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MGG-002 GEOMORPHOLOGY

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BLOCK 3: GEOMORPHIC PROCESSES: STATIC AND DYNAMIC I

All we know that the Earth's crust is under a constant collision between endogenic and exogenic forces. These forces are causing stress on rock materials and breaking in to smaller particles when exposed to longer time period. The process of weathering gradually weakens the rock, breaks it down and produces new rock fragments mostly sand, silt and clay.

Tectonically young mountains around the world are hot spots of mass movement of rocks and debris. Mass wasting cannot be prevented in long time period as it is a dynamic natural forcing but in many instances the vulnerability can be reduced and the negative impact can be mitigated. To prevent the impact of mass wasting by saving lives and reducing the damage of property and infrastructure on down slope of mountains, we must understand the dynamic and static geomorphic processes in details.

The study of landforms formed by flowing water is known as fluvial geomorphology. This is a dynamic subject of understanding water in the spatial science discipline of Geography. Fluvial geomorphology is the result of the interaction between streams and their surroundings. Water in river/stream action consists of three interconnected activities: erosion, transportation, and deposition. The wearing down of the sediments transported by the river and are deposited in somewhere else during this process.

This block introduces you to Geomorphic Processes: Static and Dynamic dealing with weathering, mass wasting, and fluvial processes and landforms in three units.

Unit 7: Weathering

This unit introduces weathering. Weathering is disintegration and decomposition of rock in-situ. The mechanism of weathering is a critical factor in the soil formation process. You will study the process of weathering, and different types of weathering in this unit. The disintegration of rock due to physical (mechanical) weathering and chemical decomposition of rocks due to chemical weathering have been described. You will also understand the various processes of mechanical disintegration, chemical decomposition as well as the disintegration of rocks due to biological agents and their associated processes from this Unit.

Unit 8: Mass Movement

The movement of rock masses is important geomorphic process which shapes the landscape by redistributing regolith to gentle slope. We see several natural and human made hazards and disasters in our environment. They are interlinked in a particular way and are affecting continuously the human as well as biological environment. To understand mass movement particularly, we have explained the concept of mass movement, the factors triggering mass movement, and also the types of mass movement in this unit.

Unit 9: Fluvial Processes and Landforms

This unit introduces fluvial processes and landforms. You will learn the concept of drainage basin, the water flow and its types. Rivers and streams erode and transport materials such as sand, gravel, boulders, and silt with the help of the speed and turbulence of currents, and finally deposit them somewhere else. We have explained various fluvial processes and their resultant landforms in this Unit.

We hope after studying this block, you will better understand the geomorphic processes by studying weathering, mass movement, and the fluvial processes and landforms.

Our best wishes are with you in this endeavour.

We suggest for any assistance regarding this course, you can contact at: knrao@ignou.ac.in and dr.krishnakumar@ignou.ac.in



WEATHERING |

Structure

7.1	Introduction	7.6	Summary
	Expected Learning Outcomes	7.7	Terminal Questions
7.2	Weathering	7.8	Answers
7.3	Physical Weathering	7.9	References and Suggested
7.4	Chemical Weathering		Further Reading
7.5	Biological Weathering		

7.1 INTRODUCTION

You must be aware about the dynamic state of the Earth's crust where there is a constant collision between endogenic and exogenic forces. These forces are causing stress on hard rock materials and breaking in to smaller particles when exposed to longer time period. Have you ever wondered how soil is formed on the Earth's surface? What will happen to present world if the soil forming process ceases? Thus, the mechanism of weathering is a critical factor in the soil formation process. Weathering is defined as disintegration and decomposition of rock in-situ.

In Section 7.2, you will study about the process of weathering and transportation of materials produced by this process. You will also study about the mechanism of breakdown of rocks by various processes. Again, you will understand the factors responsible for in-situ breakdown of hard rocks and different type of weathering. In Section 7.3, you will learn about the disintegration of rock due to physical or mechanical stress known as physical weathering. In Section 7.4, you will study about chemical decomposition of rocks known as chemical weathering. You will understand the process of chemical decomposition such as solution, carbonation, hydration, oxidation and reduction in decomposition of rocks. Finally, in Section 7.5, you will learn about the disintegration of rocks due to biological agents and their associated processes known as biological weathering.

Expected Learning Outcomes

After studying this unit, you should be able to:

- Define and understand the process of weathering;
- Describe how weathering process lead to formation of sediment and soil;

- Describe types of weathering; and
- Distinguish between physical, chemical and biological weathering.

7.2 WEATHERING

Weathering is defined as mechanical disintegration and chemical decomposition of rock material in situ. Weather and climate plays an important role in the process of weathering. The definition of the term of weathering depend on the intent of the authors whether, geomorphologist, geologist, pedologist or civil engineering, etc.

According to Reiche (1950), the term weathering is defined as *“the response of materials that were in equilibrium with the lithosphere, in the existing conditions together with its contact with the atmosphere, hydrosphere and biosphere”*. Ollier (1984) defined weathering as *“the disintegration of rocks fragments near the surface of the Earth mainly because of the reaction with air and water and final output in form of iron oxides, clay, iron hydroxides and other altercated products”*.

Selby (1993) defined weathering as a *“process of decomposition and disintegration of the soil and rocks near the Earth’s surface by physical, chemical and biological processes”*. It is the process of wear and tear of exposed Earth surface in situ with almost no major movement of rock material taking place. Again, the sharp and hard rocks are smoothen by the process of weathering and thus it is the first step for soil formation. Just think if the process of weathering ceases to exist then what will happen to our soil formation and food security. It is therefore important to learn the concept, process and type of weathering.

As you have learned that weathering is break down of rocks, minerals, soil and human-made structures exposed to the agents and their processes associated with atmosphere, water, river, glaciers, wind, waves and biological organisms. The process of weathering gradually weaken the hard rock, breaks it down and produce new rock fragments (mostly sand, silt and clay) known as sediments (Fig. 7.1). These are more stable in new environment. The process of disintegration generally becomes faster with weaker, finer, porous, denser and permeable rock masses. This process of weathering combined with erosion converts big mountains and large boulders into small loose rock fragments which ultimately reduces to sand, silt, clay and mud. The visible end product of weathering are loose unconsolidated material found in stream valleys, beneath the glaciers, in deserts and on beaches.

With the process of disintegration of rocks, the fragmented rocks are susceptible to physical, chemical and biological weathering because of exposure of their increase surface area to the various weathering agents and their processes.

The main weathering processes are:

(1) Physical weathering: which expresses the mechanical disintegration of rocks in cold and dry climates;

(2) Chemical weathering: which is the decay of rock forming minerals due to water, temperature, oxygen and mild acids; and

(3) Biological weathering: is the breaking of rocks by root wedging and burrowing animals.

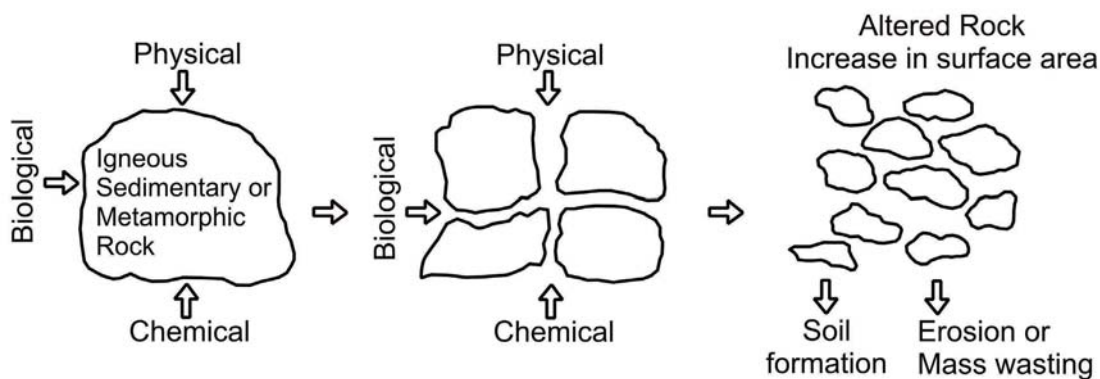


Fig. 7.1: Conceptual Framework of Disintegration of Rocks into Sediments and Soil.

7.2.1 Factors Affecting Weathering

The rate of weathering depends on factors like climate, type of rocks and geomorphology. The intensity of weathering process depend upon the resistance of minerals inside the rocks and also degree of physical, chemical and biological stress over space and time. The type and intensity of weathering at any place depend upon the following controlling factors as shown in Table 7.1.

a) Elements of Climate

The element of weather and climate are crucial factor in defining the type of weathering. These factors play a critical role in availability of water and heat which helps in breaking or disintegrating the rocks. High temperatures are very conducive for chemical reaction and disintegration and colder climate lead to more physical weathering by frost wedging.

b) Type of Rocks

The type of rocks (Igneous, Sedimentary and Metamorphic) has a differential resistance to the different process of weathering in different environmental conditions. Weathering of rocks depend upon the minerals which are cemented through crystallisation process. Again, these set of mineral formed at low temperature and pressure are resistant to weathering as compared with the minerals formed at high temperature and pressure which are less resistant to weathering process. Furthermore, tectonic activities expose the rocks formed in depths to the external processes and weather related activities.

c) Topography

The angle and amount of slope of a place are controlling factors of weathering of an area. The movement of water along the slope make the rock material vulnerable to weathering by seeping through their joints and cracks. When the

slope is steeper in the landscape, more dynamic is the process of weathering. When flatter is the slope, the process of weathering is slow.

d) Structure of the Rocks

The presence of faults, joints and cracks are zones through which water percolates inside the rock mass and widens the gaps. These weak zones are favourable for dissolving the rocks from the joints and widens the gaps and helps in breaking the rock mass.

e) Time

The duration or time period that an agent of weathering operates without interruption determines the depth and degree of weathering of blocks of rocks. Apart from the factors like Earth movements and climate change time period is a critical factor for any weathering system.

f) Soil and Organic Content

The processes of weathering are most important process of soil formation and fertile soil is an essential life supporting system to support agriculture. Again, the soil is a mixture of mineral (approx. 45%), organic matter (approx. 5%) and void space (approx. 50% filled with water and air) are important factor for growth of plants. The type and degree of weathering have major influence on soil texture and composition. Thus, the processes of weathering disintegrates and decomposes rocks, and mineral by physical, chemical and biological agents and processes adding the weathered products to form different types of soil.

Table 7.1: The Basic Type and Level of Weathering at Different Locations.

	Fast / Slow 		
Bedrock Type			
Mineral solubility in water	Low (e.g. Quartz)	Moderate (e.g. Feldspar)	High (e.g. Calcite)
Rock Structure	Massive	Some zones of weakness	Very fractural or highly bended
Climate			
Rainfall	Low	Moderate	High
Temperature	Cold	Moderate	Hot
Soil			
Thickness of soil layer	None-Bare Rock	Thin or Moderate	Thick
Organic Content	Low	Moderate	High
Length of Exposure	Short	Moderate	Long
Topography	Steep Slope	Moderate	Gentle Slope

g) Erosion and Transportation

The processes of erosion and transportation also contribute towards weathering and removal of weathered material depending on various factors. After erosion, the bedrocks are further exposed to the sub-aerial agents and processes of weathering and erosion and the processes continue in furthering the wear and tear of the rocks as well as carrying away from the place of weathering.

From definition point of view, the weathering is all about the total effect of all sub-aerial process that bring decay and disintegration of rock material without any large scale transportation of loose materials. It involves the decay and disintegration of rock materials in-situ. Thus, there is no large scale transport of weathered materials in the weathering process. But however, the weathering process often becomes a contributing factor for mass movement of broken material down the slope under the force of gravity as shown in Fig. 7.2.

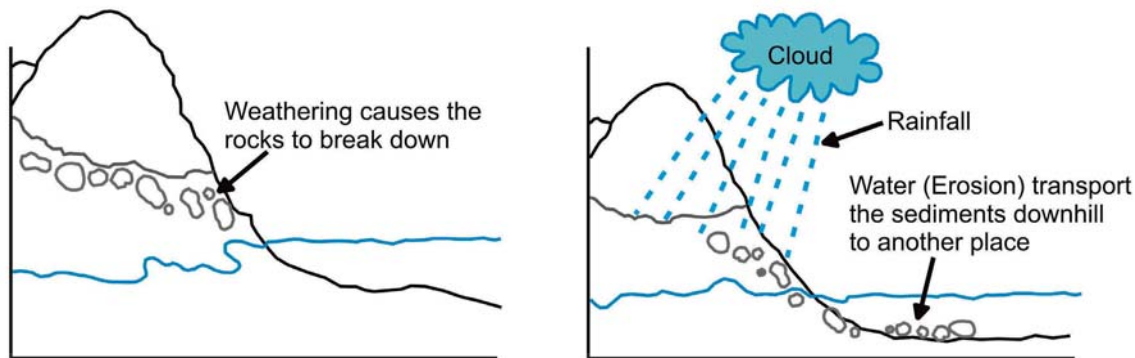


Fig. 7.2: Concept Diagram of Weathering and Erosion.

SAQ I

- Define weathering.
- Which of the following factor affect the rate of weathering?
(1) Type of rock (2) Climate (3) Organic material (4) All of three

7.3 PHYSICAL WEATHERING

Physical weathering or **mechanical weathering** is process of weakening and subsequent breaking of rock material by physical forces. The physical forces include gravitational forces, abrasion, temperature fluctuations, freezing and thawing, wind and growth of salt crystals. Majority of these forces are functional within and over the surface of the Earth which leads to weakening and breaking of rocks. Again, majority of mechanical weathering of rocks are due to thermal expansion and pressure release but it is a very slow process. Refer to Fig. 7.3 for understanding the processes of various types physical weathering.

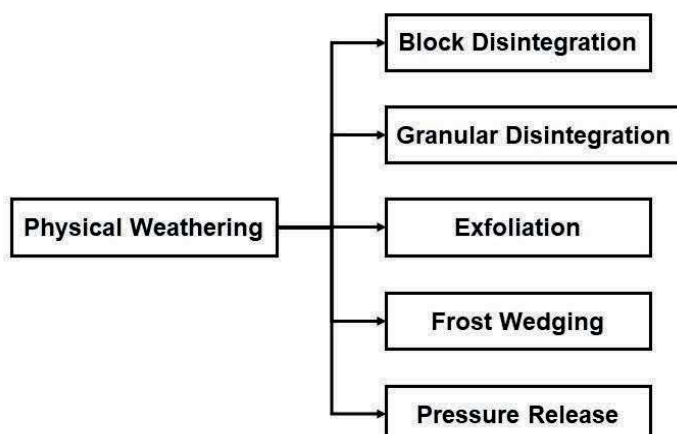


Fig. 7.3: Types of Physical Weathering.

Let us now discuss the various types of physical weathering processes one by one.

1) Block Disintegration

Block disintegration is a type of physical weathering where splitting and breaking of rocks happen along the joints due to stress created by temperature changes as shown in Fig. 7.4. The contraction and expansion happen along the crack or joints due to differential heating (hot during day time and cool during night time) and these repeated process of heating and cooling break the parent rock mass into a number of blocks. This kind of weathering is more effective in dry climate where diurnal temperature fluctuation is high.

2) Granular Disintegration

It is a form of physical weathering where the grains of rocks loosen out and falls below the parent rock mass due to expansion and contraction as a result of diurnal and seasonal temperature fluctuations. The disintegration of rock into smaller fragments is due to the properties of differential expansion and contractions of mineral grains inside the parent rock body. This process is generally effective in high altitude and cold climate where water freezes in cracks/joints/fractures in night time and melt in fissures during day time. The example is shown in Fig. 7.5.

We can understand now that the block disintegration is a process when breaking of rocks take place along weak zones (cracks/joints) and rectangular shape blocks are formed but granular disintegration takes place where the larger rocks are loosened and fall out as pitted uneven smaller fragment of rocks due to temperature fluctuations.



Fig. 7.4: Example of Block Disintegration.



Fig. 7.5: Granular Disintegration of Rocks (Pakhal Super Group).

3) Exfoliation

Exfoliation is a form of physical weathering where curved flakes of rocks are stripped off like onion peeling from parent rocks due to sudden drop of temperature. You can understand this process by studying the Fig. 7.6. The expansions and contractions are due to pressure release and unloading process where dome like hills are peeled along joints parallel to the surface. The best example is Half Dome in Yosemite National Park, which formed after glaciers caused surface rock to be removed.



