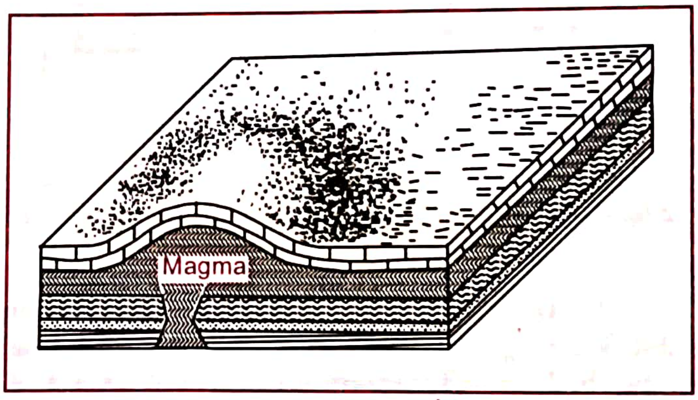


*Fig. 8.2 : Diagramatic illustration of a typical laccolith.*

(c) **Phacoliths** are formed due to injection of magma along the anticlines and synclines in the regions of folded mountains (fig. 8.3).

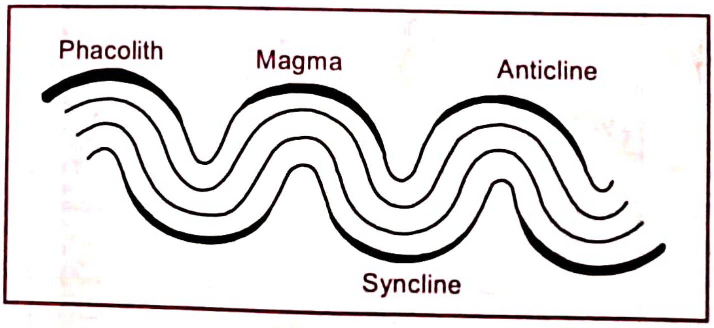


*Fig. 8.3 : An example of phacoliths.*

(D) **Lopoliths**—The word lopolith has been derived from German word 'lopas' meaning thereby a shallow basin or bowl shape body. When magma is injected and solidified in a concave shallow basin whose central part is sagged downward, the resultant form of solidified magmas is called a lopolith. The rocks of lopoliths are generally coarse-grained because of slow process of cooling of magmas.

(E) **Sills**—The word 'sill' has been derived from an Anglo-Saxon word 'syl' meaning thereby a ledge. The sills are usualy parallel to the bedding planes of sedimentary rocks. In fact, sills are formed due to injection and solidification of magmas between the bedding planes of sendimentary rocks. Thick beds of magmas are called sills whereas thin beds of magma are termed as **'sheets'**. The thickness of sills ranges between a few centimetres to several metres. When sills are tilted together with the sendimentary beds due to earth movements and are exposed to exogenous denudational processes, they form significant landforms like cuesta, hogbacks and ridges (figs. 8.4 and 8.8).

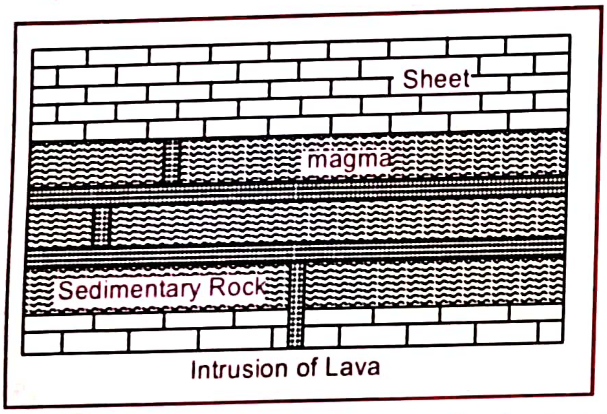


*Fig. 8.4 : Intrusion of sills between the horizontal bedding planes of sedimentary rocks.*

(F) **Dykes** represent wall-like formation of solidified magmas. These are mostly perpendicular to the beds of sedimentary rocks. The thickness of dykes ranges from a few centimetres to several hundred metres but the length extends from a few metres to several kilometres. A well defined dyke is observable across the palaeochannel and valley of the Narmada

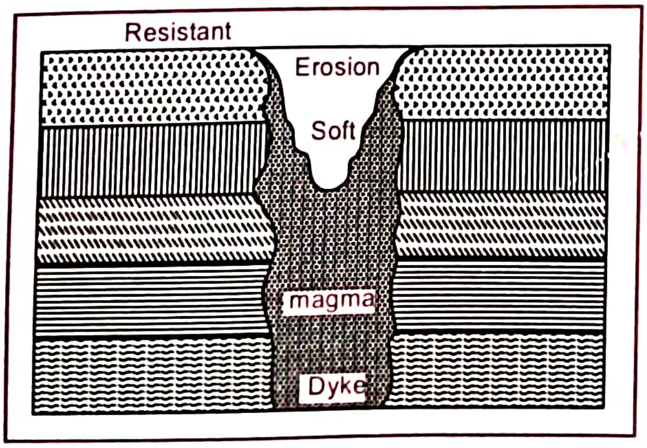


*Fig. 8.5 : The resultant feature on dyke after erosion (the rocks of dykes being less resistant than the surrounding country-rocks).*

river near Dhunwadhar Falls (Bheraghat) near Jabalpur city. The relative resistance of dykes in comparison to the surrounding country rocks gives birth to a few interesting landforms e.g. (1) If the rocks of dykes are weaker and less resistant than the country rocks, the upper portion of dykes is more eroded than the country rocks, with the result a depression is formed, which, when filled up with water, is called a 'dyke lake' (fig. 8.5); (ii) If the rocks of dykes are more resistant than the country rocks, upstanding ridges and hills are formed because of more erosion of the country rocks (fig. 8.6) and (iii) If the rocks of dykes and country rocks are of uniform resistance, both are uniformly dissected and hence no significant landform is developed but the height is gradually reduced (fig. 8.7).

