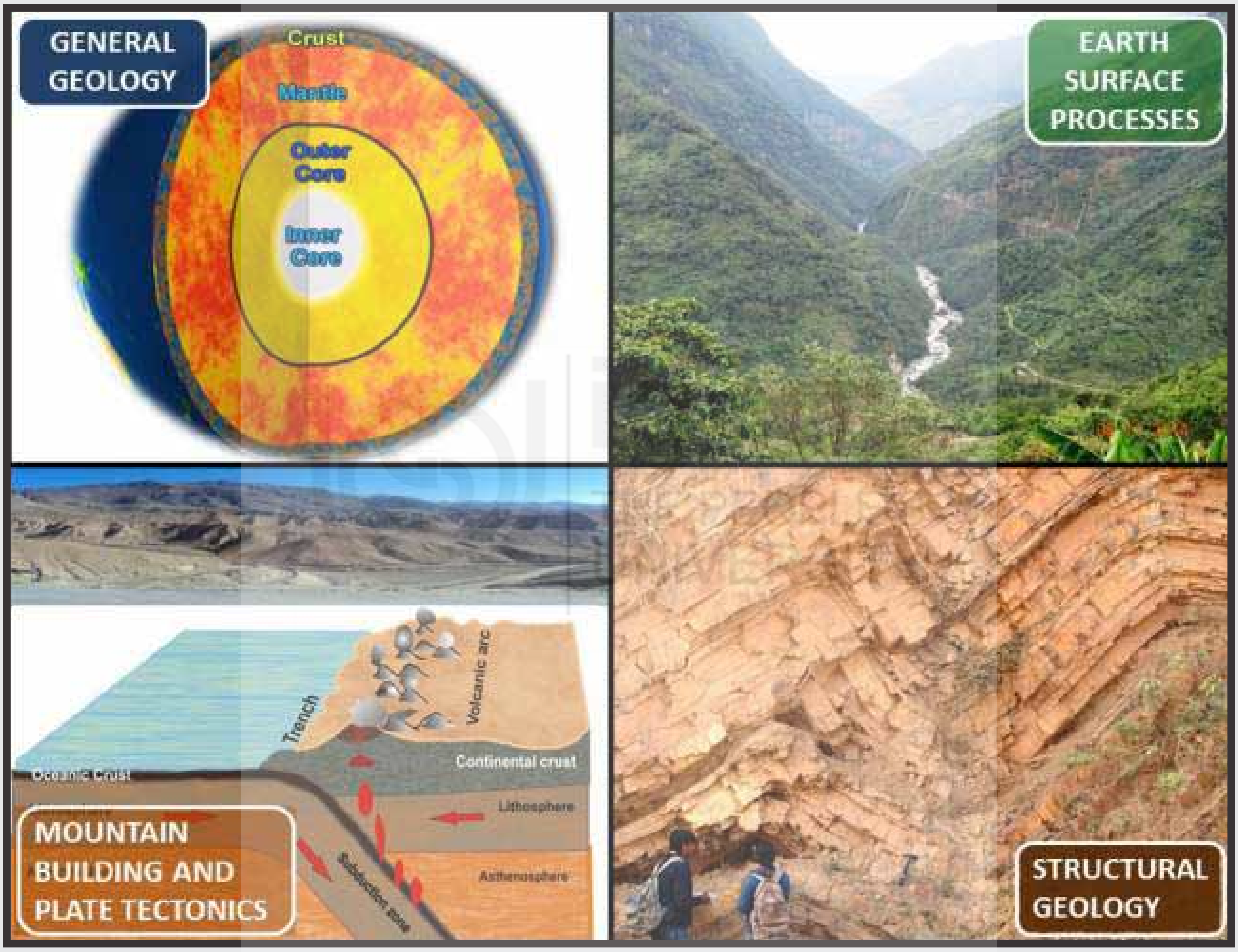
Indira Gandhi National Open University
School of Sciences

BGYCT – 131
PHYSICAL AND STRUCTURAL GEOLOGY



Earth Surface Processes

2

"शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्गगत विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।"

– इन्दिरा गांधी

"Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances."