Fig. 7.6: Exfoliation Weathering in Granites.

4) Frost Action

Frost action or **ice wedging** is one of the most effective types of physical weathering. In frost wedging where repeated cycle of freezing and thawing process take place in pore spaces or fracture zone of rocks inducing stress

and disintegration of the rock in to smaller pieces. In this process, ice formation, expansion of the cracks and joints and subsequent melting of ice of the cracks and pore spaces creates a stress for breaking of rock in to smaller pieces. When water freezes in pore spaces, volume increases by 10% as compared to melting water which produce significant amount of stress on the parent rocks. Thus, the extent and magnitude of frost wedging depend on intensity, frequency and duration of freezing and thawing cycles in the area.

This process is found to be most effective in well-bedded or jointed rocks and very common in cold climatic regions (-5° to -15°C). Frost action is responsible for most of the rock debris accumulate at the bases of mountain slope which is called as *talus slope*. Figure 7.7 gives an idea about the effect of frost action on rock.

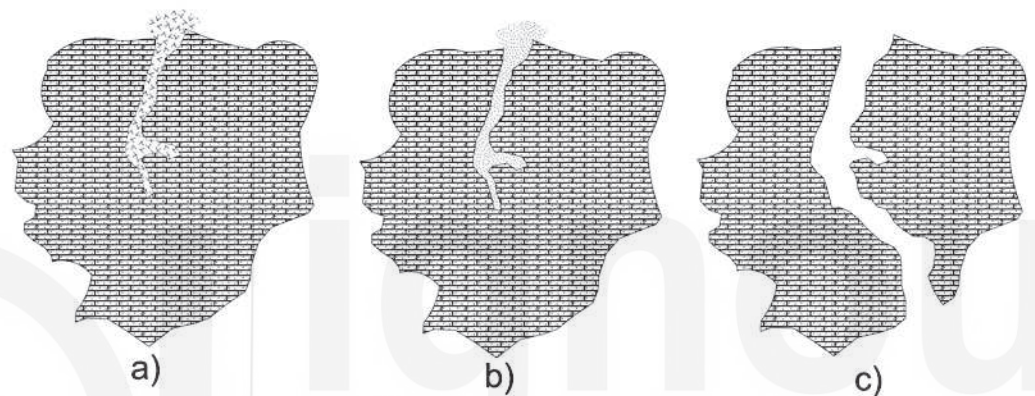


Fig. 7.7: Frost Action on Rocks a) Water Seeps into Fractures/Cracks b) Water Freezes to Ice and c) Breaks the Rock due to Expansion and Thawing the rock will gradually disintegrate.

5) Pressure Release

Deeply buried rock is unroofed and exposed to the atmosphere during the pressure release process of physical weathering. Intrusive igneous rocks, which are deep beneath the Earth's crust and formed under tremendous pressure due to overlying rocks above it. When these intrusive rocks are exposed to surface of the Earth then pressure release or unloading happen and exposed to all type of weathering agents. Thus, the removal of overlying rock due to erosion and transportation process are the causes behind the release of pressure or unloading which in long run result in expansion of these rock and finally break down into smaller pieces.

SAQ 2

- What are the different types of physical weathering?
- Physical weathering is a predominant process of which of the following?
 - Equatorial region
 - Desert region
 - Limestone region
 - Polar region.
- Exfoliation domes are formed from rocks.
- Ice Wedging is due to

7.4 CHEMICAL WEATHERING

Till now you have understood different kinds of physical weathering or mechanical weathering. Let us now discuss the chemical weathering and its types.

Chemical weathering is defined as decaying, decomposition and disintegration of rocks by chemical reaction which often result in different substance altogether. The chemical reaction happens due to exposure of parent material to water, carbon dioxide, oxygen and acids which alter the mineral component of parent rocks. These reactions either destroy or form new substances and finally alter the mineral composition of the rocks. These chemical reactions include solution, hydrolysis, hydration, oxidation, carbonation, reduction, and chelation. It is important to notice that rocks not only break down to form smaller fragments but also chemically alters and end with a different substance from parent rocks. This type of weathering is known as chemical weathering (Fig. 7.8).

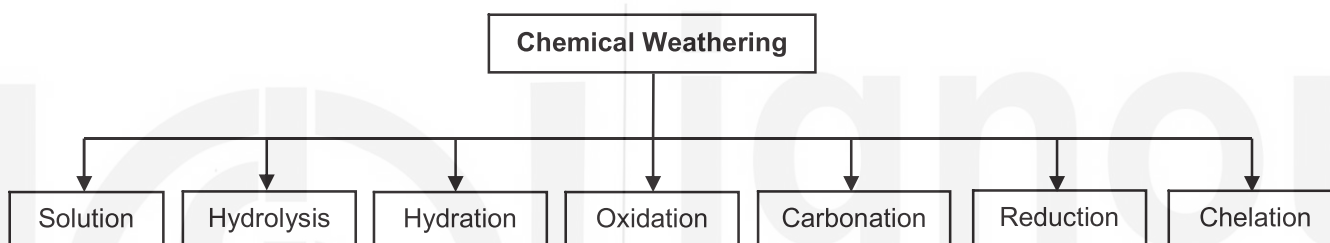


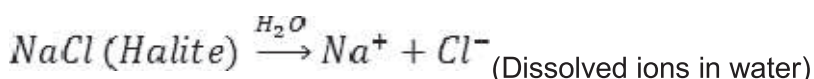
Fig. 7.8: Type of Chemical Weathering.

1) Solution

It is a type of weathering where the soluble substances present in the parent rock are washed away by continuous action of water which leads to holes and increase the surface roughness inside the rock. This process will finally decompose and disintegrate the rock. The relative solubility process depends on the presence of chemical elements present in the rocks, which are ordered as follows:

Calcium (Ca) > Sodium (Na) > Magnesium (Mg) > Potassium (K) > Silicon (Si) > Alumina (Al) > Ferrous (Fe).

For example:



The low amount of ionic concentration combined with low temperature can easily penetrate through pore spaces of rocks and expose the primary mineral for transformation. Subsequently the process like hydrolysis, hydration, oxidation, chelation and reduction are processes for formation of secondary minerals like clay which are by-product of primary minerals. The example of solution weathering is shown in Fig. 7.9.



Fig. 7.9: Solution Action as an Example of Chemical Weathering.

(Source: <https://www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle/page3722.html>)

2) Hydrolysis

In this process, chemical disintegration of rock take place in combination with water. Hydrolysis consists of two words: prefix '*hydro*' means **water**, and suffix '*lysis*' means **to break down**. The best example is the chemical reaction of rain water with granite rocks where feldspar mineral changes to clay. When rainwater percolates down the ground and interacts with granite rocks, the feldspar crystals present in granite rock chemically react with rainwater and alter the chemical composition to clay minerals and this process weakens the rocks. Thus, you can think that the process of hydrolysis loosens the chemical bonds of feldspar and make it weak to break it easily. When water chemically react with potassium feldspar, then output is a different mineral of clay and ions. The example of hydrolysis in chemical weathering is shown in Fig. 7.10.

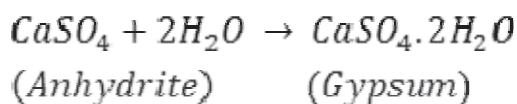


Fig. 7.10: Alteration of Feldspars to Clay by the Process of Hydrolysis.

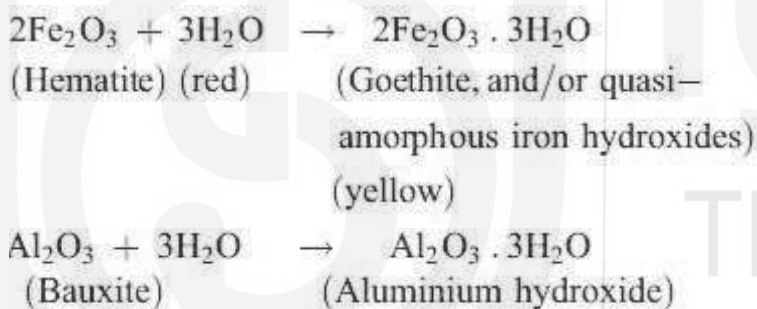
3) Hydration

It is a form of chemical weathering where water molecule reacts with minerals which leads to change in structure. In simple words, there is no chemical reaction between water and mineral but there is change in structure of the mineral. That means few minerals are capable of absorbing water in their structure and transforming them physically. In hydration, the minerals expand and swell up in volume and subsequently breaks down the rock into pieces.

On the other hand, dehydration is the process where the volumes of the minerals decrease by losing water and contract. The examples of hydration of minerals are generally seen in hydrothermal circulation which are mostly driven by igneous and tectonic activities. The most common process of hydration in nature is anhydrite (CaSO_4), which is converted to gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). The parent minerals lose their brightness, color and also become weak in nature.



The other examples are iron oxide and aluminium oxide as given below:



4) Oxidation

You must be aware about oxidation process in day-today life because it is a process which forms rust in iron. It is just like car can be rusty through oxidation process and similarly rock can be rusty and weak if it contains iron. This is due to the chemical reaction between free oxygen and iron ion which form iron oxide. Further, the iron oxide is weak and crumbles and breaks down into pieces.

The oxidation reaction provides insight about Earth's geological past because there is a clear cut transition of record of rocks between Earth containing no mineral without oxidation process and Earth containing record of rocks containing minerals which are product of oxidation process. This provides a crucial insight of the shift from an oxygen-free environment to an oxygenated atmosphere. Iron oxide is brownish-red in colour, and oxidised rock appears rusty in nature.

The beginning of oxidation process, Olivine (iron-rich) mineral taking iron out of mineral and putting it into solution of iron ion.



Then, this iron ion combines with oxygen dissolved in water and bicarbonate and produces hematite and carbonic acid:

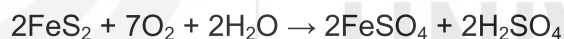


When Olivine present in basalt is oxidized, then the basalt have reddish colour which make it distinct from black or grey un-weathered basalt. The example of oxidation weathering is shown in Fig. 7.11.



Fig. 7.11: Iron-Rich Rocks with Reddish Brown Weathered Surface.

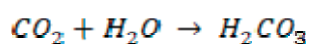
Sometime the oxidation process becomes worst environmental problem in areas where rocks having higher amount of sulphide minerals such as pyrite. It is because water and oxygen chemically react with pyrite producing sulphuric acid:



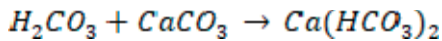
The river flowing over these oxidised rocks causes acid rock drainage, and the presence of 1% or 2% pyrite can produce considerable amounts of acid rock drainage. Again, when pyrite minerals are extracted deep down, they are exposed to oxygen and water when stacked on the surface as waste materials, resulting in acid mine drainage.

5) Carbonation

It is a sort of chemical weathering in which carbonic acid is produced by combining carbon dioxide with rainwater. These acids chemically react with minerals of rocks forming solution. When slightly acid rain and sea water hit sedimentary rock (limestone and chalk) then it either decomposes or disintegrate it. There is a chemical reaction between acidic water (carbonic acid) and calcium carbonate which give finally calcium bicarbonate. The final product is soluble and flow away as solution.



(Carbon dioxide + Water → Carbonic Acid)



(Carbonic acid + Calcium carbonate (Calcite) → (Calcium bicarbonate)

Calcium carbonate, often known as calcite, is just slightly soluble, whereas calcium bicarbonate is quite soluble. These types of weathering are found in caves. The stalagmites, stalactites and limestone pavement are example of carbonation weathering as shown in Fig. 7.12. These types of weathering occur in wet and warm conditions.

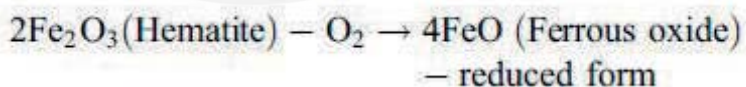


Fig. 7.12: Example of Carbonation Weathering.

(Source: <https://www.usgs.gov/media/images/lehman-cave-13>)

6) Reduction

Reduction is a form of weathering which is reverse to oxidation process and also plays an important role in transforming the colour of soil into blue, grey or green. It is due to ferric iron mineral changing to ferrous iron compounds. This phenomenon is found mostly in water logging conditions where there is less availability of oxygen and reduction weathering take place.



7) Chelation

Chelation is a form of both chemical and biological weathering where the decomposition of organic material like plant and animals, produce humic acid which can percolate inside the cracks and joints of the rocks, corrodes the rock surface and disintegrate it. The combination of organic materials and metallic ion called as chelating agents (e.g., peptides and sugars) dissolve in water and cause chemical weathering. But extreme release of chelating organic compounds affect the surrounding causing podzolisation of soils. Biological weathering is shown in Fig 7.13. This type of weathering contributes to deep weathering of underground rocks.

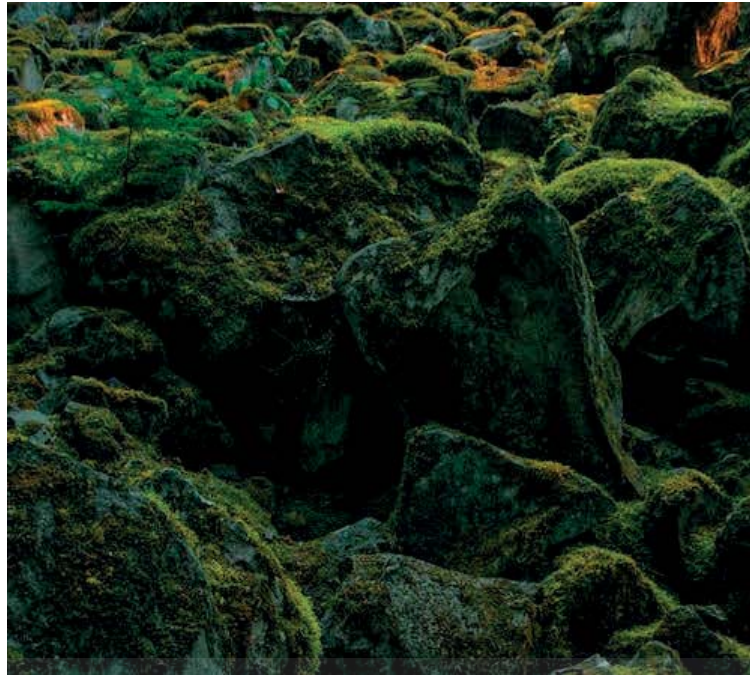


Fig. 7.13: Lichens on Rock causing Chelation.

(Source: <https://www.pexels.com/>)

SAQ 3

- a) Carbonic acid is formed in the atmosphere when a chemical reaction takes place between carbon dioxide and -----.
 - b) Which of the following is not an example of chemical weathering?
 - (1) Rusting of Iron
 - (2) Breaking of Feldspar to clay
 - (3) Formation of Acid Rain
 - (4) Movement of rock along fracture
-

7.5 BIOLOGICAL WEATHERING

Biological weathering is also known as organic weathering. It refers to weakening and subsequent breaking of rocks in to smaller pieces by living organisms like animals, plants, human beings and microbes. Biological weathering in combination with physical and chemical weathering make the process of weathering more susceptible to different kinds of rocks in different environments. Growth of plant roots inside the cracks, joints or fractures and faults produces physical pressure on the rocks. The stress build up on the rocks is a part of the biological process (growing roots). Again, the roots of plants or microbes create organic acids which can easily dissolve mineral and disintegrate the rocks. Although, we have discussed about physical, chemical, and biological weathering separately, but very often these processes act together in disintegrating the rocks. The process of biological weathering is shown in Fig. 7.14.

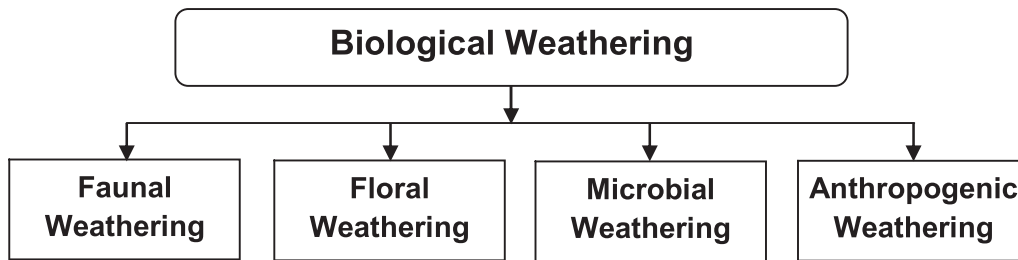


Fig. 7.14: Type of Biological Weathering.