## 2. Extrusive Igneous Rocks

The igneous rocks formed due to cooling and solidification of hot and molten lavas at the earth's surface are called extrusive igneous rocks. Generally, extrusive igneous rocks are formed during fissure eruption of volcanoes resulting into **flood basalts.** These rocks are also called as **volcanic rocks.** Extrusive igneous rocks are generally fine-grained or glassy basalts because lavas after coming over the earth's surface are quickly cooled and solidified due to comparatively extremely low temperature of the atmosphere and thus there is no enough time for the development of grains or crystals. Basalt is the most significant representative example of extrusive igneous rocks. Gabbro and obsidian are the other important

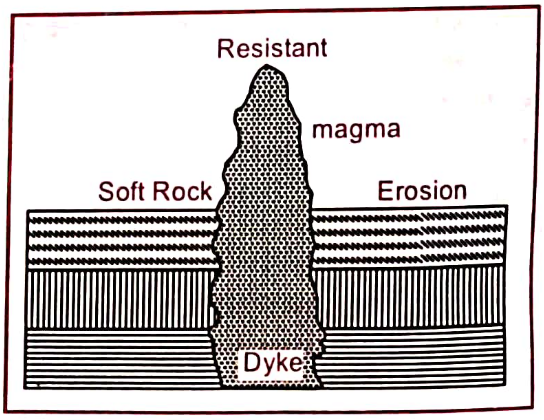


*Fig. 8.6 : Form of a dyke after erosion (when the rocks of dyke are more resistant than the country-rocks).*

examples of this group. Extrusive igneous rocks are further divided into two major subcategories on the basis of the nature of the appearance of lavas on the earth's surface e.g. (i) explosive type and (ii) quiet type.

(i) **Explosive type**—The igneous rocks formed due to mixture of volcanic materials ejected during explosive type of violent volcanic eruptions are called explosive type of extrusive igneous rocks. Volcanic materials include **'bombs'** (big fragments of rocks), **'lapilli'** (fragments of the size of a peas) and volcanic dusts and ashes. Fine volcanic materials, when deposited in aquatic condition, are called 'tuffs'. The mixture of larger and smaller particles after deposition is called **'breccia'** or **'agglomerate.'** These are more susceptible to erosion because these are not well consolidated.

(ii) **Quiet type**—The appearance of lavas through minor cracks and openings on the earth's surface is called **'lava flow'**. These lavas after being cooled and solidified form basaltic igneous rocks. Flood basalts resulting from several episodes of lava flow during fissure flows of volcanic eruption form extensive **'lava plateau'** and **'lava plains'** wherein several layers of basalts are deposited one upon another.

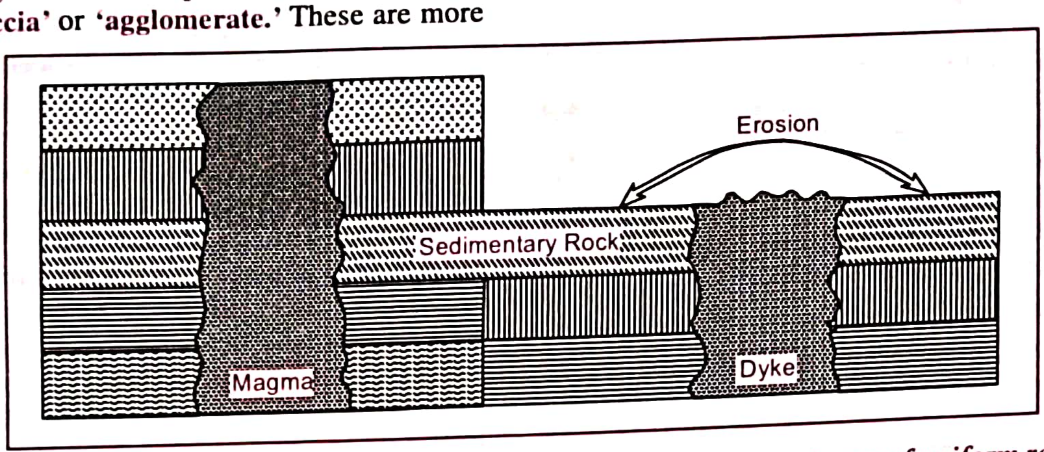


*Fig. 8.7 : Form of a dyke after erosion (when the rocks of dyke and country-rocks are of uniform resistance).*

The thickness of lavas of the Columbia plateau of the states of Washington and Oregon (USA), spread over an area of about 6,45,000 km$^2$ (2,50,000 square miles), measures about 1,216 m (4,000 feet). The extensive lava flows during Cretaceous period covered an area of about 7,74,000 km$^2$ (3,00,000 square miles) of Peninsular India. Several beds of basaltic lavas are clearly observable all along the exposed sections of the Western Ghats mainly near Khandala (between Mumbai and Pune) and over Mahabaleshwar plateau.

## Classification of Igneous Rocks on the Basis of Chemical Composition

Though the chemical composition of igneous rocks varies significantly from one group to another group but each type of igneous rock contains some amount of silica. Thus, on the basis of silica content, igneous rocks are divided into the following four types :

(i) **Acid igneous rocks** are those which carry silica content between 65 to 85 per cent. The average density varies from 2.75 to 2.8. Quartz and white and pink feldspar are the dominant minerals. Acid igneous rocks generally lack in iron and magnesium. On an average acid igneous rocks are hard and relatively resistant to erosion. Granite is the most significant example of this group of rocks. These rocks are light in weight and are used as building materials because of their less erosivity.

(ii) **Basic igneous rocks** contain silica content between 45 to 60 per cent. Their average density ranges from 2.8 to 3.0. Such igneous rocks are dominated by ferro-magnesium minerals. There is very low amount of feldspar. The rock is heavy in weight and dark in colour because of the dominance of iron content. Basic igneous rocks are easily eroded away when these come in regular contact with water. These rocks are fine grained igneous rocks. Basalt, gabbro, dolerite etc. are the typical examples of this group.

(iii) **Itremediate igneous rocks** are those in which silica content is less than the amount present in the acid igneous rocks but more than the basic igneous rocks. The average density ranges between 2.75 and 2.8. Diorite and andesite are the representative examples of this group of rocks.

(iv) **Ultra basic igneous rocks** carry silica conent less than 45 per cent but their average density varies from 2.8 to 3.4. Peridotite is the typical example of this group of rocks.

## Classification of Igneous Rocks on the Basis of Texture of Grains

The texture of the crystals (grains) of igneous rocks depends on 3 basic factors viz. (i) source region of the origin of magmas and lavas and places of their cooling and solidification; (ii) rate of cooling and solidification of magmas and lavas and (iii) quantity of water and gases (vapour) with hot and molten magmas and lavas. If magmas and lavas are cooled slowly and gradually the grains are well developed but if they are cooled and solidified at a very faster rate, grains are not well developed. The rate of cooling of magmas and lavas also depends upon several factors

Unit-IV
(Erosional and Depositional work and Topographies)

# 18

# RUNNING WATER (RIVER) AND FLUVIAL LANDFORMS

## 18.1 MEANING

The work of running water in the form of surface runoff or overland flow and streams is most important of all the exogenetic or planation processes (*e.g.* groundwater, sea waves, glaciers, wind, periglacial processes etc.) because the running water is the most widespread exogenetic process on this planet earth. The landforms either carved out (due to erosion) or built up (due to deposition) by running water are called **fluvial landforms** (both erosional and depositional) and the running waters which shape them are called **fluvial process** which include overland flow (surface runoff) and steam flow.