- Indira Gandhi

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BGYCT-131
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Block

2

EARTH SURFACE PROCESSES

Course Design Committee

Prof. Vijayshri
Former Director
School of Sciences
IGNOU, New Delhi

Prof. V. K. Verma (Retd.)
Department of Geology
University of Delhi
Delhi

Prof. Pramendra Dev (Retd.)
School of Studies in Earth Sciences
Vikram University
Ujjain, MP

Prof. P. Madhusudhana Reddy (Retd.)
Department of Geology
Dr. B.R. Ambedkar Open University
Hyderabad

Prof. L. S. Chamyal
Department of Geology
M.S. University of Baroda
Vadodara, Gujarat

Late Prof. G. Vallinayagam
Department of Geology
Kurukshetra University
Kurukshetra, Haryana

Prof. J. P. Shrivastava
Centre of Advanced Study in Geology
University of Delhi, Delhi

Prof. Deepak C. Srivasava
Department of Earth Sciences
Indian Institute of Technology Roorkee
Roorkee, Uttrakhand

Prof. H. B. Srivastava
Centre of Advanced Study in Geology
Banaras Hindu University
Varanasi, UP

Prof. M. A. Malik
Department of Geology
University of Jammu
Jammu, J & K

Prof. S. J. Sangode
Department of Geology
Savitribai Phule Pune University
Pune, Maharashtra

Prof. Arun Kumar
Department of Earth Sciences
Manipur University
Imphal, Manipur

Prof. (Mrs.) Madhumita Das
Department of Geology
Utkal University
Bhubaneshwar, Odisha

Prof. K. R. Hari
School of Studies in Geology & Water Resources Management
Pt. Ravishankar Shukla University
Raipur, Chhattisgarh

Dr. K. Anbarasu
Department of Geology
National College Tiruchirapalli
Tamilnadu

Faculty of Geology Discipline
School of Sciences, IGNOU

Dr. Meenal Mishra
Dr. Benidhar Deshmukh
Dr. Kakoli Gogoi
Dr. M. Prashanth
Dr. Omkar Verma

Block Preparation Team

Course Contributors

Dr. S. D. Shukla (Retd.) (Units 5, 6 and 7)
SGRR Degree College
Dehradun

Dr. Meenal Mishra (Unit 8)
School of Sciences
IGNOU, New Delhi

Content Editor
Prof. V. K. Verma (Retd.)
Department of Geology
University of Delhi, Delhi

Language Editor
Prof. S. K. Shah (Retd.)
Department of Geology
University of Jammu, Jammu

Transformation: Dr. Meenal Mishra

Course Coordinators: Dr. Meenal Mishra and Dr. Benidhar Deshmukh

Audio Visual Materials

Dr. Amitosh Dubey
Producer, EMPC, IGNOU

Dr. Meenal Mishra and Dr. Benidhar Deshmukh
Content Coordinators

Print Production

Sh. Sunil Kumar
Assistant Registrar (P), School of Sciences, IGNOU, New Delhi

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BGYCT-131: PHYSICAL AND STRUCTURAL GEOLOGY

List of audio / video materials related to this course

1. Earth System Science and Society -Part 1
   Link: https://www.youtube.com/watch?v=dVbjNn0ZHRg

2. Earth System Science and Society- Part 2
   Link : https://www.youtube.com/watch?v=0GMPIOrCdcE

3. Geoinformatics: An Introduction
   Link: https://youtu.be/vu7f5aFoox0

4. Applications of Geoinformatics
   Link: https://youtu.be/tfSDp2TO-Eg

5. Weathering, its types and Significance
   Link: https://www.youtube.com/watch?v=gBYijIPPVgc

6. Soil: Product of Weathering
   Link: https://www.youtube.com/watch?v=y-SENU4Abv8

7. Landslides: Its types and causes
   Link: https://youtu.be/cI73TU0hjQk

8. Landslides: Mitigation measures
   Link: https://www.youtu.be/BcUVeL43x7c

9. Deccan Volcanism-an Inside Story
   Link: https://www.youtube.com/watch?v=1a3gIcg0oGs

10. Himalaya-an Overview
    Link: https://www.youtube.com/watch?v=vK5CgIisa1Y

11. Evolution of Himalaya
    Link: https://www.youtube.com/watch?v=gVGZKqrjVZY

Development of audio/video programmes is a continuous process. For recent materials pertaining to the course you may visit Youtube page of the School of Sciences, IGNOU.