1) Faunal Weathering

Burrowing by animals like moles, rabbits, termites, earthworms, shrews and even ants contribute in breaking of rocks into smaller particles. Sometime, these animals produce holes in rocks by excavation and bring smaller rock particles to surface. These fragments become more exposed and further broken in to smaller particle by other type of weathering process. Again, the water and moisture penetrate inside the rock make it more vulnerable to chemical weathering. Some animals like gophers, prairie dogs, rabbits dug out tunnels in the rocks as their living places creating a favourable situation for fastening the physical and chemical weathering process (Fig. 7.15).



Fig. 7.15: Examples of Faunal Weathering.

2) Floral Weathering

The breaking down of rocks due to physical and chemical action of plants is referred to as floral weathering. The plants can sustain anywhere on the surface of the Earth where there is water available. Growing plants can exert stress and create cracks, fractures and eventually disintegrate the rocks into smaller fragments. Again, the dense cover of vegetation creates distinct micro-climate at the surface which play an important role in causing different type of weathering. Furthermore, the organic dead remains of plants generate carbon dioxide (CO_2) in a later time period. This carbon dioxide (CO_2) when chemically reacts with water (H_2O) to produce carbonic acid which often corrodes the limestone rocks. Floral weathering of rocks is shown in Fig. 7.16.



Fig. 7.16: Fractures get widened due to the pressure exerted by the plant causing root wedging leading to the disintegration of the rocks.

3) Microbial Weathering

It is a type of weathering done by microbes like fungi, algae and bacteria breaking the rocks by altering the chemical composition of the minerals. The best examples are lichen and algae living in symbiotic relationship inside the rocks. The Lichen which is a type of fungi releases a chemical which can disintegrate rocks and minerals. Green algae growing over the rock surfaces releases a kind of acid in their root zone which helps in corroding and disintegrating rocks. As these phenomena continue with the rocks, the joints and fractures develop inside the rock exposes it to further physical and chemical weathering. The example of microbial weathering is very often found in nature as well as over the old temple walls. Fig. 7.17 depicts the microbial weathering of rocks in nature.

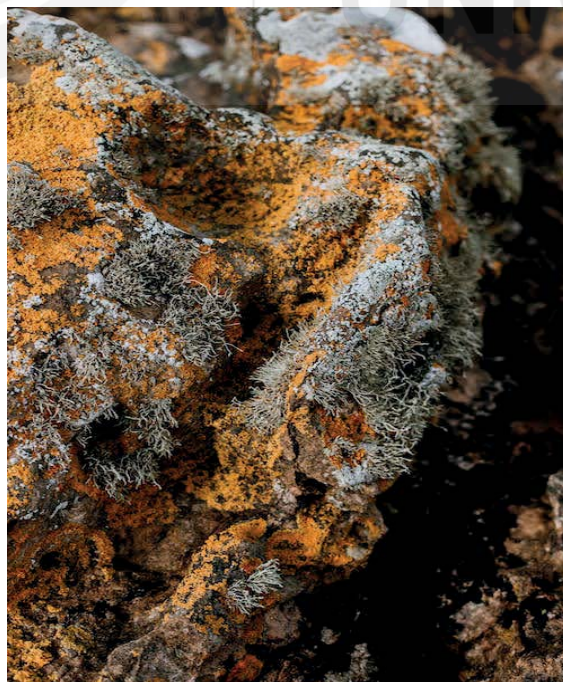


Fig. 7.17: Biological Weathering of Rocks by Lichens and Algae.

Some fungi generate siderophores which is a form of chelating agent that can absorb minerals and nutrients from rocks. It tries to trade cations from hydrogen ion and siderophores make the soil more acidic in nature and thus makes vulnerable to weathering.

4) Anthropogenic Weathering

Human being as biological agent often speed up or slow down the natural process of weathering by many fold through their activities. Human constructed world profoundly alters the physical, chemical and biological attributes of soils. The construction of infrastructure and deforestation along the hill slopes increases the slope instability and cause slope failure leading to mass movement of rocks. Use of fossil fuels are releasing sulphur dioxide and nitrogen oxide to atmosphere which help in causing acid rain. However, the feedback mechanism between physical, chemical, biological and anthropogenic weathering is still not understood to the fullest extent. The example of anthropogenic weathering is shown in Figs. 7.18 and 7.19.



Fig. 7.18: Crushing of Granitic Rocks by Humans for use as Construction Materials.



Fig. 7.19: Mining as an Anthropogenic Weathering Process.

SAQ 4

- a) Describe the biological weathering?
b) Match the following:

List I

- (A) Physical Weathering
(B) Chemical Weathering
(C) Biological Weathering
(D) Cave Weathering

List II

- (1) Plant
(2) Stalactite
(3) Till
(4) Oxidation
-

7.6 SUMMARY

In this unit, you have studied so far:

- Weathering is disintegration and decomposition of rock material and mineral on the Earth's surface. The agents like air, water, plant, animals, their processes and change in climate are important factors contributing to the rate of weathering.
- The wearing and tearing of rocks depend on length and time of exposure of surface. The disintegrated rocks become the loose sediments which contribute towards soil formation.
- The process of weathering is classified into physical weathering, chemical weathering and biological weathering.
- The physical weathering is known as mechanical weathering where rocks disintegrate by frost action, temperature change, pressure release, etc.
- In chemical weathering, there is alteration of molecular structure of the minerals inside the rocks. The decay of minerals are due to oxygen, water, hydrogen, temperature and minerals. The types of chemical weathering are solution, hydrolysis, hydration, oxidation, chelation and reduction.
- Living organism often contribute in breaking rocks which is known as biological weathering. The agents of biological weathering are plants, animals, microbes and human being. The types of biological weathering are faunal weathering, floral weathering, microbial weathering and anthropogenic weathering.

7.7 TERMINAL QUESTIONS

1. What are factors contributing towards the magnitude of weathering?
2. Describe the chemical weathering? Explain any two processes of chemical weathering.
3. How do plant and animals are the cause of weathering?

7.8 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Weathering is described as the mechanical and chemical breakdown of rock material in situ.
b) 4
2. a) Block disintegration, granular disintegration, exfoliation, frost wedging, and pressure release.
b) 2
c) Igneous rocks
d) Water freezing and thawing process
3. a) Rainwater b) 4
4. a) It is also known as organic weathering which refers to weakening and subsequent breaking of rocks in to smaller pieces by living organisms like animals, plants, human beings and microbes.
b) A-3; B-4; C-1; D - 2

Terminal Questions

1. The factors controlling weathering are elements of climate, type of rock, topography, structure of rock, time, soil and organic content. Refer to the Sub-Section 7.2.1.
2. Refer to Section 7.4.
3. Refer to Section 7.5.

7.9 REFERENCES AND SUGGESTED FURTHER READING

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MASS MOVEMENT |

Structure

8.1	Introduction		Heave
	Expected Learning Outcomes		Fall and Subsidence
8.2	Mass Movement	8.4	Summary
8.3	Types of Mass Movement	8.5	Terminal Questions
	Creep	8.6	Answers
	Flow	8.7	References and Suggested
	Slide		Further Reading

8.1 INTRODUCTION

Tectonically young mountains around the world are hot spots of mass movement of rocks and debris. The movement of rock masses or rock waste are important natural geomorphic process that shapes the landscape by redistributing regolith to gentle slope.

Just think the impact of mass wasting on life, property and economic damage on down slope of mountains. It can be noted that mass wasting cannot be prevented in long time period as it is a dynamic natural forcing but in many instances the vulnerability can be reduced and the negative impact can be mitigated. It is comforting to think about preventing the impact of mass wasting by saving lives and reducing the damage of property and infrastructure. It is therefore important to learn the concept, process and type of mass wasting.

In Section 8.2, you will study about the concept of mass movement or mass wasting and the factors triggering mass movement. You will also study about the types of mass movement in details in Section 8.3.

Expected Learning Outcomes

After studying this unit, you should be able to:

- Describe the concept and meaning of mass movement;
- Explain what are the factors which can trigger mass wasting; and
- Describe the types of mass wasting and the types of materials involved in mass wasting.

8.2 MASS MOVEMENT

You must be aware about the occurrence of landslides in Himalayas during the monsoon season which are potent risk to life, property and threatening to economic development. Have you ever wondered why movement of mass of rocks and debris in mountainous or hilly region is a common phenomena but it does not occur in flat terrains?

The Earth's landscape has been modified by geomorphic processes like weathering, mass wasting, erosion, and deposition over a span of geological time and it play an important role in shaping the topography and development of landforms. Mass movement of rocks can take place in a number of ways like flow, spread, slide, topple and fall or their combinations. The primary driving force behind these mass movements of rock materials are gravitational force and sometime supplemented by water.

Mass movement some time called mass wasting or slope movement is defined as large movement of fragmented rock material down the slope under the force of gravity. In other wards it is the movement of large block of rock and waste material (debris, soil and artificial fill) down the hill slope (Fig. 8.1). It is bulk movement of rock debris along the slope due to gravitational pull. Mass movement is combination two processes: detachment of rock material from the parent body and downward movement of the detached and fragmented rock material.

According to Bloom (1998), "the gravitation forces are single factor for movement of rock along the surface of Earth and transporting agents (like glaciers, rivers, wind and wave) have no role to play in mass movement". But according to Southard (2021), that "Everything at or near the surface of the Earth is pulled toward the Earth by the force of gravity ("Gravity: it's a law you can live with") that includes all Earth materials, rock and regolith". Majority of undulated landscape are smoothened by large scale geomorphic processes of mass movement. These processes have been predominant in the mountainous areas around the world. Tectonic activity and high intensity rainfall in the mountainous areas have made it susceptible to mass movements. In particular, For example, the Himalayan mountain region is vulnerable to mass movement due to very steep terrain, intense monsoon rains, avalanches, the high number of earthquakes, weak bed rock, and strain caused by the northward movement of the Indo-Australian plate beneath the Eurasian plate.

The Himalayas is known for high intensified geodynamic processes in Quaternary time. However, the human induced changes like construction of roads in mountain areas, trail construction, forest conversion, and developmental activities in hazard prone areas have accelerated the process of mass movement. These movements of soil or rock material in mountainous region have increased the risk of loss of human life and property.

According to estimate of World Health Organization, about 4.8 million population were affected directly and indirectly by mass movement and 1800 death occurred between 1998-2017 around the world. The rising temperature

in 21st century will force the permafrost to melt and will make the rock slopes more unstable by triggering more mass movements of rocks.

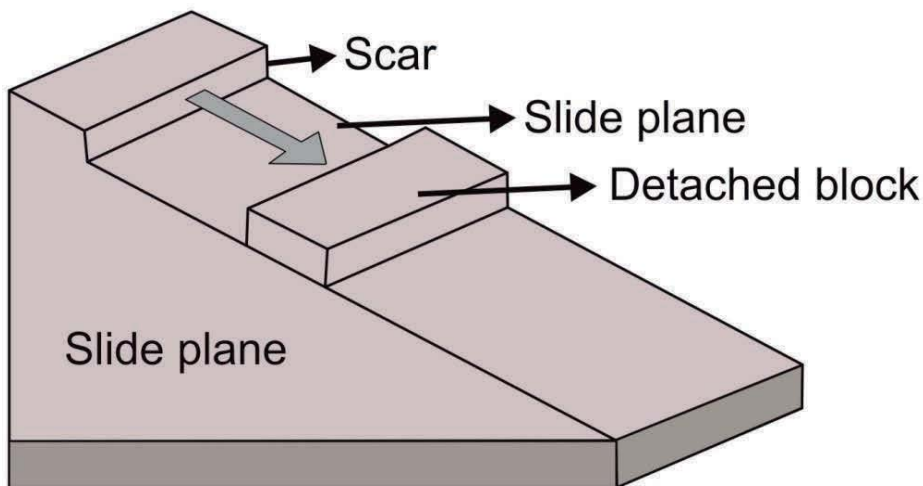


Fig. 8.1: Mass Wasting along the Slope.

According to Chorley et al. (1985), “mass movement include both process of detachment of rock material and downward movement of large fragmented rock material along the slope” whereas Bloom (1998) stated that “mass wasting is only about the downslope transport of fragmented rock materials”. It is evident from two definitions that mass movement sounds more scientific and broad in defining the fragmentation and down slope movement of rock waste along the slope. The young mountains around the world become more vulnerable to the process of mass movement because of steep slope. Mass wasting and associated morphological changes in mountain landscape are very common geomorphic phenomena. These changes are time dependant i.e. the rock is there but in next few minutes it is gone or it happen more slowly.

You must be thinking in your mind about examples of landslide happening around the Himalayan mountain areas. The landslides can be synonym with mass wasting but landslides limit us not describing the entire triggering forces behind these large-scale changes. Weathering and erosion become favourable factors for the mass-wasting process yet serve as a category of transitional phenomena that separate the two major categories of processes.

Thus, it can be concluded that mass movement is a dynamic geomorphic denudation process where the detachment of rock material happen through different weathering process and unblocked rock waste are transported down the slope by the force of gravity without any medium of transporting agent (running water, glaciers, wind and sea waves) except water or ice as a lubricating agent.

8.2.1 Factors Affecting Mass Movement

Once the rock are broken in to small pieces, gets detached from the parent rock and these detached and unstable broken material moving down under the force of gravity is known as mass wasting or mass movement. There are several factors in triggering mass movement on Earth surface but the ultimate battle is between gravity and friction. The gravitation forces (F_g) as usual pull down rock material towards the Earth's centre. The force of gravity is constant

throughout the Earth surface but small variations are found with change in elevation and density of rock material. But the surface over which the mass movement takes place, creates a resistance depending upon the nature of the surface roughness.

The F_g acting on slope can be classified as:

F_s – Driving or shear force (pushing the rock material down the slope)

F_n – Frictional or Normal Force (pushing the rock material into the slope).

The relation between normal force and shear forces is called shear strength which is shown in Fig. 8.2.

- If $F_s > F_n$, then unstable (when shear forces is greater than normal (frictional) forces then down slope movement of the block occurs).
- If $F_n > F_s$, then stable (when normal (frictional) force is greater than shear forces then there is no down slope movement of blocks).
- If $F_n = F_s$ then stable (when shear forces is in equilibrium with frictional force, then there is no down slope movement).

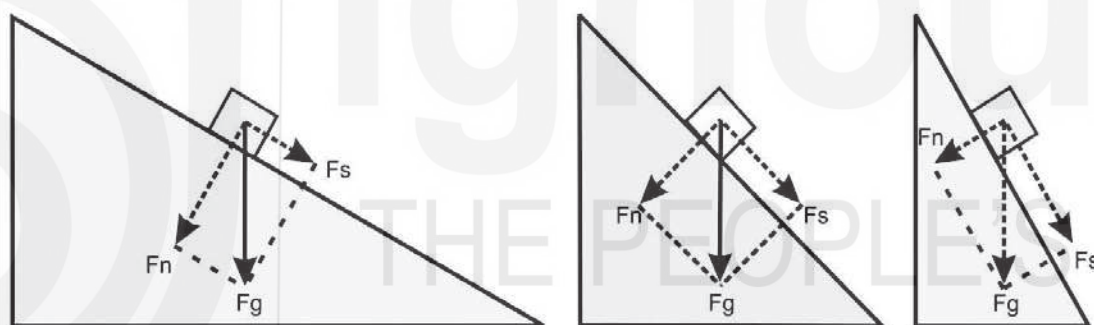


Fig. 8.2: Change of Force Vector with Change in Slope Angle.

(Source: <https://opengeology.org/textbook/10-mass-wasting/>)

According to Varnes (1978), the factors which control mass movement of rock wastes are classified into two categories and many sub-categories as shown in Table 8.1.

Category I: Factors which increase the shear strength; and

Category II: Factors which decrease (reduce) the shear strength of materials.

Table 8.1: Factors Controlling Mass Movement.

Category I: Factors which increase the Shear Strength

1. Increase in Height or Length and Angular Value of the Slope

Natural factors:

River and glacial erosion.
Marine erosion by sea waves.
Weathering and denudation process.
Previous rockfall or slide, subsidence or faulting.