The rainwater reaching the earth's surface becomes **surface runoff** when it spreads laterally on the ground surface. The surface runoff becomes a stream when water flows from certain height down the slope under the impact of gravity. Streams are generally divided into four broad categories viz. perennial or permanent streams, non-permanent or seasonal streams, intermittent streams and ephemeral streams. The geological works of fluvial processes or rivers are called **three-phase work** comprising **erosion, transportation** and **deposition**. The fluvial landforms are divided into two major groups *e.g.* 1. **erosional landforms** and 2. **depositional landforms.** The landforms resulting from progressive removal of the bedrock mass are called erosional landforms *e.g.* various types of valley (viz. gorges, canyons, broad and flat, mature and senile valleys, multi-storeyed valleys etc.), pot holes, rapids and water falls, structural benches, terraces, meanders etc. The landforms shaped by the deposition of different types of eroded materials become depositional landforms such as alluvial fans and cones, natural levees, flood plains, terraces, deltas etc.

## 18.2 EROSIONAL WORK OF RIVERS

The word **'erosion'** has been derived from a Latin word, **'erodere'** which means to gnaw. Erosion is, in fact, a dynamic process which involves the removal of geomaterials from the rocks and other deposited materials. Though weathering greatly assists in the erosion of rocks but it is not a prerequisite condition as remarked by W.D. Thornbury. 'It is true, of course, that weathering is a preparatory and may make erosion easier, but it is not prerequisite to nor necessarily followed by erosion.' In fact, erosion is that process in which various erosive agents (running water-river, wind, glacier, periglacial, sea waves and groundwaters) obtain and remove rock debris from the earth's crust and transport them for long distance (Savindra Singh, 1973).

The erosional work of the rivers depends on channel gradient, volume of water, velocity and thus kinetic energy, water discharge, sediment load (tools of reosion) etc. The sediment load of the rivers includes gravels, sands, silt and clay. Gravels include boulders (256 mm diameter), cobbles (64-256 mm), pebbles (4-64mm) and granules (2-4mm). The quantity, size and calibre (angularity) of erosional tools (river load) largely control the nature and magnitude of fluvial erosion. The erosional tools of fairly big size and high calibre (with high degree of angularity) help in active down cutting of valleys. The size of river load is of paramount significance because if the load consists of very fine sediments, they move with the water in suspension (suspended sediment load) and hence becomes passive in fluvial erosion but if they are of fairly big size, they roll down along the valley floor and help in valley deepening. The amount of load should be of optimal level *i.e.* the rivers should neither be overloaded nor underloaded because if the river is overloaded in relation to its transporting capacity, it would start deposition of additional load and if the river is underloaded, the erosional work becomes negligible. The following relationships may be identified between the rate of fluvial erosion and river load :

(1) Erosion becomes minimum in the absence of required amount of river load (underloaded river).

(2) Erosion also becomes minimum when the river has maximum load (overloaded river).

(3) Erosion becomes maximum when the river carries load according to its transporting capacity.

The **law of erosion** states that the rate and amount of erosion increases before the attainment of equilibrium between the transporting capacity of the river and its load while it decreases after the attainment of their equilibrium condition.

It may be pointed out that besides the river load, velocity and channel gradient are also significant parameters which effectively control fluvial erosion. Erosion becomes maximum when the river having steep channel gradient and optimal amount of load of good size and high cablibre flow with high velocity. The velocity of water flow depends on (i) channel gradient and (ii) volume of water. Normally, the erosional power of the stream is proportional to the square of the velocity which (**erosional power α (velocity of the stream)2** means if the velocity is doubled, the erosinal power of the streams increases four times, if the velocity is increased 4 times, the erosional power increases 16 times and so on. Besides, lithological and structural characteristics of geomaterials also affect the nature and magnitude of fluvial erosion.

## 18.3 TYPES OF FLUVIAL EROSION

The erosional work of the rivers is performed in two ways viz. (i) through chemical erosion and (ii) through mechanical erosion. **Chemical erosion** involves corrosion or solution and carbonation while **mechanical erosion** comprises corrasion or abrasion, hydraulic action and attrition. Fluvial erosion is also divided into (i) vertical erosion or downcutting (which leads to valley deepening) and lateral erosion (which causes valley widening).

(1) **Solution** or **corrosion** involves the dissolution of soluble materials through the processes of disintegration and decomposition of carbonate rocks. The soluble materials are removed from the parent rocks and are mixed with the running water of the streams. Most of the salts are removed from the bedrocks through the process of carbonation (see chemical weathering in chapter 15 of this book) and are suspended in river water. According to the estimate of Murray every cubic mile water of the river contains about 7,62,587 tons of suspended minerals of which about 50 per cent is calcium carbonate. On an average the world rivers discharge about 6,500 cubic miles of water into the oceans every year. On the basis of Murray's estimate it may be inferred that about 5 billion tons of minerals are removed from the bedrocks by the world rivers each year and these minerals are carried to the seas and oceans in solution.

(2) **Abrasion** or **corrasion** involves the removal of loosened materials of the rocks of valley walls and valley floors with the help of erosional tools (boulders, pebbles, cobbles, etc.). The erosional tools or river loads move down the channel gradient along with water and thus strike against the rocks which come in contact with them. The repetition of this mechanism weakens the rocks which are ultimately loosened and broken down. Thus, abrasion is the mechanism of breakdown of rocks occasioned by erosional tools carried by the rivers. The nature and magnitude of abrasion depends on the nature, size and calibre (angularity) of erosional tools. Boulders, cobbles and pebbles of various sizes and angularity are by far the most important tools of erosion which are generally called **drilling tools**. The erosional mechanism of abrasion operates in two ways *e.g.* (i) vertical erosion leading to the erosion and deepening of valley floors and (ii) lateral erosion leading to the erosion of valley walls. Lateral abrasion causes valley widening while the vertical abrasion leads to valley deepening wherein the erosional tools drill the valley floor though the mechanism of **pot hole drilling** resulting into the formation of numerous pot holes (cylindrical depressions) of various sizes in the valley floors. Vertical abrasion (downcutting) becomes more effective during the juvenile stage (youthful) of river and valley development when channel gradient and velocity are very high.

(3) **Attrition** is the mechanical tear and wear of the erosional tools in themselves. The boulders, cobbles, pebbles etc. while moving with water collide against each other and thus are fragmented into smaller and finer pieces in the transit. Thus, the rock

particles are so broken down that ultimately they are communitted into coarse to fine sand particles which are transported down the channel in suspension.