Alternatively, you can visit eGyankosh website of IGNOU
Link : http://egyankosh.ac.in/handle/123456789/36575

BLOCK 2: EARTH SURFACE PROCESSES

Earth is a unique, complex and dynamic planet that has continuously changed since its origin, about 4.6 billion years ago. Surface features referred to as landforms are sculptured by the ongoing natural processes. **'The present is the key to the past'** warrants that the effects of geomorphic processes whether constructive or destructive seen in action today may be legitimately used to decipher the causes of assumed landscape changes in the past. Earth's surface features are the result of constructive and destructive forces. Constructive forces cause landforms to grow whereas the destructive forces wear down the landforms. The slow processes of weathering and erosion work over time to change once high mountains into smooth flat plateaus. Geomorphology is the part of Earth Science that studies the changes on Earth's surface and the forces and processes that develop them. It is therefore 'a discourse on Earth forms'. Earth's physical land surface features, its landforms are developed and sculptured by the persistent action of the agents like rivers, wind, glaciers, ocean, underground water and lake. The decomposition and disintegration of rock is a primary process in the tectonic cycle and landscape evolution.

This block comprises four units, wherein you will be introduced to the basic concepts of rock weathering and the geological work done by river, wind, underground water, glacier and ocean.

Unit 5 is an introduction to the fundamental concepts of three types of weathering processes, i.e. physical (mechanical), chemical and biological and the factors affecting them. This unit also elaborates on the relative stability of minerals and the products of weathering. We will also discuss the factors affecting and processes of soil formation, its profile, and classification and soils of India. In addition, this unit also discusses mass wasting, its types and causes.

In **Unit 6** you will study about the geological action of running water, i.e. river, stages of river and drainage systems and patterns. We will also learn about types of load carried by the river in its channel and the processes involved in fluvial erosion. We will also identify and discuss the landforms sculptured by the erosional and depositional processes of fluvial action.

In **Unit 7** you will learn about the geological work done by wind and the resulting erosional and depositional landforms. This unit also elaborates on the landforms resulting and developed by the action of the underground water and karst topography.

Unit 8 introduces you to the geological action of glacier and ocean. This unit elaborates on their erosional processes apart from the erosional and depositional landforms created by glacial and marine processes.

Expected Learning Outcomes

After studying this block, you should be able to:

- discuss basic concepts of physical, chemical and biological weathering and factors affecting them;
- recognise types of mass wasting and their causes;
- identify different horizons in a soil profile, classify soil types based on texture and composition and their geographic distribution in India;

- define geological agents and their functions;
- explain erosional, transportational and depositional processes involved in fluvial and aeolian action;
- elaborate erosional and depositional landforms developed due to geological action of rivers and wind;
- discuss erosional and depositional landforms developed due to geological work of underground water and karst topography; and
- list and describe the erosional and depositional landforms developed due to geological action of glaciers and oceans.

We hope that after studying this block you will acquire understanding of the basic concepts of rock weathering and geological work of river, wind, underground water, glacier and ocean and the landforms sculptured by their action.

Wishing you success in this endeavour!

UNIT 5

ROCK WEATHERING

Structure

5.1 INTRODUCTION

You have been introduced to the discipline of Geology and Planet Earth in Block 1 General Geology. You have also learnt about the four constituents of Earth, viz. atmosphere, hydrosphere, lithosphere and biosphere. Various geological processes (both external and internal) operate continuously and will continue operating at the interface of these spheres. These processes bring about changes that result in the development of beautiful landscapes. We will try to explore more about the external (exogenic) and internal (endogenic) geological processes in this unit. In this unit, we will focus on weathering, erosion and mass wasting which are brought about by external (exogenic) geological processes.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define and recall the exogenic and endogenic processes;
- ❖ describe the factors affecting them;
- ❖ discuss aspects of physical, chemical and biological weathering;
- ❖ identify different horizons in a typical soil profile;
- ❖ classify soil types based on texture and composition;
- ❖ recognise geographic distribution of different soils in India;
- ❖ define mass wasting and list their types; and
- ❖ evaluate the relation between weathering and erosion.

5.2 GEOLOGICAL PROCESSES AND THEIR SIGNIFICANCE

You have learnt about different theories of origin of the Earth in the previous units. The geological processes started operating on our planet immediately after its formation. Some of the processes continue to operate bringing about visible changes at the interface of solid crust-lithosphere and the atmosphere. Many of these changes are brought about due to processes operating internally within the Earth. The internal processes work deep below the Earth's surface. Though you cannot directly observe these processes but their effects are quite obvious. As mentioned earlier, the geological processes can be divided into:

- Exogenic
- Endogenic

5.2.1 Exogenic Processes

This term is used to describe geological processes operating on the Earth's crust. These include the activities involved in weathering, erosion, transportation and deposition of eroded materials. They are together called **external** or **exogenic geological processes** because they operate at or near Earth's surface. You must be familiar with the terms related to exogenic processes, i.e. weathering, erosion and mass wasting.