Anthropogenic factors:

Construction of quarries, pits, dams, canals, roads, and
Alteration of water levels in rivers, lakes and reservoirs.

2. Pressure increase on the Slope (Loading of Slope)

Natural factors:

Increase in accumulation of talus or scree or ice on the slope.
Increased stress due to the weight of large trees.
Seepage pressure of percolating water.

Anthropogenic factors:

Increase in pressure on the slopes by reservoirs or other construction works.
Building a house on a slope destroys the stability of the slope due to its pressure.

3. Transient Earth stress (Endogenetic Processes of Earth)

Natural factors:

Massive earthquakes and Volcanoes

Anthropogenic factors:

Shocks and vibrations, blasting.
Vibrations from vehicles or machinery

4. Removal of Underlying Support

Natural factors:

River or sea waves erode the lower part of the slope (Toe-erosion).

Anthropogenic factors:

Solution at depth and mining activities

5. Lateral Pressure

Storage and accumulation of water in cracks, swelling and stress release

6. Reduction of Pressure on the Slope

Denudation process' lateral expansion of bedrock, increased rock permeability

Category II: Factors which decrease the Shear Strength of Materials

1. Weathering and Physico-Chemical Reactions

The regolith that forms as a result of weathering differs physically and chemically from the parent rock.

As a result of continuous weathering, the particle size of the material changes from very small to clay particles.

Physical disintegration of rocks and the hydration process reduces the Cohesion and internal friction angle of clay minerals.

Drying of clays and shales and pore water pressure.

2. Corrosion by Infiltrating Water (Seepage Erosion)

Adhesion is reduced as water penetrates the rock.

Reduces the surface tension of drained soils.

The hardness of the material is reduced.

The formation of rills and gullies due to surface erosion

3. Changes in Structure

Liquefaction of soil.

Remoulding the soil (loess, sand and sensitive clay).

Frictional resistance.

Reduction in angle of internal friction.

4. Others

Burrowing animals, Decay of roots, and Progressive failure

(Source: Varnes (1978) slope movement types and processes, special report, 176)

SAQ I

- a) The process by which masses of rock and soil move downhill under the influence of gravity is called -----.
- b) Which of the following factors render makes Himalayan region are more vulnerable to mass movement.
- A. Steep terrain/weak bed rocks
 - B. Intense monsoon rainfall
 - C. Seismically active zone
 - D. All of the above
- c) Which factor/agent is most likely to increase the risk for mass wasting.
- A. Water content
 - B. Temperature
 - C. Pressure
 - D. None of the above
-

8.3 TYPES OF MASS MOVEMENT

The classification of mass movement depends upon the variation in terms of direction, rate and triggering factor of mass movement in different places in varying climatic conditions. Research progress on mass movements has generally been traced to the 1950s–1970s. During this period, different geographers classified mass movements in different ways. The majority of mass movements occur in the mountainous region where the movement of rock waste takes a sudden or slow movement. But however, most of the slow mass movements remain unnoticed. Again, mass movements are classified further on the basis of triggering causative factors i.e., the direction of movement, rate of movement, type of movement, mechanism of morphology and lubricating substance (ice and water).

There are numerous classifications of the rock mass. For example- the concept of mass movement was endorsed by Sharpe (1938). He classified mass movement into three main classes (Flow, Slide and Subsidence) and several sub-classes. Hutchinson in 1968 introduced a classification based on the mechanism of the mass movement, shape, motion of the sliding material and nature of the material. He divided the mass movement into main three divisions (Creep, Frozen ground phenomena and Landslide).

Varnes (1958) introduced a popular classification of mass movements, which is more popular in USA. His classification was approved by the 'Swiss Association for Rock Mechanisms' in 1964. In 1978, he revised the classification into six types of mass movements (Fall, Topple, Slide, Lateral Spread, Flow, and Complex Slide). Thereafter, Chorley (1985) has exhaustively classified mass movement phenomena on the basis of direction (Vertical, Lateral and Diagonal) of movement and type of movement in presence of transporting agents (Fig. 8.3).

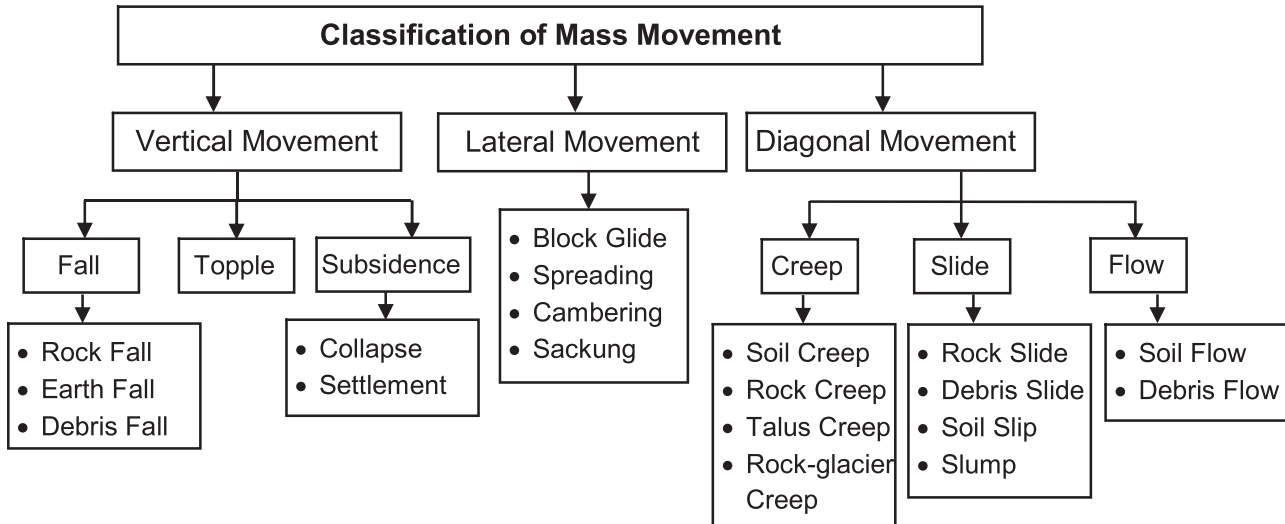


Fig. 8.3: Classification of Mass Movement.

(Source: Chorley et al., 1985)

8.3.1 Creep

The very slow down slope movement of unconsolidated Earth materials and soil is known as creep. The slope movement of creep may be in mm/year to cm/year. Further, it affects only the upper few centimetres loose Earth materials and down slope movement are very slow for several years or even centuries. This phenomenon is found in almost all slopes and also can visualize by naked eyes in a longer time interval. The movement of creep is indicated through curved tree trunks, leaning fences, tilted poles and small soil ripples on the slopes as shown in Fig. 8.4.



Fig. 8.4: Example of Creeping Mass Movement.

The process of creep are facilitated by the phenomena like heating and cooling, freezing and thawing, wetting and drying and also triggered by burrowing animals. The side walk, telephone and electric pole, walls, fence post are often destroyed by the phenomena of creeping.

The process of creep is time dependant and goes through three stages explained given below (Fig. 8.5).

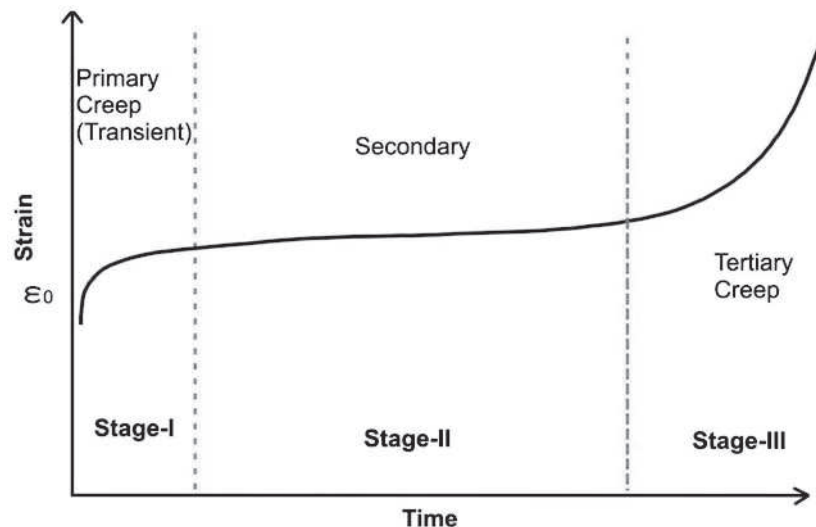


Fig. 8.5: Stages of Creep Formation.

(Source: <https://material-properties.org/stages-of-creep-primary-secondary-tertiary-definition/>)

1. **Stage I or Primary Creep:** Strain rate are quite high but decreases with time due material hardening.
2. **Stage II or Secondary Creep:** The strain rate is at steady state and changes is quite slow with time.
3. **Stage III or Tertiary Creep:** Accelerated strain rate and ultimate material failure.

Based on movement of material the creep were classified as soil creep, talus creep, rock-glacier creep, and rock creep by Sharpe (1938). They are as follows:

1. Soil Creep

It is the down slope movement of soil under the process of gravity. The slow movement of soil is not visible when the slope is gentle and covered with vegetation. The first types are related to fine grained material and other are concern to rock debris. But the movement is visible in steep slope and most commonly found in damp soils.

2. Talus Creep

It is down slope movement in slow pace of rock fragments or rock as a whole. The talus creep comprises of down slope movement of accumulated fragments of different shape and size due to gravitational falling. The talus creep are mostly seen in peri-glacial environments.

3. Rock-Glacier Creep

It is a rapid form of talus creep associated with freeze and thaw process. It takes place in cold region where ice melting forces the debris to move down slope in slow pace.

4. Rock Creep

It is a very slow downhill movement of rock debris. The movement can be observed on a cliff face. During rock creeping, large joint bounded sheets and blocks slowly creep or lean outward until they become unstable and topple over or slide downhill. 'It is distinguished from soil creep by its great depth and

isolation from daily and seasonal climatic conditions, and from land sliding by the lack of a single clearly defined failure plane and slow rate of deformation' (Selby, 1989).

8.3.2 Flow

The rock fragments and soil with enough amount of water behave like a fluid is known as flow. The flow consists of rock fragments or sediments or mixture of regolith and rock material flowing down along with some amount of water. Thus, the flow can be divided into two types on the basis of amount of water as shown in Fig. 8.6.

1. **Granular Flow:** It consists of 0 to 20% of water and it happens with little or no water.
2. **Slurry Flow:** It consists of 20 to 40% water and when water content increases more than 40% it become streams.

1. Granular Flow (Lower Amount of Water)

- (a) **Creep:** We have already studied about creep in the above sub-section.
- (b) **Earth Flow:** The movement of Earth material down slope are associated with heavy amount of rainfall and velocity of movement are with range between several cm/yr and 100s of m/day. This geomorphological phenomena are found in steep mountains where the process remain active for longer period of time.

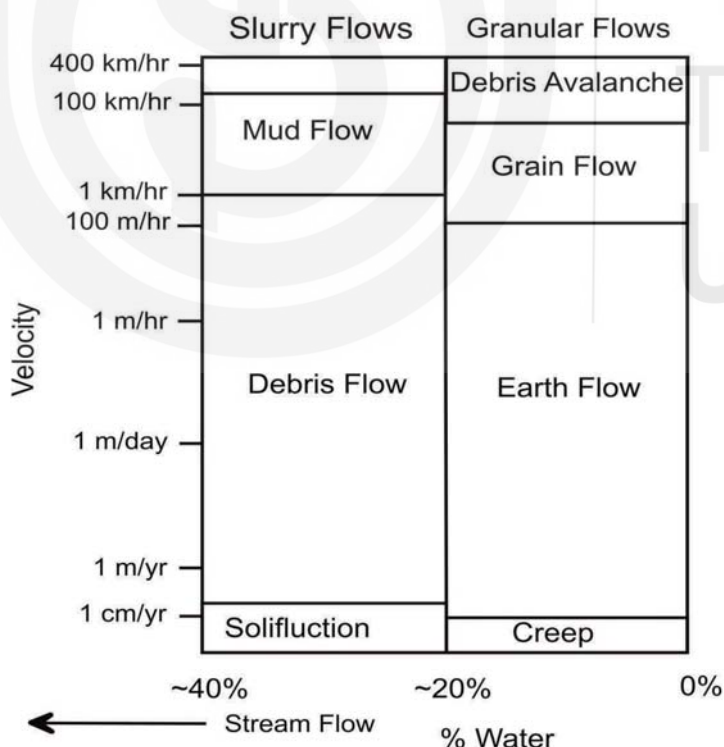


Fig. 8.6: Types of Flow.

(Source: http://www2.tulane.edu/~sanelson/Natural_Disasters/masswastproc.html)

- (c) **Grain Flow:** It is usually rapid down slope movement of unconsolidated grains due to small disturbances in dry regions. The movement of sand dunes in steep slope in dry regions are example of grain flow as shown in Fig. 8.7.



Fig. 8.7: Grain Flow in Desert Areas.

(Source: <https://www.geol.umd.edu/~jmerck/geol342/lectures/04b.html>)

- (d) **Debris Avalanches:** A sudden collapse of unstable slope consisting of a mass of snow, ice, rocks and debris which rushes down a mountainous slope at high speed is called as debris avalanches. They can travel for considerable distances along relatively gentle slopes and are often triggered by earthquakes and volcanic eruptions.

2. Slurry Flows (Higher Amounts of Water)

- (a) **Solifluction:** It is the flowage of water saturated regoliths down a steep slope and velocity of movement is around centimetres per year. It occurs in permafrost region where overlying soil become over saturated and flow down due to pull of gravity. Thus, the soil weakened by the action of such process of expansion and contraction of freeze and thaw becomes susceptible to solifluction as shown in Fig. 8.8.



Fig. 8.8: Example of Solifluction and Debris Flow.

(Source: <https://www.sciencedirect.com/topics/Earth-and-planetary-sciences/solifluction>;
<https://phys.org/news/2016-09-debris.html>)

- (b) **Debris Flow:** Debris flow is the downslope movement of large size rock fragments and soil at higher velocity than solifluction, and is often the result of heavy rains causing saturation of the soil and regolith with water.

It sometimes start with slumps and then flow downhill forming lobes with an irregular surface consisting of ridges and furrows.

- (c) **Mud Flow:** It is a type of downhill movement of high velocity mixture of sediments and water (due to heavy rains) resulting into soft wet mud and rock debris, a highly fluid by rain or melted snow, and capable of moving down slope at great speed (Fig 8.9).
- (d) The water contained is more in mudflows than Earth flow and debris flow as such it can travel for long distances over gently sloping stream beds. The high velocity and long distance of travel results very dangerous types of mass movements. Mudflows can also result from volcanic eruptions that cause melting of snow or ice on the slopes of volcanoes, or draining from crater lakes on volcanoes.



Fig. 8.9: Example of Mud Flow.

(Source: <https://epod.usra.edu/blog/2013/08/mudflow.html>)

SAQ 2

- a) What are the different types of mass movements?
- b) When shear force (F_s) is greater than normal force (F_n) then down slope movement block occurs.
- 1) True 2) False
- c) The slowest mass movement types are _____ .
- 1) Flow 2) Fall 3) Creep 4) None of the above

8.3.3 Slide

Slides are sudden downhill movement of masses of rock or sediment or soils along discrete shear surface. It happens when section of rock material or soil move downward along a steep slope. Slides are also called translational slides, as they involve only straight movement along a direction.

On the basis of nature of materials, slope gradient, degree of saturation and rate of movements' slides are subcategorised into slump, rock slide and debris slide.

1. Slump

The term slump refers to a slipping of coherent rock material along the curved surface of a hill slope. Slumps are also called as Rotational Slides due to the type of movement involved. These are special category slides wherein the downward rotation of rock or regolith occurs along a concave-upward curved surface. The upper section of each slump block remains relatively stable, as do the individual blocks. It is very often triggered by heavy rainfall percolating through the joints and fractures and during the earthquakes. Slides often happen due to human activities also. Slumps are common along the roads where slopes have been over steepened during construction. They are also common along the river banks and sea coasts, where erosion has under-cut the slopes. These are very common and usually are thicker and slower than slide

2. Rock Slide

The simplest form of transitional slide is a rock slide or block glide. Rock slides are rapid movement of large rock blocks down slope. This is mostly common where steeply dipping strata moves down slope causing rock failure in mountainous region as shown in Fig. 8.10. Rock slides and debris slides result when rocks or debris slide down a pre-existing surface, such as a bedding plane or joint surface.