(4) **Hydraulic action** involves the breakdown of the rocks of valley sides due to the impact of water currents of channel. In fact, hydraulic action is the mechanical loosening and removal of materials of rocks by water alone. It may be pointed out that chemical weathering, abrasion and hydraulic action are so intimately interrelated that it is unwise to think of pure hydraulic action without chemical erosion and abrasion.

## 18.4 BASE LEVEL OF EROSION

There is a limit for maximum vertical erosion by a river beyond which it cannot degrade its valley. This limit of maximum downward erosion by a river is called **base level of erosion** or simply a **base level.** Base level, in fact, is the ultimate limit of vertical erosion by a river. J.W. Powell postulated the concept of base level in 1875. According to him the sea level becomes the **grand base level** beyond which no dryland can be further degraded. Besides grand base level, there are local and temporary base levels in a particular river.

(1) **Grand base level** is also called general or ultimate or permanent base level which is determined by the sea level. Base level is a smooth curve which rises and becomes concave upstream. In other words, grand base level is such an imaginary smooth curve below the land the slope of which gradually decreases downstream towards the sea where the river enters the sea. This imaginary smooth curve of the grand base level denotes the limit of maximum downward erosion by a particular river. The sea level is a tangent on this smooth curve of the grand base level of erosion. The grand base level depends on the position of sea level. In other words, it changes with changes in the sea level. When a river degrades its valley upto sea level near its mouth, the river is said to have attained its base level. The rise and fall in sea level also causes rise and lowering of base level. Thus, changes in base level of erosion in response to sea level changes produces different suites of landforms.

(2) **Temporary base level :** There may be several temporary base levels in a particular river due to a variety of factors *e.g.* due to the presence of lakes, different beds of hard and soft rocks etc. in the longitudinal course of the rivers. The temporary base levels are eliminated when the whole course of the river attains its grand base level or permanent base level determined by the sea level.

(3) **Local base level** is in fact the level of the confluence of a tributary stream with its receiving master stream. The tributary streams first erode their valleys according to the level of their confluences and thus grade their longtitudinal profiles. Ultimately, the sea level becomes the grand base level of erosion for the entire drainage basin.

### Changes or Movements of Base Level

The changes or movements in the base level of erosion are guided by the changes in sea level. Sea level changes are generally of two types viz. (i) **eustatic changes** (which have global impacts) and (ii) **local changes.** Sea level changes are divided in two categories on the basis of timal factor *e.g.* (i) long-term changes and (ii) short-term changes. Sea level changes and consequent changes and movements in the base level of erosion are always considered in terms of relative position of the coastal land and sea level. Thus, changes in sea level and base level are grouped into two categories viz. (i) **positive change** and (ii) **negative change.** Postive change in the sea level and hence in the base level of erosion occurs when either there is subsidence of the coastal land in relation to the sea level or there is upheaval of the sea floor. On the other hand, the negative change in sea level and base level of erosion occurs when either there is emergence of the coastal land in relation to the sea level or there is subsidence of the sea floor. The above mentioned causes of sea level and base level changes are related to tectonic factors. Besides, glaciation and deglaciation during ice ages at global level also cause lowering (negative change) and rise (positive change) of sea levels and base levels respectively. It is apparent from the above discussion that negative change in sea level and base level (lowering of base level) causes emergence of coastal land while positive change (rise) leads to submergence of coastal land.

The **positive change** or upward movement of base level due to rise in sea level causes the following geomorphic events in a particular river profile- (i) interruption in the fluvial cycle of erosion leading to shortening of cyclic time because the stage of cyle of erosion is advanced forward, (ii) formation of ria coasts and estuaries because of the submergence of valleys of the rivers at their mouths, (iii) filling of river mouths leading to the formation of buried valleys or channels, (iv) formation of flood plains because of increased sedimentation and alluviation due to lowering of channel gradient and decrease in the transporting capacity of the rivers because of rise or upward movement of base levels, (v) filling of lowlands by aggradation, (vi) formation and development of sea islands near the coasts due to transgression of sea water on the coastal land etc.

The **negative change** in base level caused by lowering of sea level brings the following geomorphic changes in the affected areas : (i) interruption in the fluvial cycle of erosion leading to lengthening of cyclic time because the stage of cycle of erosion is pushed back (*i.e.* from old to mature or from mature to young stage), (ii) rejuvenation leading to accelerated rate of downward (vertical) erosion and active valley deepening, (iii) evolution of topographic discordance having young topographic features in the lower segments of the valleys and old features in the upper part of the valleys, (iii) formation of multistoreyed valleys and paired terraces on either side of the valley, (iv) development of polycyclic reliefs, (v) development of knick points, knick point waterfalls, and incised meanders, (vi) breaks in slope in the longitudinal profiles of the rivers etc.

## 18.5 EROSIONAL LANDFORMS

The significant landforms resulting from fluvial erosion by streams include river valleys, water falls and rapids, pot holes, structural benches, river terraces, meanders, peneplians etc.

### River Valleys

The valleys carved out by the rivers are significant erosional landforms. The shape and dimension of fluvially originated valleys change with the advancement of the stages of fluvial cycle of erosion. The valley formed in the youthful stage of fluvial cycle of erosion and in the initial stage of valley development is V-shaped having steep valley side slope of convex element. The valley is very deep and narrow, both the valley sides meet together at the valley floor and thus water always touches the valley sides. Such type of V-shaped valleys are the result of accelerated rate of downcutting (vertical erosion or valley deepening). The valleys are gradually widened due to lateral erosion with the advancement of the stage of cycle of erosion and they become quite broad with flat valley floor and uniform or rectilinear valley side slopes during mature stage or valley development and fluvial cycle of erosion. They are further transformed into very broad and shallow valleys having concave valley side slope of very gentle gradient during old stage. V-shaped valleys are divided into two types viz (1) gorges and (2) canyons.