You will learn more about the basic concepts of exogenic processes in this unit.

5.2.2 Endogenic Processes

As you know, the Earth comprises three layers, i.e. crust, mantle and core that are differently structured at different levels possessing distinct characteristics. The internal or endogenic processes operate within the Earth. The endogenic processes bring about major changes on the surface and help in exploring the Earth's interior. These processes comprise earthquakes, volcanic activity, Earth movements and mountain building processes, convection currents leading to continental drift and Plate tectonics. We have discussed about these endogenic processes in Unit 3 Structure and Composition of Earth of the previous block. **Convection currents** transfer heat by movement from areas of high heat to low heat. **Continental drift** refers to the horizontal displacement of the continents. **Plate tectonics** is a special branch of Earth science that deals with the processes by which the lithosphere moves laterally over the asthenosphere.

5.3 WEATHERING

You have read about weathering earlier in your school textbooks. **Weathering** refers to the natural processes of disintegration and decomposition of rocks. It includes activities whereby the rocks at or near the surface, break, decay or crumble. The process of weathering is triggered with the change of environmental conditions. For example, when a depositional basin is uplifted, the rocks are exposed to a different kind of environmental setup. As a result of this change, the rocks may be disintegrated, fragmented or decomposed to survive in the new conditions they are exposed to. Weathering, one of the major processes in the rock cycle, is the first step in flattening the mountains that have been uplifted by endogenic processes. **Rock cycle** is the cyclic movement of rock material, in the course of which rock is formed, destroyed and altered by internal and external Earth processes. Weathering shapes Earth's surface topography/configuration and alters rock materials, converting them into sediments and soils.

- Watch this video to know about weathering its types and significance link : https://www.youtube.com/watch?v=gBYijIPPVgc

Weathering can also be defined as a set of physical, chemical and biological processes that breaks down rocks and minerals in the crust to create sediments, new minerals, soil and dissolved ions and compounds (Fletcher, 2011).

There are three processes of weathering, let us read about them.

1. **Physical weathering** takes place when solid rock is fragmented into pieces by physical disintegration or mechanical breakdown that does not change the chemical composition. It is also known as **mechanical weathering.**

2. **Chemical weathering** occurs when the minerals in the rock undergo chemical alteration or dissolution.

3. **Biological weathering** occurs when rock disintegrates or decomposes due to physical and/or chemical activity of the living organisms.

Physical, chemical and biological weathering may work together in unison to breakdown the crustal rocks. Chemical weathering results through chemically active fluids operating on the exposed surfaces. Physical and biological weathering causes the rock(s) to fragment into smaller particles, which increases the surface area that is vulnerable and thus enhances effectiveness of chemical weathering. Now you can recognise the effect of increased exposed surface area, illustrated in Fig. 5.1. Suppose you divide a block of 4cm x 4cm into eight equal cubes of 2cm x 2cm each the surface area doubles so on and so forth. As the cubes are divided the exposed surface area increases and the effectiveness of chemical weathering also increases with it.

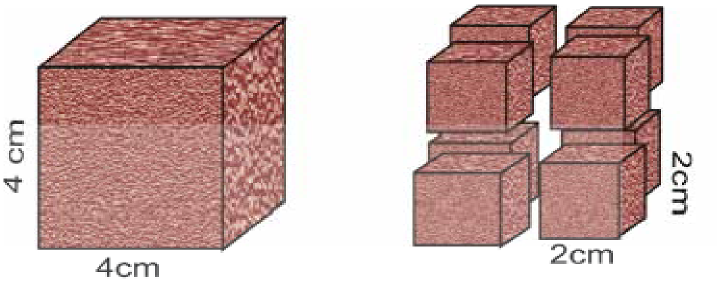


Fig. 5.1: Physical weathering increases the exposed surface area and effectiveness of chemical weathering.

Before discussing other aspects of weathering let us learn about the related terms. Erosion refers to weathering, which is followed by removal of the weathered material grain by grain. **Transportation** is implicit in erosion. Weathering produces sediment and erosion transports it across the landscape. Thus, weathering associated with removal of the weathered material is included under the term 'erosion'. **Erosion** may be defined as a complex group of related processes by which rock is broken down and then its products are removed by various agencies, viz. water, wind and ice. You would study about these agencies in the next unit. Weathering prepares ground for erosion. The eroded materials carried away from the site are eventually deposited. These processes of erosion and deposition may form erosional or depositional landforms on the surface of the Earth.