Fig. 8.10: Examples of Rock Slides.

(Source: <https://www.shutterstock.com/image-photo/landslide-rocks-blocking-santa-susana-pass-644352745>)

3. Debris Slide

It is more extensive and catastrophic types of sudden down slope movement of unconsolidated mass of rocks (mixture of soils and rock fragments). Debris slide often occurs with little amount of water which causes the saturation of rocks. It is a fast moving slide which is dangerous to life and property and often damage without offering the scope of warning (Fig. 8.11).

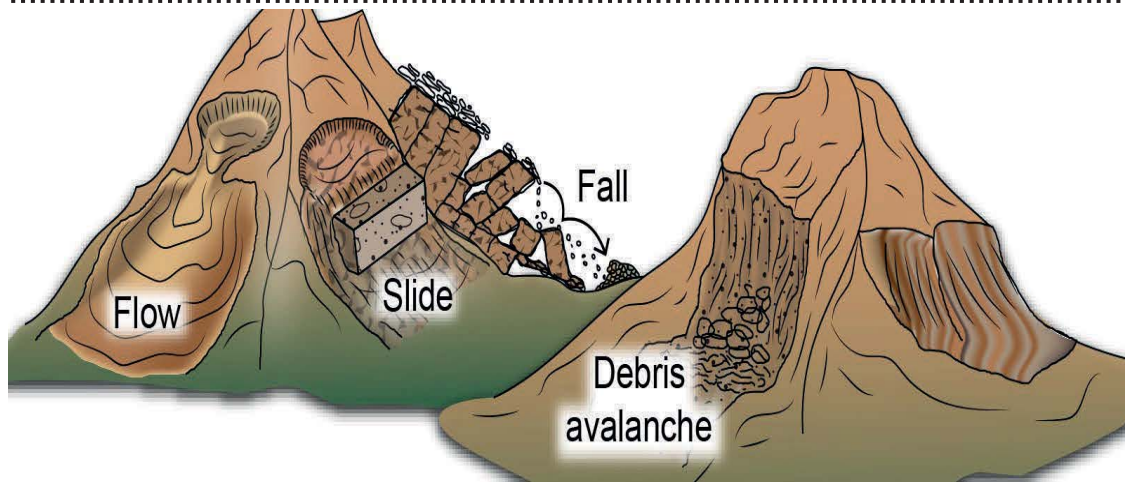


Fig. 8.11: Example of Debris Slide, Flow and Fall.

8.3.4 Heave

It is another slow form of mass movement of rock material or soil down the slope due to contraction and expansion (thaw and freeze conditions) of broken rock fragments (Fig. 8.12). The cause of movement along the slope may be due to freezing and thawing (frost creep), wetting and drying, temperature changes and also loosening by burrowing animals. The expansion move the materials at right angle to slope and vertical fall during drop down due to gravitational force.



Fig. 8.12: Example of Heave.

8.3.5 Fall and Subsidence

1. Falls

Fall of weathered rock materials from steep slope or cliff under the influence of gravity is called fall. It happens when the rock fragments fall from its place of rest to the bottom of the slope. The falls are characterized by presence of vertical displacement from a crack or fracture or plane of dislocation without water.

On the basis of size of the rock materials, the fall process is divided into rock fall, debris fall and Earth fall.

- a) **Rock Fall:** Rock fall occur when a rock fragment or a mass of rock after dislodgment from the parent body fall from a steep rock face or cliff. Rock fall usually occurs from the steep cliffs. Sometimes falls may occur along the cliff faces of the steep river embankments due to under cutting action of streams or rapid weathering of underlying weak rocks. The rock material may be loosened by tremors or earthquakes, rain, plant-root wedging and expanding ice of the cracks and joints. It can be triggered by heavy rainfall, freeze/thaw action, changes in groundwater conditions and earthquakes.
- b) **Debris Falls:** It is a relatively free forward or downward falling of mixture of soil, regolith, vegetation, and rocks debris from a cliff, cave or arch. It can be triggered by intense rainfall, cloud bursting, glacial lake outburst flooding and dam break.

2. Subsidence

It is caused when loose saturated unconsolidated sediment begin to compact and trigger the ground surface to collapse. There are two types of subsidence:

- a) **Slow Subsidence:** It happens when the water in pore spaces of sediment squeezes out slowly due to overlying weights. The best examples of slow subsidence are Venice, Italy submerging on delta of Brenta River.
- b) **Fast Subsidence:** It occurs when acidic lime water dissolve underground caverns and form a network of ground water caverns. Further, when these water are pumped then caverns collapse and form sink holes. The best example of first subsidence is Guatemala City in 2007 when a massive sinkhole formed 300 feet deep (Fig. 8.13).



Fig. 8.13: Example of Slow and Fast Subsidence.

(Source: <https://www.coursehero.com/study-guides/geophysical/subsidence/>)

SAQ 3

- a) -----is also known as transitional slides.
- b) Which of the following process involves in heave?
- 1) Freezing and thawing
 - 2) Burrowing animals
 - 3) Both A and B
 - 4) None of the above
- c) What are different types of falls?
-

8.4 SUMMARY

In this unit, you have studied so far:

- Degradation of weathered rock or soil from higher slopes to lower slopes mainly under the influence of gravity is called mass movement. As a result of the dominant force of gravity, also with the help of water, wind or glaciers, the process of flowing or transferring the fragile material that forms the slope from higher places to lower slopes is also called mass movement or mass transfer.
- The important factors of mass movement are - the angular value of the land slope and its relative position, rate of sediment migration downwards along the land slope, subsidence of rock strata and effect of gravity force, size and volume of fossils, effects of vegetation and human activities, and capacity of watercourses, etc.
- The ratio of shear stress and shear strength is known as safety factor. A safety factor value of 1 or less than 1 creates an environment conducive to mass movement.
- Types of mass movement are creep, flow, slide, heave, and falls.
- The very slow down slope movement of unconsolidated Earth materials and soil is known as creep. Creep can be of soil creep, talus creep, rock-glacier creep, and rock creep.
- The rock fragments and soil with enough amount of water behave like a fluid is known as flow. The flow can be divided into two types as granular flow and slurry flow.
- Slides are sudden downhill movement of masses of rock or sediment or soils along discrete shear surface. Slides are subcategorised into slump, rock slide and debris slide.
- Heave is another slow form of mass movement of rock material or soil down the slope due to contraction and expansion of broken rock fragments.

- Fall refers to weathered rock materials that have fallen from a steep slope or cliff due to gravity. The falls are divided into rock fall, debris fall and earth fall.

8.5 TERMINAL QUESTIONS

1. Discuss the concept of mass movement.
2. Describe the factors that influence the mass movement of surface material?
3. What are the different types of mass movements? Explain.
4. Explain about process and type of subsidence?

8.6 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Mass wasting
b) D
c) A
2. a) Creep, Flow, Slide, Heave, Fall and Subsidence
b) A
c) C
3. a) Rock slide
b) C
c) Rock fall and debris falls.

Terminal Questions

1. Mass wasting is the movement of fragmented rock material down the slope under the force of gravity. Refer to Section 8.2.
2. Refer to Sub-Section 8.2.1.
3. Refer to Section 8.3.
4. Refer to Section 8.3.5.

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FLUVIAL PROCESSES AND LANDFORMS

Structure

9.1	Introduction	9.7	Fluvial Erosional Landforms
	Expected Learning Outcomes	9.8	Fluvial Depositional Landforms
9.2	Drainage Basin	9.9	Summary
9.3	Water Flow	9.10	Terminal Questions
9.4	Fluvial Erosional Processes	9.11	Answers
9.5	Fluvial Transportation Processes	9.12	References and Suggested Further Reading
9.6	Fluvial Deposition		

9.1 INTRODUCTION

In the previous Units of this block, you have studied about weathering and mass wasting. In this Unit, you will learn about fluvial processes and landforms. Fluvial processes and landforms is an important branch of geomorphology that deals with the origin and evolution of landforms carved by running water. The processes enacted by streams are called fluvial processes. The word 'fluvial' refers to *running water*, 'geo' refers to *Earth* and 'morphology' refers to *channel forms or shape*. Thus, fluvial geomorphology is the study of landforms produced by running water. Fluvial geomorphology is the manifestation of the interaction between the streams and their surrounding landscape.

We have started with the discussion by introducing the concept of drainage basin in Section 9.2. The primary landscape unit involved with the collection and distribution of water and sediment is the drainage basin. Water flows naturally in streams and rivers. Water flow has a force and a velocity. In Section 9.3, we have explained the water flow and its types.

River erosion is the process through which the river bed and bank erode. The wearing down of the sediments transported by the river is a part of the erosion process. You will learn about the fluvial erosional processes in Section 9.4.

Rivers transport tiny particles such as silt to coarser particles such as sand, gravel, and boulders. The speed and turbulence of currents enable transportation of these materials. Section 9.5 explains the fluvial transportation processes followed by fluvial deposits in Section 9.6. Finally we have described various erosional and depositional landforms formed by the river processes in Section 9.7 and 9.8, respectively.

Expected Learning Outcomes

After studying this unit, you should be able to:

- Understand the concept of drainage basin;
- Explain the flow of water in rivers;
- Explain the fluvial processes related to erosion, transportation and deposition of sediments; and
- Describe various fluvial erosional and depositional landforms.

9.2 DRAINAGE BASIN

We are all aware that the flow of water begins after each rain. Rivers obtain water largely from rainfall, snow, hail, or sleet, and the same water eventually reaches the sea after passing through many processes. Rainwater that falls on the land surface collects and begins to flow over the land as overland flows. The finger strip streams merge together along the converging slopes joint together and run as the mainstreams. The mainstream normally carries the cumulative volume of water of all smaller streams and flow downstream through a single outlet. The outlet is sometimes called as the river mouth. The entire area encompassing the catchment zone up to the river mouth, controlling this cumulative flow is known as a **river basin** or a **drainage basin**.

Drainage basin is the fundamental landscape unit concerned with the collection and distribution of water and sediment. Each basin is separated from its neighbor by a water divide or interfluvium. The basin can be viewed as a geomorphic system or unit. The basin is linked with hill slope processes that contribute water and sediment to the channel network in accordance with the regional climate, underlying bedrock and tectonic regime. Any portion of the basin can be considered a subsystem having its own unique set of processes, geology and energy gains and losses. Streams are flowing water bodies.

A drainage basin can further be divided into major regional basins, to sub-regional basins, or to local basin or smaller basins based on the size of drainage area. Small sub-basins sometimes referred to watershed/sub-watershed or micro-watershed. A river and its tributaries are broadly called as river network system. As we know that river system drain through a particular area which is bounded by ridge line formed a drainage basin (Fig. 9.1). Every tributary stream has its own watershed. Hence, watershed may be the smallest unit of any river basin which is ideal and logical unit to understand the problems related to soil, land and water resources. A watershed is ideally covered area of 500 square kilometer (sq. km) and above, if it is below 100 sq. km then we call it as sub-watershed.

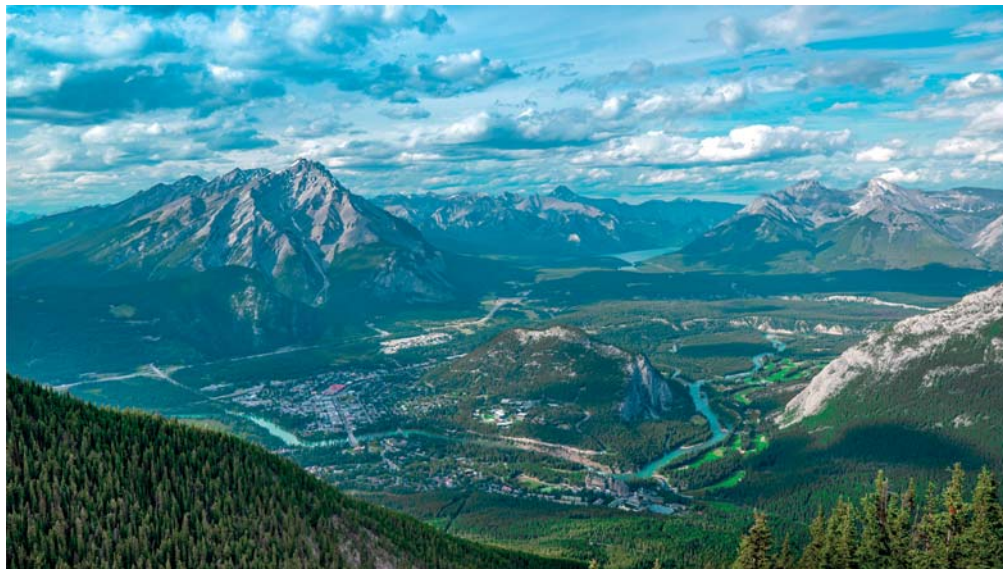


Fig. 9.1: A Panoramic View of Drainage Basin.

(Source: <https://www.pexels.com/photo/mountainous-terrain-on-cloudy-day-4933957>)

There are many parameters that play a significant role in planning and management of a drainage basin include climate, stream network, lithology, geological structures, landforms, soil, landuse and landcover, etc. Basin morphometry is a fundamental quantitative approach for analyzing drainage basins. Morphometry is measurement and mathematical analysis of the configuration of Earth's surface, shape and dimensions of landforms. The drainage basin study provides insight into its shape, dimensions, and numerous aspects. The quantitative analysis of basin morphometry is essential in studying drainage characteristics, identifying and assessing groundwater promising areas, runoff characteristics, and understanding issues related to soil erosion management due to flash floods during high flow of water, among other things.

Drainage patterns are spatial arrangements of drainage networks that relate to spatial interactions between streams or rivers. In drainage patterns, the influence of initial slope, changes in rock hardness, structural controls, recent diastrophism, climatic conditions, and denudational history may be visible. Drainage patterns are critical for understanding different landforms. Drainage patterns (Fig. 9.2) may be divided into six major categories as explained below:

1. Dendritic

The irregular branching of tributary streams in diverse directions at any angle, often less than 90° , distinguishes the dendritic pattern. This is one of the most visually appealing types of drainage as it looks like the branching pattern of tree roots. This pattern emerges in locations underlain by homogenous material and indicates a lack of structural control. The permeability of the underlying rocks, the characteristics of rainfall and surface runoff, and the time factor all influence the development of the dendritic pattern.

2. Parallel

Parallel patterns are particularly prevalent in regions with a steep slope or structural controls that result in regular spacing of parallel or nearly parallel streams. It is a common feature of ridge and valley topography.

3. Trellis

The main stream in this drainage system frequently makes almost right-angled bends to bridge or pass through aligned hills. The main tributary streams are generally intersected at right angles by subsidiary tributary streams, the paths of which frequently parallel the main stream. Trellis patterns are quite noticeable in the folded and faulted region, where stream erosion has truncated alternating weak and strong strata.

4. Radial

This pattern is also known as the centrifugal pattern because the streams radiate in all directions like the spokes of a wheel. It is developed around an elevated centre point. The radial pattern is most common in conical features such as volcanoes.