(1) **Gorges** and **canyons** represent very deep and narrow valleys having very steep valley side slopes say wall-like steep valley sides. It is difficult to draw a line of distinction between these two types of valleys. Normally, a very deep and narrow valley is called a gorge and the extended form of a gorge is called a canyon (fig. 18.1). Gorges are formed due to active downcutting of the valleys through the mechanism of pothole drilling during juvenile (youth) stage of the fluvial cycle of erosion. Gorges are also formed due

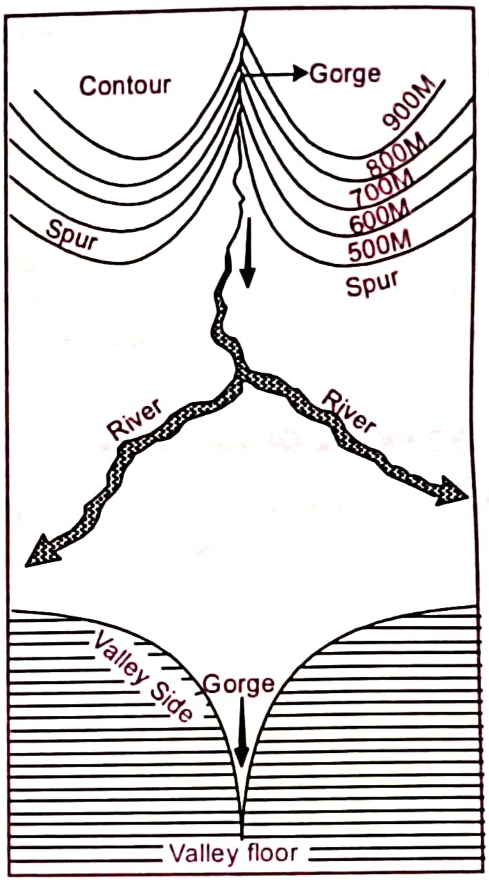


*Fig. 18.1 : Contour plan of gorge and spurs and cross section of a gorge.*

to recession of water falls. Most of the Himalayan rivers have carved out deep and narrow gorges. The significant gorges formed due to recession of waterfalls include Hundrughagh gorge on the Subarnarekha river (near Ranchi), gorge of the Raru river below Johna or Gautamdhara falls (east of Ranchi), Dassamghagh gorge below Dassamghagh falls on the Kanchi river (east of Ranchi), Pheruaghagh gorge on the South Koel river (south of Ranchi), Chachai gorge on the Bihar river (Rewa, M.P.), Kevti gorge on the Mahana river (Rewa, M.P.), gorge of the Odda river (Rewa, M.P.) etc.

(2) **Canyons** are extended form of gorges. Canyons represent very deep, narrow but long valleys. The steepness of the valley sides depends on the nature of the rocks. Relatively resistant rocks support steep valley sides whereas resistant rocks alternated by soft rocks give birth to undulating valley sides. The Grand Canyon of the Colorado river in the state of Arizona (USA) having a length of 482.8 kilometres and depth of 2088.3 m is one of the most important canyons of the world. The Indus river has cut across the Himalayan ranges and flows through 17,000-foot deep gorge and canyon.

## Waterfalls

Waterfalls or simply falls are caused because of sudden descents or abrupt breaks in the longitudinal course of the rivers due to a host of factors *e.g.* variation in the relative resistance of rocks, relative difference in topographic reliefs, fall in the sea level and related rejuvenation, earth movements etc. A waterfall may be defined as a vertical drop of water of enormous volume from a great height in the long profiles of the rivers. **Rapids** are of much smaller dimension than waterfalls. Generally, they are found upstream from the main falls but they are also found independently. There is a chain of waterfalls along the junction of the Piedmont and Atlantic coastal plain from New England Region in the north-east to central Alabama in the south-west (USA) wherein all the Atlantic bound streams while descending through the Piedmont make numerous waterfalls. This chain of water falls is called fall line in the USA.

There is also a well marked **fall line** in India. This **Indian fall line** extends between the Purwa or Tons falls on the Tons river (in the north-west part of the Rewa district of Madhya Pradesh) in the west and Sasaram (Bihar) in the east along the junction of the northern foreland of Peninsular India and the Ganga plains. Hundreds of waterfalls ranging in height between 15m and 180m are found along this fall line as all the major streams emerging from the Kaimur ranges and draining due northward make stupendous water falls while descending through the rim of the northern foreland of the Indian Peninsula. Significant waterfalls of this fall line are Purwa or Tons falls (70m) on the Tons river (in Rewa district, M.P.), a tributary of the Ganga river, Chachai falls (127m) on the Bihar river (Rewa district), tributary of the Tons river, Kevti falls (98m) on the Mahana river (Rewa district), a tributary of the Tons river, Odda falls (145m) on the Odda river (Rewa district), a tributary of the Belan river (which is itself a tributary of the Tons river), Devdari falls (58m) on the Karamnasha river (Rohtas plateau, Bihar), Telharkund falls (80m) on the Suara West river (Rohtas plateau), Suara falls (120m) on the Suara East river, Durgawati falls (80m) on the Durgawati river (Rohtas plateau), Okharean Kund falls (90m) on the Gopath river (Rohtas plateau), Dhuan Kund falls (30m, Rohtas plateau, near Sasaram) on the Dhoba river, Kuaridah falls (180m) on the Ausane river (a tributary of the Son river, Rohtas Plateau), Rakim Kund falls (168m on the Gayghat river, a tributary of the Ausane river (Rohtas plateau) etc.

**Types of Waterfalls** The waterfalls vary so greatly in terms of their height, shape and size, dimension and volume of water that it becomes difficult to classify them in certain categories. Generally, waterfalls are divided into two broad categories on the basis of mode of their origin viz. (1) normal waterfalls and (2) minor waterfalls. Normal waterfalls include those falls which are formed due to variation in the resistance of rocks. These waterfalls are indicative of youthful stage of stream development and ungraded long profiles of the streams. Minor waterfalls include the falls which are originated due to interruption in the cycle of erosion caused by rejuvenation. Such water falls are called knick-point falls. The following is the detailed scheme of the classification of fluvially originated waterfalls.

**1. Normal waterfalls**

- (i) Step waterfalls
- (ii) Caprock falls
- (iii) Barrier falls
- (iv) Plateau falls

**2. Minor waterfalls**

- (A) Falls originated due to endogenetic forces
  - (i) Fault falls
  - (ii) Falls due to upliftment
- (B) Falls originated due to changes in the level of valley floors
  - (1) Due to lowering of valley floor
    - (i) Hanging valley falls
    - (ii) Glacial hanging valley falls
    - (iii) Falls due to river capture
    - (iv) Coastal hanging valley falls
    - (v) Knickpoint falls
  - (2) Due to obstructions in the river courses
    - (i) Falls due to landslides
    - (ii) Falls due to lava dams
    - (iii) Falls due to glacial moraines

(1) **Waterfalls due to structural and lithological variations**—The waterfalls originated due to variations in the structural and lithological characteristics of terrestrial rocks are called normal waterfalls. Various hierarchical orders of water falls (*e.g.* catracts, rapids and cascades) depend on the relative resistance and disposition of the beds of different rocks. The cliffs formed due to the presence of hard and soft rocks in the courses of the rivers form large waterfalls which are called **cataracts**. Alternate bands of hard and soft rocks give birth to a series of small step-like falls which are called **cascades.** The disposition of rock beds gives birth to waterfalls of varying dimensions in the following manner :

(i) **When the rock beds dip upstream**—When the alternate bands of hard and soft rocks dip upstream in the longitudinal course of the river and if the caprock is resistant the underlying soft rocks are eroded more rapidly due to cliffing and thus the resistant rock beds form precipitous wall-like scarps which allow the river water to fall downstream vertically and ultimately a stupendous waterfall is formed. Such waterfall recedes at faster rate due to cliffing and tumbling down of hanging head walls of the falls (fig. 18.2). Such falls, called as caprock falls, disappear when the river attains its graded profile of equilibrium.