5.3.1 Factors Affecting Weathering

Before discussing the factors affecting the weathering you would realise that weathering produces all the sediments and soils of the world as well as dissolved substances that the streams carry to the seas and oceans. All the rocks exposed on the Earth's surface weather varyingly. Following four key factors effect weathering:

- **Parent rock**: The following properties of a parent rock affect the weathering processes:

  i) **Nature of the parent rock**: The mineralogy and crystal structure of parent rock play an important role that greatly affects the rate of weathering. The rocks are composed of various minerals which weather differently. Stability of minerals plays an important role in affecting the susceptibility of parent rock material to weathering. You might have observed that the hillocks or ridges comprise resistant parent material while the valleys consist of weathered materials.

  ii) **Topography**: It describes differences in elevation, slope and landscape position. Topography plays an important role as factors like elevation; slope and landscape position may either hasten or retard the weathering process. Steep slopes generally encourage rapid soil loss by erosion and allow less rainfall to enter soil before running off. Therefore, soil on steep terrain tends to have rather shallow and poorly developed profiles.

iii) **Structure**: Geological structures such as folds, faults and shear zones also control topography. Shear zones have good capacity of holding water. Generally, the rivers follow the course of major fault zones. Fault is a crack or fracture in the Earth's crust, which involves displacement of the rocks on one side relative to those on the other. Shear zone is tabular area of rock that has been crushed and brecciated by many parallel fractures.

- **Climate**: Climate influences the weathering processes to a larger extent. This includes rainfall, temperature, aridity and humidity in a region. The rates of physical, chemical and biological weathering not only vary with the properties of parent rock but also with the climate, especially the temperature and amount of rainfall in the region where parent rock is located. Water is essential for the chemical weathering reactions. It may be present as reactant and/or carrier. For effective weathering water must be available to the parent rock. Now let us evaluate how water is important for chemical weathering reactions. The rainwater dissolves atmospheric carbon dioxide to form carbonic acid that is enough to dissolve great quantities of rock over long periods. You can study the reaction involving **feldspar** (an important mineral constituent of crustal rocks) as given below. Feldspars are the most important single group of rock-forming silicate minerals with general formula $XAlSi_3O_8$ where X can be a cation namely, K^+, Ca^{+2}, Na^+ or Ba^{+2}.

$$\underset{\text{feldspar}}{2KAlSi_3O_8} + \underset{\text{carbonic acid}}{2H_2CO_3} + H_2O \longrightarrow \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4} + \underset{\text{potassium ion}}{2K^+} + 2HCO_3^- + SiO_4$$

  The climate is affected by **topography** or **relief** of a region. Topographic setting may either enhance or retard the chemical action. Topography affects the absorbance of solar energy in given landscape. Rainfall or humidity of a region affects vegetation. Vegetation in turn enhances biological weathering. Thus, you have seen that climate affects biological weathering because vegetation is controlled by temperature, rainfall, aridity and humidity.

- **The presence and absence of soil**: You have already learnt that acidic water weathers feldspar. Let us discuss why chemical reactions are faster in feldspars that are buried in damp soils than on bare rock outcrops. The obvious explanation behind this is the presence of thin soil cover over the weathered surface which enhances longevity of interaction aiding the weathering process. This basic concept would help you to better appreciate why feldspars on bare outcrops are better preserved than those buried in damp soils. This also answers the question why the chemical weathering process is more rapid in the tropics than in temperate and cold climates. This is mainly because plants and bacteria grow more quickly in warm humid climates and they contribute more of carbonic acid and other acids that promote weathering. You will read more about the role of biota in subsection biological weathering discussed later in this unit.

- **The length of time of exposure**: The time period to which a rock is exposed to weathering conditions is also very important. Longer the operating time more will be the impact.