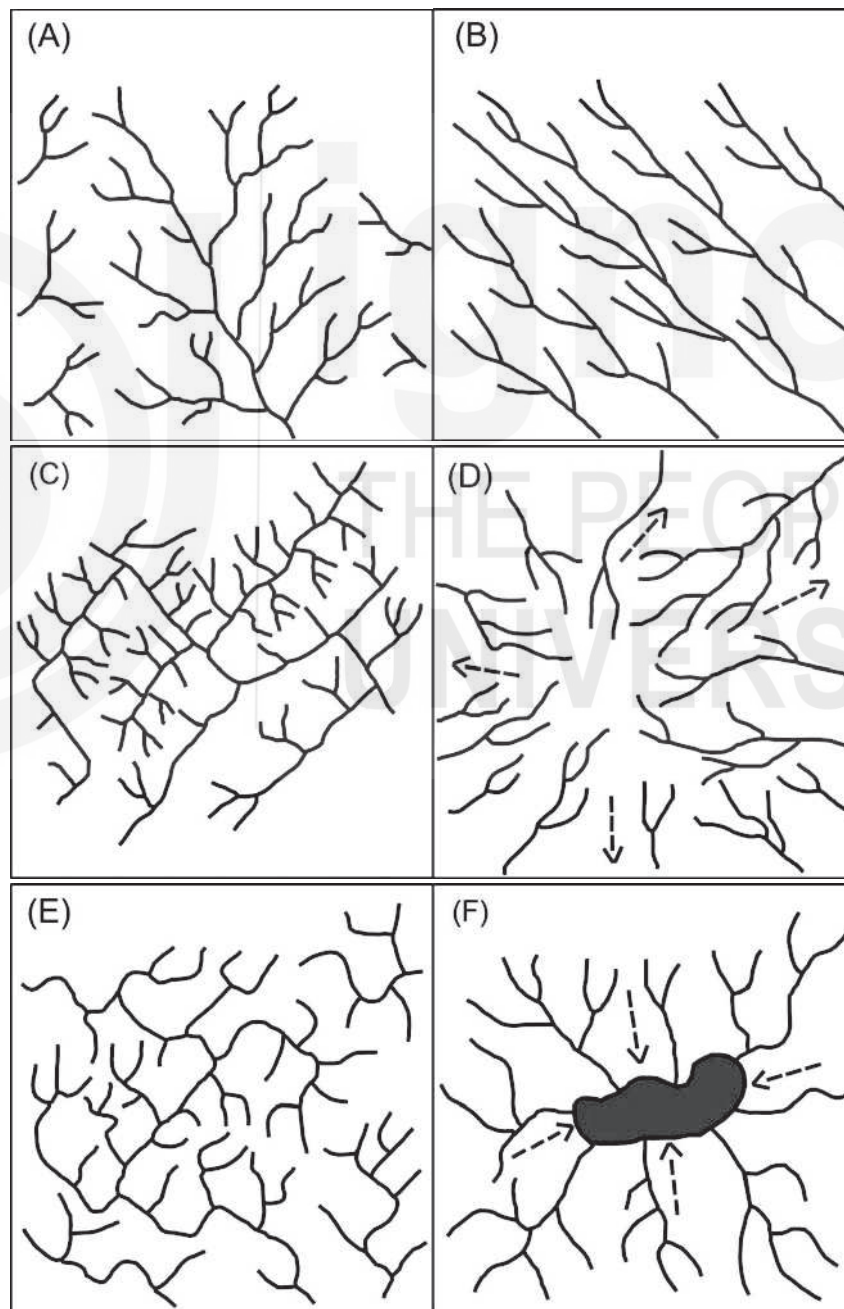


Fig. 9.2: Drainage Patterns a) Dendritic; b) Parallel; c) Trellis; d) Radial; e) Rectangular and f) Centripetal.

5. Rectangular

In a rectangular drainage system, the main stream and its tributaries have right-angled bends. This is typical in areas where joints and faults intersect at a 90° angle. The pattern develops in relatively small area. Streams take the path of least resistance, and hence concentrate in areas where exposed rock is the weakest.

6. Centripetal

The centripetal drainage pattern is the opposite of the radial drainage pattern, with streams flowing toward a central depression. Several streams arise from the surrounding uplands and converge in a centrally low land, which might be a depression, basin, or crater lake. These streams feed ephemeral lakes during the wet seasons, which evaporate during the dry seasons. Salt flats emerge in these dry lake beds as salt dissolved in lake water precipitates out of solution.

Aside from the drainage patterns described above, you may identify different more patterns by reading a basic Geomorphology book. You can also study more about a drainage basin and morphometric analysis of drainage basin in the 1st Semester course of Cartography.

SAQ I

Name different types of drainage patterns.

9.3 WATER FLOW

Rivers are natural streams of water that flow from higher to lower elevations across the land surface. Their continued existence relies upon the supply of water from overland flow, through flow, inter-flow, base flow and precipitation falling directly into the river. Channelizations of rivers are streams structurally engineered to control floods, improve drainage, and maintain navigation and so on. Water flowing in an open channel is subject to gravitational and frictional forces.

The **flow of water** has a force, velocity and capability to generate power. There are many natural and dynamic processes happening along a river. When there are circumstances, there may be severe floods along the river courses which can destroy everything along the path. Flowing water has the ability to dissolve the soluble mineral substances available on its way. The fluvial processes refer to the interaction of flowing water of the rivers and streams with its surroundings landscape producing different kinds of landforms. Such processes play an important role in denudation of land surfaces and transport of rock detritus from higher to lower levels.

Over much of the world, the erosion of landscape including the reduction of mountains and the building of plain surfaces is brought about by the flow of water. Rainfall creates open channels and carry water which brings water erosion. The process of water erosion not only degrades the land, but the

products of erosion themselves become the tools with which the rivers carve the valleys in which they flow.

The velocity of the flow of a river depends mainly upon the slope and the roughness of its channel. A steeper slope causes higher flow velocity but a rougher channel decreases it. Water flowing in an open channel is subject to gravitational and frictional forces. Gravity impels the water downslope, while friction of the river bed between the flowing water and the channel surface resists movement. It can be understood that the water flows downstream due to gravity forces, but forces also oppose the downstream flow, which is known as frictional forces.

Water flow can be of three types such as laminar flow, turbulent flow and helicoidal flow (Fig. 9.3). Let us briefly discuss one by one.

1. Laminar Flow

Laminar flow occurs on smooth river beds. The water tends to flow in layers parallel to the river bed and to each other. In laminar flow, particles of water move in a straight path that are not disrupted by the movement of neighbouring particles. There are no eddies, swirls, or cross-currents that run parallel to the flow direction. In laminar flow, sometimes called streamline flow, the velocity, pressure, and other flow properties at each point in the fluid remain constant.

Low momentum convection and high momentum diffusion are the two characteristics of laminar flow. It is distinguished by the fluid flowing smoothly in distinct layers that do not combine. Laminar flow occurs at lower velocities, below a threshold at which the flow becomes turbulent. The Reynolds number, a dimensionless flow parameter that also depends on the fluid's density and viscosity as well as the channel's dimensions, determines the velocity.

2. Turbulent Flow

In **turbulent flow**, the water does not move in parallel layers, its velocity fluctuates continuously in all directions within the fluid. The speed of the fluid at a point is continuously undergoing changes in both magnitude and direction in a turbulent flow. The energy of a river decreases when its flow is turbulent because energy has to be used to overcome the friction within the water caused by turbulence. The uneven roughness of the river bed creates friction as well, which might result in turbulence.

Turbulent flow, or turbulence, is characterized by eddies and swirls that mix layers of fluid together. Turbulence is caused by a plethora of eddies of varying sizes. These eddies overlap, eventually merging into the mean flow. The fluctuating velocities of all eddies are of comparable magnitude and just because of this their typical times, or periods are different, the larger an eddy, the larger is its period. The greatest eddies, whose magnitude is proportional to the region in which the flow occurs, play a vital role in any turbulent flow.

3. Helicoidal Flow

Helicoidal flows are a natural result of convection in planetary dynamo regions due to their spherical geometry and rapid rotation. The helicoidal motion of the flow aids the processes of hydraulic action and corrasion on the outside of the meander, and sweeps sediment over the meander's floor towards the inner side.

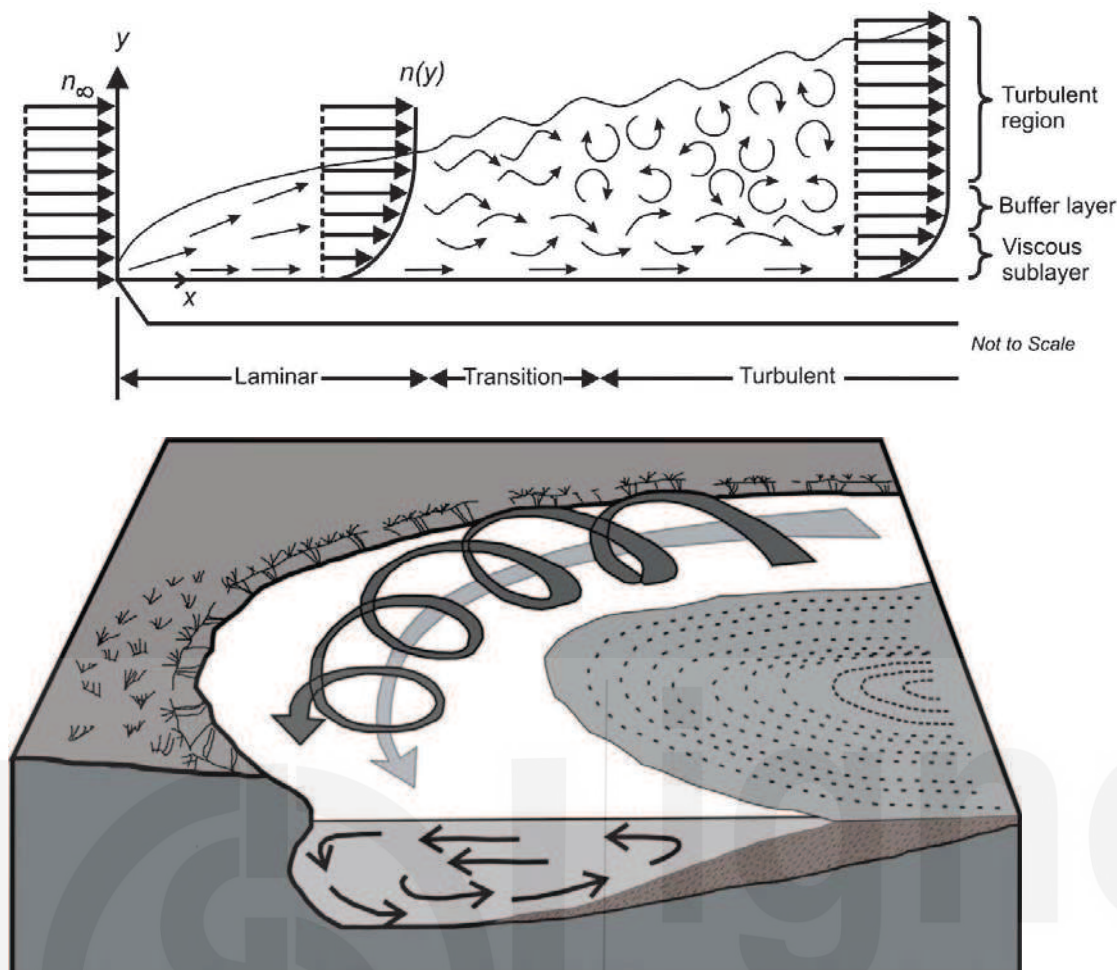


Fig. 9.3: Types of Flow of Water a) Laminar Flow b) Turbulent Flow and c) Helicoidal Flow.

SAQ 2

Differentiate between laminar flow and turbulent flow.

9.4 FLUVIAL EROSIONAL PROCESSES

As you are aware, the main erosional agents responsible for material erosion, transportation, and deposition include flowing water, groundwater, glaciers, sea waves, and wind. You now know the fluvial processes of flowing water. In the next Block of this course, we have explained the work of other geomorphic agents of groundwater, ice, sea waves and wind. River or flowing water action is one of the most significant exogenetic activities because rivers take materials from land areas and carry them to ocean basins. River action consists of three interconnected activities: erosion, transportation, and deposition. Rivers and streams are classified into two types: ephemeral and perennial. Non-perennial or ephemeral streams sustain water sometimes when storms occur and dry the rest of the time, whereas perennial rivers hold water flow almost throughout the year in humid climates.

River erosion is the gradual removal of rock material from the river banks and beds. The energy in a river causes erosion. The bed and banks can be

eroded making it wider, deeper and longer. **Headward erosion** is a process by which a river increases its upstream length. This happens more in the upper stages of a river. The river cuts back upstream there by increasing the length of its valley. Headward erosion makes a river longer.

Streams may erode their channels downwards or sideways. **Vertical erosion** is the main process in the upper course of the river. Vertical erosion in an alluvial channel bed takes place when there is a net removal of sands and gravels. Vertical erosion makes a river channel deeper.

Lateral erosion is the dominant process in the middle course of the river, as it is getting closer to sea level, so does not want to erode downwards, but has more energy due to the increased volume of water. Therefore, the river erodes sideways.

Erosion is a process in which the surface of the Earth is worn away by various agents of erosion like wind, water or ice. The removed material is carried away and deposited elsewhere. Erosion by streams occurs through several processes going together. These processes are hydraulic action, corrosion, abrasion, attrition and eversion (Fig. 9.4).

1. Hydraulic Action

This type of erosion is caused by the shear force of water. As the water flows, it is thrown into the cracks of rocks on the banks and the bed. The force of the water loosens rocks and transports the material downstream. Hydraulic action is common in well-jointed rocks. Hydraulic action also occurs through compression of air in cracks of the rocks of the bed and banks. As the water swings from side to side, the air is trapped in the cracks. It is compressed creating pressure in the cracks and this widens the cracks. As the water retreats, the pressure in the cracks is released, and the repeated compression of air and widening of cracks eventually shatters the rocks. The loose material is carried away by the water. This erosion process is called hydraulic action.

2. Corrosion

Corrosion is also known as solution. While removing the materials, the stream channel undergoes some type of chemical process of solution or acid reactions which dissolves the soluble rocks and transports the minerals in solution form. This process is known as corrosion. For example, rocks such as limestone, gypsum and rock salt are easily eroded through solution.

3. Abrasion

It is also known as corrasion. Running water when carrying sand, silt, gravel and other sediments act as a very effective means of erosion of the river bed and banks. They scratch, scrape and grind the river bed and banks in the processes of widening the river channel and deepening it too. As the process takes place, rocks are dislodged from the banks and bed of the channel and carried downstream. In the upper reaches, the river with a steep gradient carries a lot of materials which act as a tool and are effective in carving valleys, gorges and canyons. In contrast, if the river is free of these sediments the erosion by abrasion is minimal and the river would take a much longer time to erode its bed.

4. Attrition

This is the process of wearing away of the rock materials by rubbing, friction and collision. As the water moves, the particles like pebbles and sands collide against each other along the banks, on the bed as well as while in suspension and in the process disintegrate into smaller pieces. This rounding and shaping of these pebbles and boulders amongst themselves are called attrition.

5. Evorsion

The erosion by eddies in the rock bed of a stream, forming potholes is known as evorsion. It plays an important role in denudation.

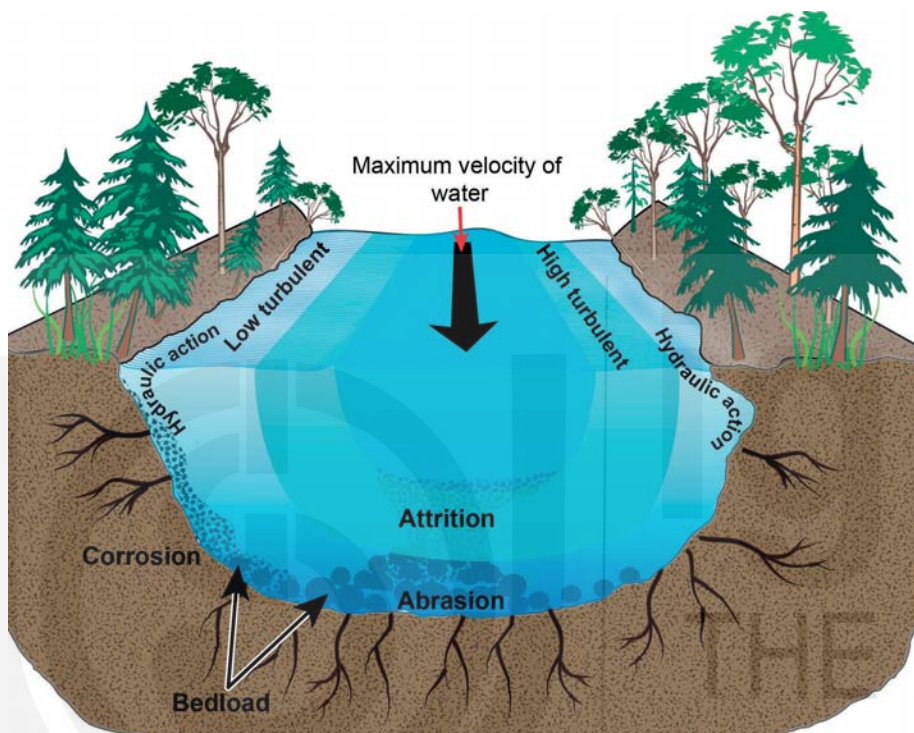


Fig. 9.4: Erosional Processes.