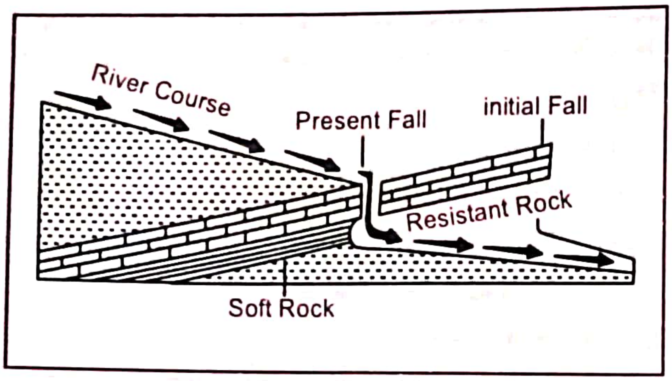


*Fig. 18.2 : Origin of waterfalls when the rocks dip upstream.*

(ii) **When the rock beds dip downstream** : Rapids are formed when the alternate bands of hard and soft rocks dip downstream and the caprock is resistant to erosion. Such falls are called **caprock rapids** (fig. 18.3).

(iii) **When the rock beds are horizontal** : Very massive and stupendous waterfalls are formed when the rock beds are arranged in horizontal manner and the caprock is quite resistant such as quartzitic sandstones, dolomitic limestones, granite-gneisses and the underlying rocks are soft and vulnerable to quick fluvial erosion such as shale, volcanic ash and unconsolidated geomaterials, because soft rocks are eroded more than the overlying resistant caprocks and thus resistant rocks form wall-like scarps which allow river water to fall down vertically. Niagra Falls come under this category of waterfalls. The caprock of this waterfall is dolomitic limestones which are

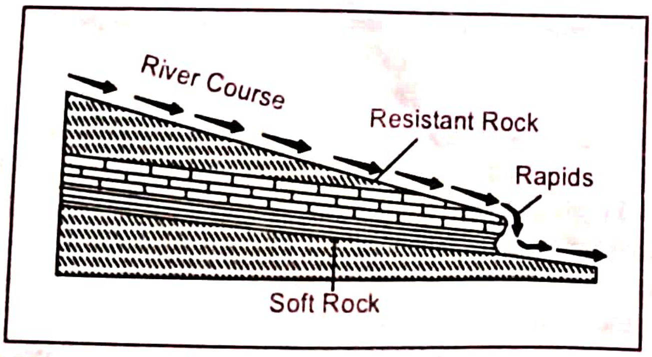


*Fig. 18.3 : Formation of rapids when the rock beds dip downstream.*

succeeded below by the successive beds of shales, limestones, sandstones, sandstones intercalated with shales, sandstones, and shales (fig. 18.4). The height of the fall is now 52m and the water discharge is 17,000 cumecs (cubic metres per second). The fall is supposed to have been formed about 10,000 years ago. It is receding at the rate of 3 to 4 feet per year. It is estimated that the Niagra fall has registered a total recession of about 7 miles (11.2 km) till now, Kaieteur falls (British Guiana) also fall under this category of **caprock falls.** The caprock is of resistant conglomerates. The Potaro river has cut deep through conglomerates and thus has formed 225.5 m high waterfall.

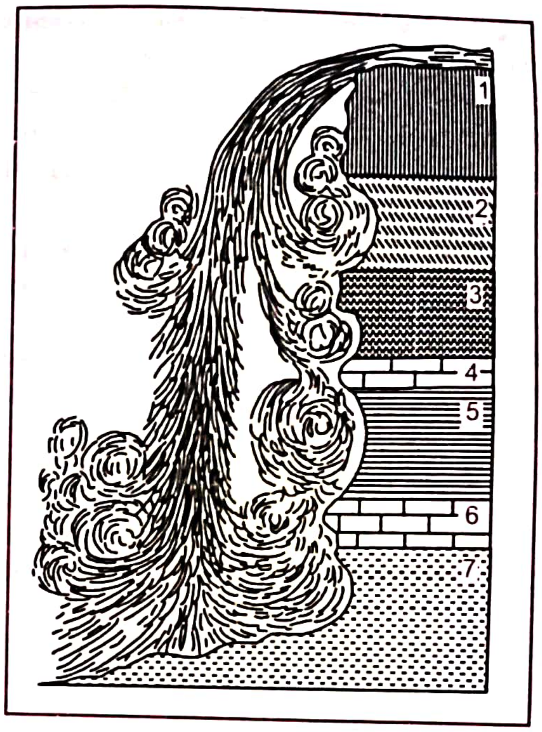


*Fig. 18.4 : Formation of waterfalls when the rock beds are horizontal and the caprock is resistant to erosion. Example of Niagrafalls, (1) dolomitic limestones, (2) shales, (3) limestones, (4) sandstones, (5) sandstones and shales, (6) sandstones, and (7) shales.*

The waterfalls of the Rewa (Madhya Pradesh) and Rohtas (Bihar) plateaux (as mentioned above) also come under this category as the caprocks are sandstones and quartzitic sandstones underlian by weaker shales of Vindhyan formations. Chachai falls (127m, on Bihar river), Kevti falls (98m, on Mahana river), Odda falls (145m, on Odda river), Kuaridah falls (180m, on Ausane river), Rakimkund falls (168m, on Gayahat river) etc. are typical examples of caprock waterfalls.

(iv) **When the rock beds are vertical**—When alternate resistant and soft rocks are arranged in vertical manner, soft rocks are eroded away rapidly but the resistant rock beds are less eroded and hence form precipitous scarps in the course of the river which give birth to waterfalls of steep slope. The intrusive dykes also form waterfalls because of their less (fig. 18.5) erosion than the surrounding rocks. Such waterfalls are called **vertical barrier falls.** Great Fall of the Yellowstone river of the Yellowstone National Park (USA) is a typical example of vertical barrier fall. Several such waterfalls have been formed in the 'Patlands' of Ranchi and Palmau (Jharkhand) but their heights range between 3m and 30m only. These waterfalls have been formed because of structural and lithological controls and differential erosion.

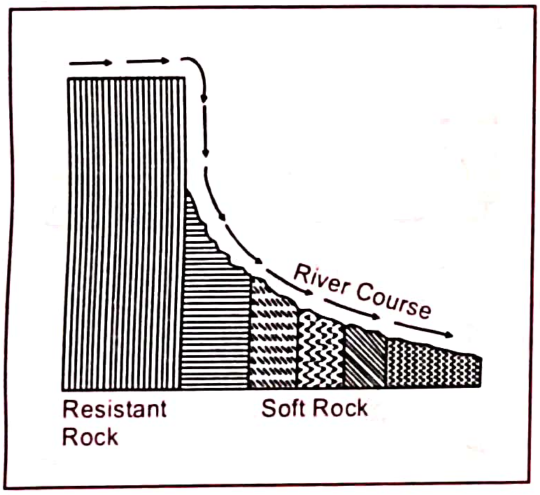


*Fig. 18.5: Origin of waterfalls when the rock beds are vertical.*

(v) **Plateau waterfalls :** The rivers coming from over the plateau surface form waterfalls when they descend through the precipitous escarpments of the plateau and enter the region of significantly lower height. The Congo river has formed 275 m high Livingstone Falls while descending through the African Plateau. Similarly, the Orange river has formed 140 m high Aughrabies Falls at the margin of the plateau. Nearly all of the significant northward draining streams and their tributaries have formed waterfalls at the northern margin of the Rewa plateau (M.P.) *e.g.* Chachai Falls (127 m) on Bihar river, Kevti Falls (98 m) on Mahana river, Odda Falls (145m) on Odda river etc. Karo river has formed 17 m high Pheruaghaugh Falls at the southern margin of the Ranchi plteau. Such falls are called as **scarp falls.** Hundru falls (75 m) on Subaranrekha river (near Ranchi), Dasam falls (39.62 m) on Kanchi river (east of Ranchi), Sadni falls (60m) on Sankh river (Ranchi plateau) etc. are the examples of **scarp falls** or **knick line falls.** The Tons river while descending through the Rewa plateau and draining northward to meet the Ganga makes a vertical falls of 70m known as Purwa falls. Similarly, its tributary the Bihar river makes a stupendous Chachai falls of 127 m height.

Yenna falls (180m) on Mahabaleshwar plateau, Gokak falls (54 m) in Belgaun district (Karnataka), Gersoppa falls (253m) on the Sharavati (in North Kanara), Sivasamudram (90m) on the Cauvery river etc. are also examples of scarp falls.

(vi) **Step falls** The arrangement of alternate bands of horizontal beds of hard and soft rocks in the course of the rivers produces a series of low water falls due to differential erosion. These falls are in fact rapids. Bhagawati falls on the Krishna river in the Raichur district of Karnataka (India) is an example of step (cascade) falls.

(2) **Waterfalls due to faults and fractures** Waterfalls are formed along the fault scarps which are created due to faulting across the river valleys. Victoria falls on the Zambezi river (110 m high) is a typical example of fault falls.

(3) **Waterfalls due to upliftment :** Waterfalls of varying dimensions are formed due to upliftment of local nature in the courses of the rivers. These waterfalls are obliterated when the rivers regrade their longitudinal profiles. A series of waterfalls on the rivers along the junction of Palamau upland and the northern flat plain (Palamau district, Jharkhand) are said to have been formed due to origin of escarpment caused by the upliftment of southern Palamau during Tertiary period. Patam falls (45.72 m) and Datam falls (30.45 m) on the Patam river (in Bhandaria Anchal, Palamau, Bihar) are typical examples of such categories. Gersoppa falls (253m) or Jog falls is also believed to have been formed due to upliftment. The waterfalls on the eastern margin of the Ranchi plateau (*e.g.* Hundru falls on the Subarnarekha river, Dasam falls on the Kanchi river, Jonha or Gautamdhara falls on the Gunga river etc.) are also quoted as the examples of waterfalls resulting from upliftment.

(4) **Hanging valley falls :** Some times, waterfalls of varying dimensions are formed when the tributary streams join their master streams from great height forming hanging valleys (fig. 18.6). In other words, hanging valley falls are formed when the level of the junction of the tributary streams is much higher than the level of the main valley of the master stream. The Rajroppa falls (10m) at the junction of the Bhera nadi and the receiving Damodar river (located to the north of Ranchi city) is a typical example of **hanging valley waterfalls** as the Bhera nadi after coming from over the Ranchi plateau hangs above the Damodar river at its confluence with the latter. The Gautamdhara or Jonha falls (25.9m) is another example of this category of falls. In fact, the Gunga river hangs above its master stream, Raru river, (to the east of Ranchi city) and forms the said falls.

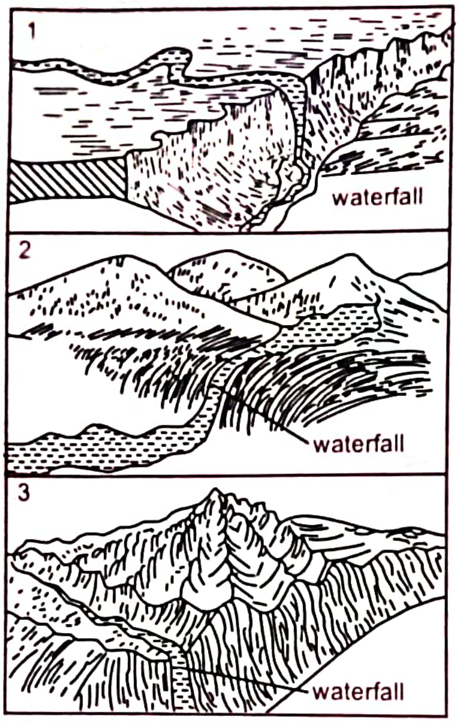


*Fig. 18.6 : Origin of waterfalls due to (1) hanging valley, (2) lava dam and (3) glacial hanging valley.*

(5) **Glacial hanging valley falls** : The fluvially originated river valleys are largely modified by glaciers during ice ages. The glaciers flowing through the main valleys deepen them more due to erosion than the tributary valleys. Thus, the tributary valleys hang over the main valleys and discordant levels are formed. These valleys are again occupied by the rivers after the ice age is over and glaciers are ablated. Consequently, the tributary streams hang over the main rivers at their junctions and waterfalls are formed (fig. 18.6). Such glacial hanging valley waterfalls are found in Norway, Sweden, Finland, Canada etc.

(6) **Waterfalls due to river capture** : Some times, waterfalls are formed when the streams flowing over higer but flat lands are captured by the streams of relatively lower height. Thus, the captured streams drain into the captor streams by making waterfalls. Such falls are abundantly found in the Himalayas.

(7) **Coastal hanging valley falls** : The rivers while descending through sea cliffs or cliffed coast form vertical waterfalls before debouching into the sea (fig. 18.7). Such waterfalls are also called coastal hanging valley falls as the river hangs through the vertical cliffed coast.