9.5 FLUVIAL TRANSPORTATION PROCESSES

Once erosion has occurred on the river channel, the material is transported downstream through various ways. Transportation of material in a river begins when friction is overcome. Material that has been loosened by erosion may be transported along the river. The ability of a river to transport its material depends on the following factors:

- Volume of the water – the higher the volume, the larger the amount of load that can be moved.
- Velocity of the water – the higher the velocity, the greater is the energy and hence the river is able to transport more materials.

There are four main processes of transportation. These are including solution, suspension, traction, and saltation (Fig. 9.5).

1. Solution

Solution load is when dissolved material is carried by a river. The dissolved load or solute load comprises ions and molecules derived from chemical

weathering plus some dissolved organic substances. Its composition depends upon several environmental factors including climate, geology, topography and vegetation.

2. Suspension

Suspended load consists of solid particles, mostly silts and clays that are small and light enough to be supported by turbulence and vortices in the water. Sand is lifted by the strong current and small gravel can be suspended for a short while during floods. Faster-flowing turbulent rivers carry more suspended material. This is why the river appears muddy as they are approaching bank-full discharge and towards the mouth of the river.

3. Traction

Traction is when large materials such as boulders are rolled and pushed along the river bed by the force of the river. Bed load or traction load is consisting of gravel, cobbles and boulders which are rolled or dragged along the channel bed by traction. The bed load moves more slowly than the water flows as the grains are moved fitfully, the particles may move singly or in groups by rolling and sliding

4. Saltation

Saltation is when materials such as pebbles and gravels that is too heavy to be carried in suspension, is bounced along the river by the force of water.

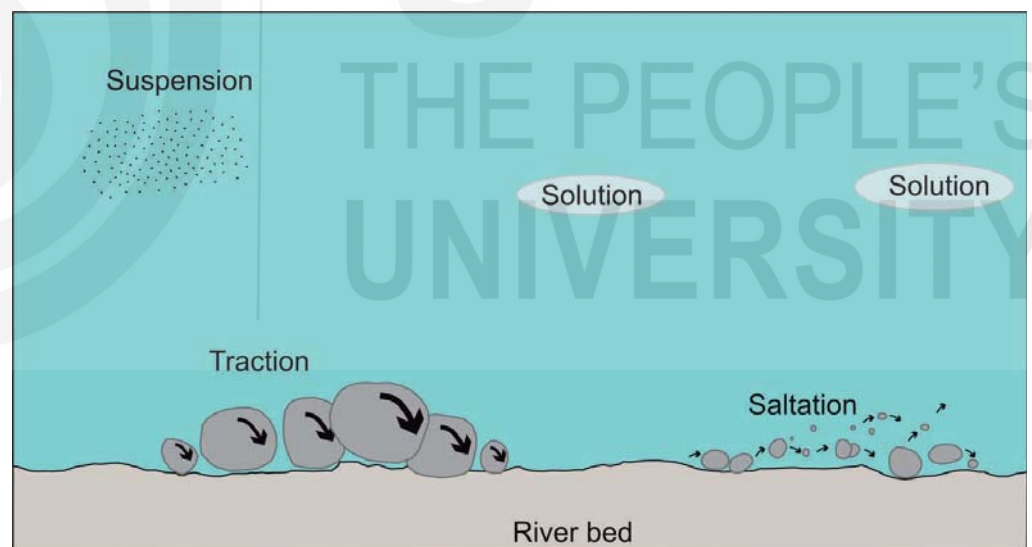


Fig. 9.5: River Transportation Processes.

SAQ 3

- Differentiate between vertical and lateral erosion of river.
- What are different types of fluvial erosional processes?
- Name a few transportation processes of river.

9.6 FLUVIAL DEPOSITION

Rivers may deposit material anywhere along their course, but they mainly deposit material in valley bottoms where gradients are low, at places where gradients change suddenly or where channel flow diverges, with a reduction in depth and velocity. There are four types of fluvial deposits i.e. channel deposits, channel margin deposits, overbank floodplain deposits and valley margin deposits. When studying stream deposition, it is useful to take the broad perspective of erosion and deposition within the deposition. In addition, flat low-lying land bordering stream that forms a suitable platform for deposition is more common at downstream sites.

Alluviation may be studied by calculating sediment budgets for alluvial or valley storage in a drainage basin. The change in storage during a time interval is the difference between the sediment gains and the sediment losses. Where gains exceed losses, storage increases resulting aggradation of channels or floodplains or both. Where losses exceed gains, channels and floodplains are eroded (degraded).

Hjulstrom Graph

The Hjulström Graph, named after Filip Hjulström, is a graph used by hydrologists to determine whether a river will erode, transport, or deposit sediment. The graph shows the relationship between the velocity of a river and the particle sizes that may be transported. It shows the critical velocity needed for the material to be moved or eroded and the settling velocity when deposition will take place. The area in between indicates the velocities where transportation of the material will continue to occur once the material is eroded.

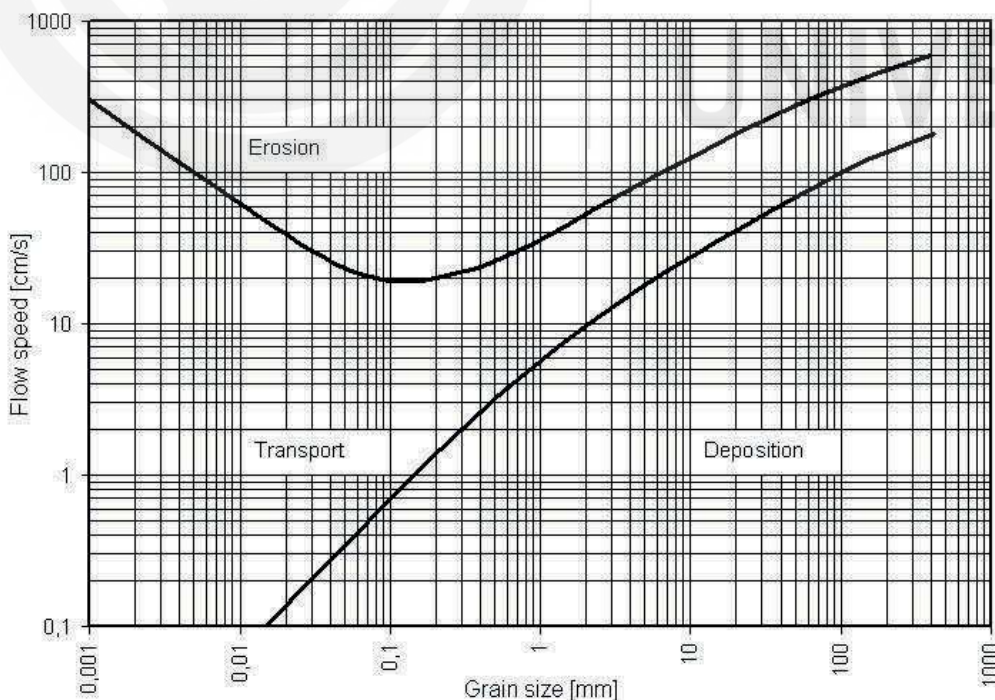


Fig. 9.6: Hjulstrom Graph.

(Source: https://commons.wikimedia.org/wiki/File:Hjulstr%C3%B6ms_diagram_en.PNG)

The graph shows that –

- a) Sand may be eroded and transported at much lower velocities than clay or silt.
- b) A river with high discharge and velocity, increases its capacity and competence allowing increased erosion of the river channel.
- c) The velocity needed to keep particles in suspension is less than that needed to erode them.
- d) For pebbles, cobbles and boulders there is only a very narrow gap between the amount of energy needed for erosion and deposition. Therefore, only a small drop in velocity is needed to cause deposition of the larger material.

9.7 FLUVIAL EROSIONAL LANDFORMS

So far you have studied concept of river basin and fluvial processes. In their landforms research, fluvial geomorphologists strive to understand the link between river water flow, processes, and the resulting geomorphic features. Now let us study the resultant landforms formed by various fluvial processes.

Most of the erosional landforms associated with running water are made by youthful rivers vigorously lowering over steep gradients. With the passage of time stream channels over steep gradients turn gentler due to continued erosion and as a consequence, lose their velocity, facilitating active deposition. There are two components of running water- overland flow on the land surface and linear flow as in valleys. The landforms formed by erosion are explained below:

1. Rills and Gullies

Rills are tiny hillside channels a few centimeters wide and deep that are cut by ephemeral rivulets. They grade into gullies. An arbitrary upper limit for rills is less than a third of a meter wide and two-thirds of a meter deep. Any fluvial hillside channel larger than that is referred to as a gully.

Gullies are intermediate between rills and arroyos which are larger incised stream beds. They tend to be deep and long and narrow and continuous or discontinuous. Gullies bear many local names like dongas, vocarocas, ramps and luvakas.

2. V-Shaped Valley

Deep cutting and erosion by the rapid flow of the stream carve out a valley that resembles the English letter 'V'. The V-shaped valley has a deep and narrow bottom (or valley) floor with steep valley sides. V-shaped valleys are found in the upper course of the river and are a result of both erosion by the river and weathering. V-shaped valleys are deep river valleys with steep sides and they are found in the upper course because this is where the river has the greatest gravitational potential energy.



(a)



(b)



(c)

Fig. 9.7: a) Process of Headward Erosion, b) Rills and Gullies and c) A View of Valley.

(Source: <https://www.pexels.com/photo/geological-layers-on-mountain-slopes-5429562/>,
<https://www.pexels.com/photo/conifers-countryside-dawn-daylight-210068/>)

3. Gorge

Gorge is a form of V-shaped valley which is deep and narrow with precipitous rocky walls occupied by a river at its bottom. It is more steep-sided and enclosed than a ravine. Corrasion is larger than deposition in the upper course of a river, therefore the river deepens its channel and produces a valley. If the rocks through which the valley is cut are strong and resistant, the valley's sides or valley walls will be steep and narrow. The amount of rain also has an effect on the steepness of the valley walls. For example, the Kali Gandaki Gorge is one of the deepest gorges in the world. River Sutlej enters India through a huge gorge near Shipkila pass. The Brahmaputra also moves through various gorges and enters the Indian Territory.

4. Canyon

A canyon is a variant of the gorge. A canyon is wider at its top than at its bottom. The canyon is characterized by steep step-like side slopes. Canyons commonly form in horizontal bedded sedimentary rocks e.g., Grand Canyon carved by the Colorado River in the United States of America.

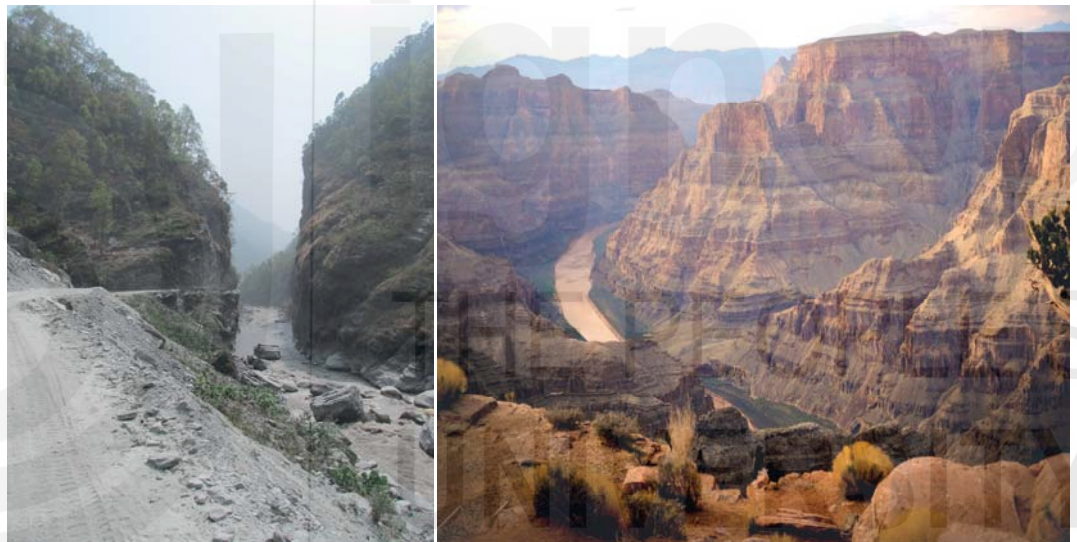


Fig. 9.8: a) The Kali Gandaki Gorge, also known as Andha Galchi, is the Gorge of the Gandaki River in Nepal's Himalaya and b) The Grand Canyon was created when the Colorado River eroded a deep path through layers of rock. It has some of the Earth's oldest exposed rock.

(Source: https://commons.wikimedia.org/wiki/File:Kali_Gandaki_Valley02,_Nepal.JPG#filelinks, <https://www.pexels.com/photo/scenic-view-of-the-grand-canyon-8372649/>)

5. Rapids and Waterfalls

These are liable to occur at any part of the river course, but they are most numerous in the mountain course where changes of the gradient are more abrupt and also more frequent. Due to the unequal resistance of hard and soft rocks across a river valley, the river develops the rapids and waterfalls alternately. Thus, rapids are formed where the gradient of the river is steep and the bed is composed mainly of hard rocks.

Waterfall represents a point in the long profile of a stream where the water descends vertically. Waterfall may develop when a river flows over a cliff caused either by a fault scarp or by resistant rock encountered by river while

deepening its valley. The hanging valley also causes waterfalls. Streams flowing through plateaus build-up by layers of successive lava flows generally develop waterfalls. When a bed of more resistant rock, horizontal or gently inclined upstream, overlies softer rocks, undercutting the softer bed rocks leads to undermining and recession of the waterfall.

Rapids are substantially smaller in scale than waterfalls. Knickpoint is the point at which the stream profile abruptly steepens, resulting in a vertical drop. This characteristic may be found in every waterfall. The Himalayan region is home to numerous waterfalls.

6. Potholes and Plunge Pools

Pothole is a more or less circular hole in the rocky bed of a stream. In rapids and at the base of waterfalls, potholes are formed on solid rocks through the grinding action of sand and pebbles which lodge in slight initial depression and are swirled around by the swift water. Their greater pressure and force usually wear out a plunge-pool beneath.

A pothole's depth is far greater than its diameter. Larger potholes are referred to as plunge pools. Plunge Pools form on the river bed primarily as a result of hydraulic action, in which water falls from great heights and causes bedrock erosion.



Fig. 9.9: Fluvial Erosional Landforms: Waterfall and Potholes.

(Source: <https://www.pexels.com/photo/man-standing-in-front-of-waterfalls-1881420/>;
<https://www.pexels.com/photo/view-of-creek-cascades-in-narrow-rocky-gully-8493361/>)

SAQ 4

- What is a gorge?
 - There is an abrupt break in a river's lengthy profile where the gradient suddenly increases is known as
-

9.8 FLUVIAL DEPOSITIONAL LANDFORMS

The loosely consolidated sediments, also known as alluvium, carried by alluvial channels indicate the river's capacity to transport material. Braided channels and meandering channels are two types of alluvial channels. Braided channels are shallow and broad, and they transport sand and gravel by water flow, whereas meandering channels are deep and smooth, and they transport mud, which is silt and clay.

You can see that the flooded channels have unpredictable flow regimes with volume changes. When the strength of the erosional forces reduces, the load of rock pieces, sand, and silt is deposited close or far from the point of flow. This results in forming of various fluvial depositional landforms. Some of the depositional landforms are explained below:

1. Alluvial Fan

The alluvial fan is a depositional landform of the river's lower course. It is a cone-shaped landform formed by streams that flow from a mountain and debouch onto a plain. The transporting ability of rivers decreases drastically when they leave the mountains and approach flat territory at the foothill zones. As a result, finer to coarser and relatively large sediments from upstream are deposited at the point of slope break or foothill zone, resulting in the formation of alluvial fans (Fig. 9.10).

The alluvial deposits radiate from the fan apex, which is the point at which the stream emerges from the mountains. The zone of deposition on the fan runs back from the break of slope between the fan surface and the flat land in front of the fan toe. The steepness of the fan slope depends on the size of the stream and the coarseness of the load, with the steepest alluvial fans being associated with small streams and coarse loads.