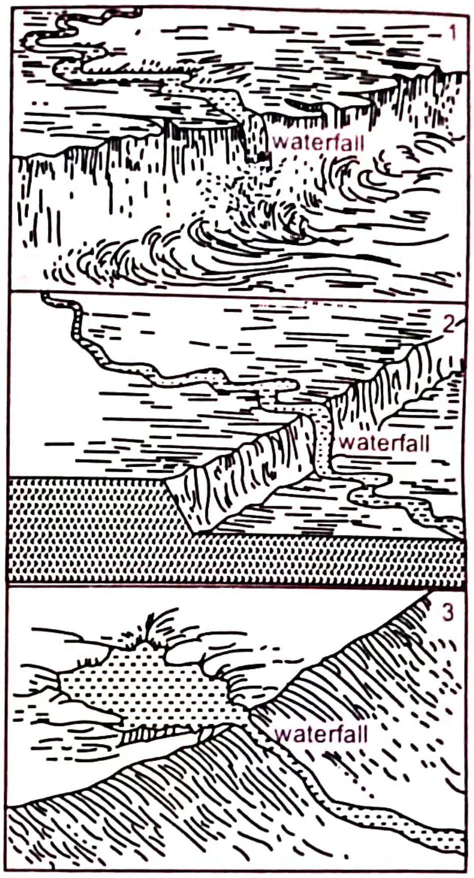


*Fig. 18.7 : Origin of waterfalls due to (1) cliffed coast, (2) faults and (3) upliftment.*

(8) **Knickpoint falls** : The breaks in channel gradient caused by rejuvenation (either due to upliftment or fall in sea level) are called knick points or heads of rejuvenation. These breaks in channel gradient or knickpoints denote sudden drops of elevation in the longitudinal profile of the rivers and allow the water to fall down vertically giving birth to waterfalls of varying dimensions. Hundru falls (76.67 m) on the Subarnarekha river (near Ranchi city), Jonha or Gautamdhara falls at the confluence of the Raru and the Gunga rivers (to the east of Ranchi), Dasam falls (39.62 m and 15.24 m) on the Kanchi river (east of Ranchi), Burhaghaugh falls (148 m) on the Burha river, a tributary of the North Koel (Palamau upland, Jharkhand), Dhunwadhar falls on the Narmada river (near Jabalpur, M.P.), major falls of Rewa plateau (*e.g.* Chachai falls-127 m on the Bihar nadi, Kevti falls-98 m on the Mahana nadi, Tons or Purwa falls-75m on the Tons river, Odda falls -145 m on the odda nadi etc.) etc. are the examples of knick point waterfalls.

(9) **Waterfalls due to obstructions in the river flow** : Some times, temporary water falls are formed

due to temporary damming of the river flow through natural processes in a number of ways.

(i) **Lava-dammed waterfalls** are formed when the flow of river water is obstructed due to formation of lava barrier across the valley. Such falls are almost permanent.

(ii) **Landslide-dammed waterfalls** are originated when huge volume of debris slides down from the nearby hillslopes into the river and obstructs the free flow of the river by making barrier across the valley.

(iii) **Moraine-dammed waterfalls** are formed due to damming of river flow by morainic debris. The rivers make falls while crossing through the morainic ridges formed across the valleys.

**Recession of waterfalls**—It may be pointed out that waterfalls and rapids are not permanent landforms. They disappear when the rivers attain their graded curves and profiles of equilibrium during mature stage of valley development and normal cycle of erosion. In fact, the rivers try to grade themselves through vertical erosion (valley deepening) in relation to base level of erosion (sea level). The obliteration of waterfalls takes place through two processes viz. (1) horizontal recession through backwasting and (2) lowering of height through downwasting. Niagra falls are receding at the rate of 1.2 to 1.4 m per year. It has been estimated that Niagra falls have receded upto about 11 km till now. No attempts have been made to record the recession of waterfalls in India.

## Pot Holes

The kettle-like small depressions in the rocky beds of the river valleys are called potholes which are usually cylindrical in shape. Potholes are generally formed in coarse-grained rocks such as sandstones and granites. Potholing or pothole drilling is the mechanism through which the grinding tools (fragments of rocks *e.g.* boulders and angular rock fragments) when caught in the water eddies or whirling water start dancing in circular manner and grind and drill the rock beds of the velleys like drilling machine and thus form small holes which are gradually enlarged by the repetition of the said mechanism. The potholes go on increasing in both diameter (and perimeter) and depth. The diameter of pot holes ranges from a few centimetres to several metres. The depth of potholes is far more than their diameters. Potholes of much bigger size are called **plunge pools.** In fact, plunge pools are generally formed at the base of waterfalls due to pounding of rocks by gushing water of the falls (waterfalls). Many of the river valleys are studded with numersous potholes in Chotanagpur highlands where the rivers have been rejuvenated due to upliftment effected during Tertiary period. The basaltic bed of the Gaur nadi near Bhadbhada (east of Jabalpur, M.P.) presents a magnificent view of numerous potholes of various dimension. Pothole drilling is the effective mechanism of valley deepening.

## Structural Benches

The step-like flat surfaces on either side of the present lowest valley floors are called terraces. The benches or terraces formed due to differential erosion of alternate bands of hard and soft rock beds are called structural benches or terraces because of lithological control in the rate of erosion and consequent development of benches (fig. 18.8).

## River Terraces

The narrow flat surfaces on either side of the valley floor are called river terraces which represent the level of former valley floors and the remnants of former (older) flood plains. Some times, the river valleys are frequented by several terraces on either side wherein they are arranged in step-like forms. River terraces are generally formed due to dissection of fluvial sediments of flood plains deposited along a valley floor. There are much variations in terraces as regards their morphology, structure and mode of origin. River terraces are classified in various ways. For example, terraces are divided into (1) **paired terraces** and (2) **unpaired terraces** on the basis of nature of erosion. Paired terraces are formed due to rapid rate of vertical erosion resulting into the occurrence of terraces on both the sides of the river valley almost at the same level (fig. 18.9). It may be pointed out that paired terraces mean occurrence of terraces on both the sides of valley at the same height. Unpaired terraces are formed due to concamitant vertical erosion (valley deepening) and lateral movement of the channel. River terraces are also divided into (1) **rock terraces** and (2) **aggradational terraces.** Rock terraces are characterized by bedrock platform covered by fluvial deposits whereas aggradational terraces consist of very thick deposits of fluvial sediments. River terraces are generally formed due to erosion of former flood plains consequent upon rejuvenation caused by either upliftment of the landmass or fall in sea level. Alternatively, river terraces are divided into alluvial terraces and strath terraces (stony terraces).

The mechanism of the formation of river terraces may be explained in the following manner. The rivers