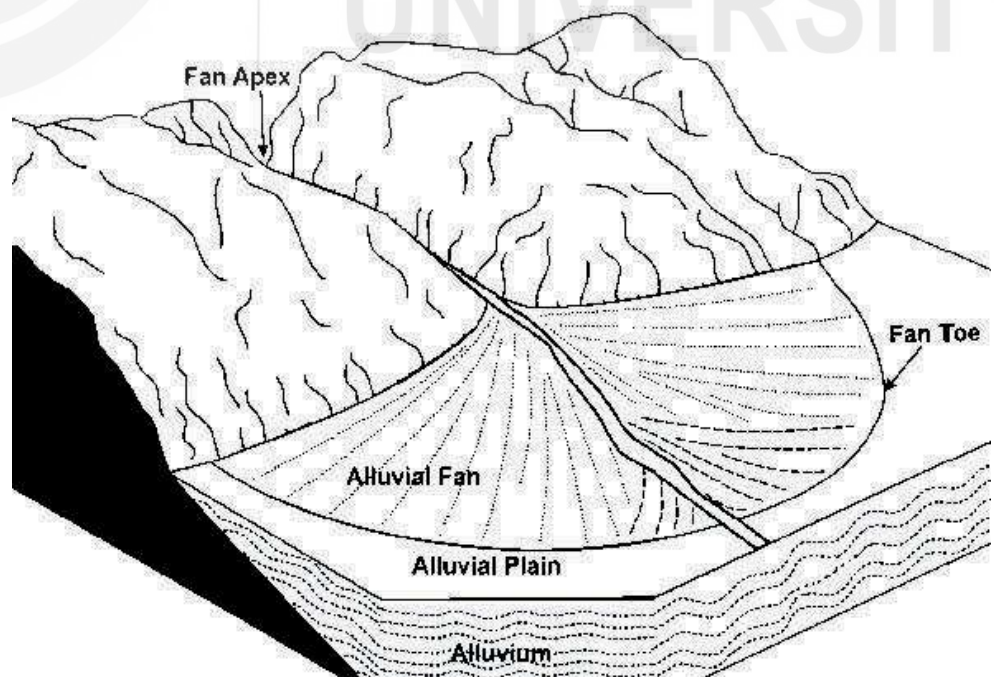


Fig. 9.10: An Alluvial Fan-A Depositional Landform.

2. River Terraces

River terraces are the narrow flat surfaces on each side of river valley bottoms. They are the remains of old valley floors that were left on valley slopes following river down cutting. They are remnants of former flood plains, despite having little or no alluvium. River terraces can broadly be categorized into two types 1) paired terraces and 2) unpaired terraces.

Paired terraces form when the river's vertical downcutting surpasses its lateral movement. Unpaired terraces occur when the channel shifts laterally quicker than it cuts down. Therefore, terraces are created by cutting each side of the valley in turn.

3. Floodplains

The floodplain is the best example of depositional morphology, with coarse material depositing as levees along the channel, and bars primarily outside the river meander bends. The flood plain is covered with fine silt and clay deposits. Flood plains are historical landforms formed by stream movement and sediment deposition. Floodplains are produced by debris deposited during a flood stage of a river. Small floods that occur regularly cover a portion of the floodplain, whereas large floods that occur seldom submerge the whole region. Floodplain width is typically proportional to river discharge.

A floodplain region is formed by the vast amounts of silt transported by a river and its deposition. These sediments are scattered over low-lying neighbouring areas during regular or infrequent floods. During each flood, a layer of silt is thus deposited, eventually forming a floodplain. A riverbed made of river deposits is referred to as the active floodplain. The floodplain above the bank is no longer active and is called an inactive floodplain. There are two types of deposits in the dormant floodplain above the banks: flood deposits and channel deposits.

The deposition of suspended material, i.e. fine material, results in thick deposits, which are known as alluvial deposits. For example, the thick alluvial deposits of the rivers Ganga and Yamuna cover huge regions of Uttar Pradesh, Bihar, and West Bengal. Flood plain features are shown in Fig. 9.11. You can also find some other features like oxbow lakes, sloughs, ridge and swale topography, back swamps, etc. in flood plain regions.

Meandering streams, which are frequently seen on flood plains, consist of a single sinuous course with vast looping arcs known as **meanders**. The river runs in a zigzag pattern known as meandering. The deposition occurs on the convex sides of the meanders, where the relative velocity of the river water is lowered, causing the channel to obstruct and forming an **ox-bow lake**. The ox-bow lake is also termed 'horse shoe lake' because of its appearance.

Floodplain is the greatest illustration of depositional morphology, with coarse material depositing as levees along the channel and bars primarily on the outside of river meander bends. A **point bar** is a low, crescent-shaped sand and gravel deposit that accumulates on the inner bank of a meander where the water velocity is low. Natural levees are formed by consecutive floods, which are ridges of coarse material that keep the stream inside its banks

between floods, even when water levels are high. These are the elevated sections of the banks called as **levees**.

4. Delta

A delta is a body of sediment that contains numerous horizontal and vertical layers. The delta, which resembles the Greek letter Δ (*delta*), is a relatively flat triangular or fan-shaped plain at the mouth of a river. The bulk of the material that rivers transport is eventually deposited into a lake or the ocean. The deposited sediments accumulate into a sizable, flat-topped deposit, creating the low, swampy delta plain. Deltas are created when the sediment load carried by a stream is deposited because of a sudden reduction in stream velocity. The surface of most of the deltas is marked by small shifting channels that carry water and sediments away from the main river channel. These small channels also act to distribute the stream sediment load over the surface of the delta.

India's east coast is mostly a depositional coast, with several rivers creating their deltas into the Bay of Bengal. The Ganges Delta, often referred to as the Sundarbans Delta or the Bengal Delta, is a river delta in South Asia which is constituted of Bangladesh and the Indian state of West Bengal. It is the world's largest river delta, flowing into the Bay of Bengal with the combined waters of the Brahmaputra and Ganges rivers. Other examples are the deltas of the Mahanadi, Godavari, Krishna, and Cauvery rivers. The Godavari and Krishna rivers, which are India's second- and third-largest river systems after the Ganges, have formed their deltas next to one another, nearly merging into a single, expansive delta complex in the middle of the country's east coast.

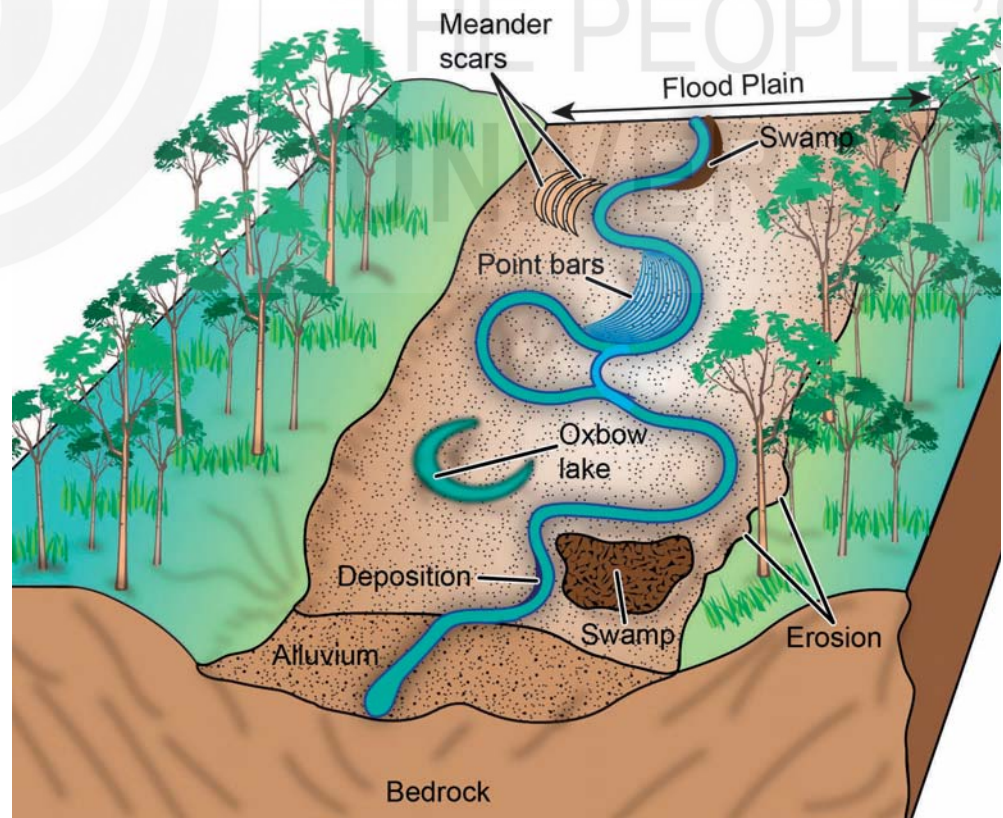


Fig. 9.11: Depositional Landforms.

SAQ 5

- a) How does an alluvial fan form?
 - b) Is a point bar the result of fluvial erosion or deposition?
 - c) What is delta? Which regions of India give rise to deltas?
-

9.9 SUMMARY

In this unit, you have studied so far:

- A drainage basin is developed when a river or stream network drains through a specific region that is bounded by ridge lines. Many factors influence drainage basins, including climate, stream network, lithology, geological formations, landforms, soil, landuse, and landcover.
- Basin morphometry is quantitative study of the Earth's surface configuration. The drainage basin study provides insight into its shape, dimensions, and numerous aspects.
- Fluvial processes refer to the interaction of moving water in rivers with the surrounding terrain, which results in many types of landforms. These processes are critical in the denudation of land surfaces and the movement of rock debris from higher to lower levels.
- Water flows downstream due to gravity forces, but forces opposing the flow are known as frictional forces. Water flow may be classified into three types: laminar flow, turbulent flow, and helicoidal flow.
- In laminar flow, water tends to flow in layers parallel to the river bed and to each other. Water does not travel in parallel layers in turbulent flow; instead, its velocity swings continuously in all directions inside the fluid. Because of their spherical form and fast rotation, helicoidal flows are a natural outcome of convection in planetary dynamo areas.
- River action consists of three interconnected activities: erosion, transportation, and deposition.
- Erosion is the process through which the Earth's surface is worn away by different causes of erosion such as wind, water, and ice.
- The principal process in the upper course of the river is vertical erosion. Vertical erosion deepens a river channel. Lateral erosion is the major process in the river's middle course, when it approaches sea level.
- Stream erosion happens as a result of various interconnected processes. Hydraulic action, corrosion, abrasion, attrition, and eversion are main types of fluvial erosional processes.
- The types of transportation processes are solution, suspension, traction, and saltation.
- The majority of the erosional landforms linked with flowing water are formed by aggressively trying to lower rivers over steep slopes. Rills and

gullies, v-shaped valleys, gorges, canyons, rapids, waterfalls, potholes, are examples of erosional landforms.

- Alluvial fans, flood plains, river terraces, deltas, natural levees, point bars, meanders, and oxbow lakes are examples of fluvial depositional landforms.

In the next Block 4 of Volume 2, you will study various processes and landforms related to wind action, sea waves, underground water, and glaciers.

9.10 TERMINAL QUESTIONS

1. Explain the importance of drainage basin.
2. Describe different types of water flow with a neat sketch.
3. What are fluvial erosional processes? Describe any three types of erosional processes.
4. Explain any three fluvial erosional landforms.
5. Write a note on fluvial depositional landforms.

9.11 ANSWERS

Self-Assessment Questions (SAQ)

1. Dendritic, trellis, parallel, rectangular, radial and centripetal.
2. Laminar flow occurs on river bottoms that are smooth. The water flows in strata parallel to the river bed and to one another. Water does not travel in parallel strata in turbulent flow; instead, its velocity fluctuates continuously in all directions within the fluid.
3. a) The principal process in the upper course of the river is vertical erosion. In the middle course of the river, lateral erosion is the major process. It does not degrade downwards, but gains energy as the volume of water increases. Therefore, the river erodes sideways.
b) Fluvial erosion by streams occurs through several processes going together. These processes are hydraulic action, corrosion, abrasion, attrition and evorsion.
c) There are four main processes of river transportation. These are including solution, suspension, traction, and saltation.
4. a) A gorge is a V-shaped valley with deep and narrow rocky walls and a river at its bottom.
b) Knickpoint
5. a) The alluvial fan is a depositional landform of the river's lower course. It is a cone-shaped landform formed by streams that flow from a mountain and debouch onto a plain.
b) Point bar is fluvial depositional landform.
c) The delta is a relatively flat triangular or fan-shaped plain at the mouth of a river. The Sundarbans Delta of West Bengal, the Mahanadi Delta of

Odisha, Godavari and Krishna Deltas of Andhra Pradesh, and Cauvery Delta of Tamilnadu.

Terminal Questions

1. A drainage basin is developed when a river or stream network drains through a specific region that is bounded by ridge lines. To elaborate further, refer to Section 9.2.
2. Rivers are natural streams of water that flow from higher to lower elevations across the land surface. The flow of water has a force and velocity. To explain different flows of water, refer to Section 9.3.
3. Fluvial erosional processes are hydraulic action, corrosion, abrasion, attrition, and evorsion. Refer to Section 9.4.
4. Rills and gullies, V-shaped valleys, gorges, canyons, rapids, waterfalls, and potholes are examples of erosional landforms. Further explanation, refer to Section 9.7.
5. Refer to Section 9.8.

9.12 REFERENCES AND SUGGESTED FURTHER READING

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GLOSSARY

Biological Weathering	: The group of processes that are caused by, or assisted by, the presence of vegetation, or to lesser extent animals, including root wedging and the production of organic acids.
Chemical Weathering	: The decay of rock forming minerals caused by water, temperature, oxygen, hydrogen and mild acids.
Creep	: This phenomenon is found in almost all slopes. The movement of creep is very slow, indicated through curved tree trunks, leaning fences, tilted poles and small soil ripples on the slopes.
Debris Avalanche	: The vertical fall of loose soil piles due to river head erosion in the lower part of the slope is called debris avalanche.
Debris Flow	: In high-altitude mountain areas, when various rock fragments deposited on steep slopes mix with muddy snow and move down suddenly through narrow channels in the form of debris, it is called a debris flow.
Earth Flow	: In areas with a slope of 10 to 15 degrees, fine-grained soil wetted by contact with water and flowing down the slope from a high point is called earth flow.
Gravitational Force	: Mass movement of regolith down the slope by the force of gravity without the aid of a transporting medium such as water, ice, or wind.
Mud Flow	: The flow of saturated fine-grained soil is called mud flow.
Physical Weathering	: The effects of fluctuating temperature on rocks create physical weathering, which causes the rock to break apart. Water is occasionally used to help the process.
Rock Creep	: In this case, large sandstones, conglomerates, granites etc. descend downwards along the slopes. Rocks on a stratified or rifted floor move slowly downslope to gradually expand and contract due to changes in day and night temperatures.
Slide	: If a weak part, such as a stratum, slips along the plane of the rock interface, the downslope of cohesive rock sediments is called a slide.
Slump	: A rock or soil block is called a slump when it gradually slides downwards along certain cracks or curves in a slightly rotating manner.
Soil Creep	: Soil creep is the very slow gravitational descent of soil layers and bedrock in areas with slopes of

generally 5° to 20°. Rainwater, frost action, and cracks in rock formations due to extreme dryness are the main causes of soil creep.

Subsidence : When the area below the slope suddenly subsides, it is called a Subsidence.

Talus Creep : In areas with steep slopes, angular rock blocks or talus or scree gradually descend along the slope as a result of weathering erosion, it is called talus creep.

Talus Slope : The talus is steep slope where rock fragments of any shape and size accumulated and formed due to gravitational pull. Talus slope consist of bigger sized rocks and scree is smaller consisting of fragmented rocks.

Topple : As a result of an extensional fault, usually in the upper part of a river bank or in a valley region, a rock or soil block is loosened and the block falls vertically, bearing down on a point below its center of gravity, called a topple.

Weathering : It refers to the breaking down or dissolving of rocks and minerals on the surface of the Earth. Water, ice, acids, salts, plants, animals, and changes in temperature are all agents of weathering.

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