5.3.2 Physical Weathering

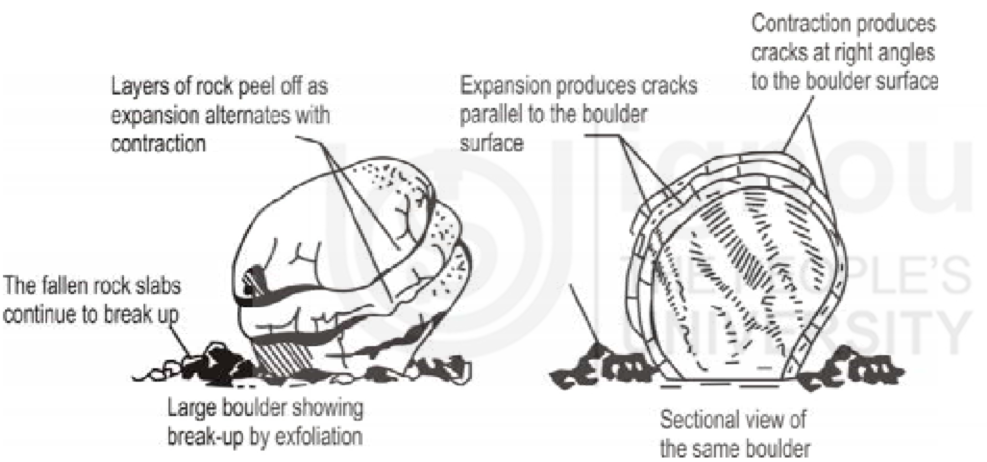
You have already learnt that physical weathering plays a crucial role by increasing the surface area of rocks as shown in Fig. 5.1. It also changes the appearance of Earth's surface as a result of several processes: temperature, pressure release, abrasion, freeze-thaw, hydraulic action and action of gravity. It involves the mechanical breakdown of minerals and rocks by a variety of processes hence physical weathering is also known as **mechanical weathering**. It occurs when rock is fragmented by physical processes. This does not involve change in the chemical composition of the parent body. Rocks can physically break due to variety of reasons:

- **Temperature**: You might have observed that the rocks expand with the rise of temperature and contract on cooling like any other substance or material. During the day time the temperature rises and the nights are cold. Different rocks expand and contract differently because of varying mineralogical composition. Accordingly, as stresses develop differently within the rocks, the constituent minerals are affected differently. Dark coloured minerals absorb more heat than the light coloured minerals and hence may be more affected. Effects of temperature changes are more important in deserts and high mountains because the rocks are barren. The strain develops due to unequal expansion giving rise to cracks and fractures as shown in Fig. 5.2.

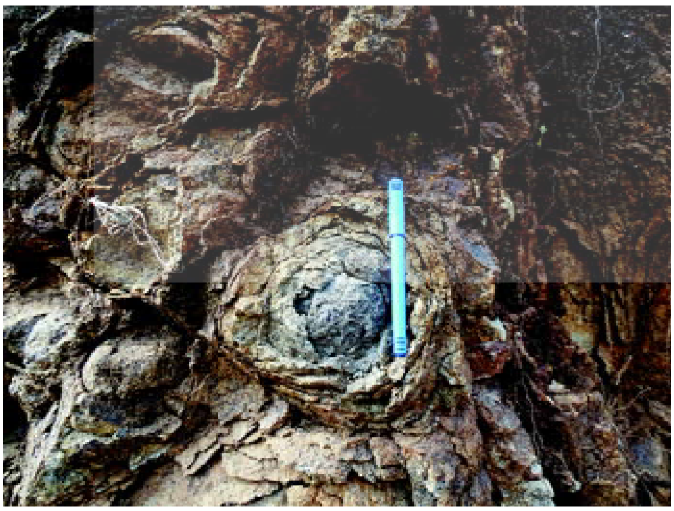
- **Pressure Release**: Rocks are brittle and they tend to break when overlying pressure is released due to unloading of overburden. The pressure released leads to the development of fractures and joints. Exfoliation is the physical weathering process in which large flat or curved sheets are detached from the outcrop. These sheets may look like the layers of peeled onion. The projections and corners are affected to the maximum. The hills become dome shaped and boulders become rounded as shown in Figs. 5.3a and b.

- **Abrasion:** It is an important process of physical weathering. This happens when small particles of rock carried by wind, water or ice collide with larger rocks. When rock particles collide with one another or a stable rock mass, it leads to grinding on their surfaces. Blowing wind and running water are usually laden with suspended particles that can abrade any surface they encounter. Fig. 5.4 shows an example of effect of abrasion.

Fig. 5.2: A granite boulder of ~5m height, displaying fracture developed due to excessive temperature variation.



(a)



(b)

Fig. 5.3: a) Diagram showing exfoliated boulders; and b) Exfoliation in basaltic rocks, notice the curved layers resembling a peel of onion. (Photo credit: Dr. Nishi Rani)

Fig. 5.4: Effect of abrasion leads to the outcrops with unusual shapes as shown here, i.e. Deccan basalt near Manmad, Maharashtra.

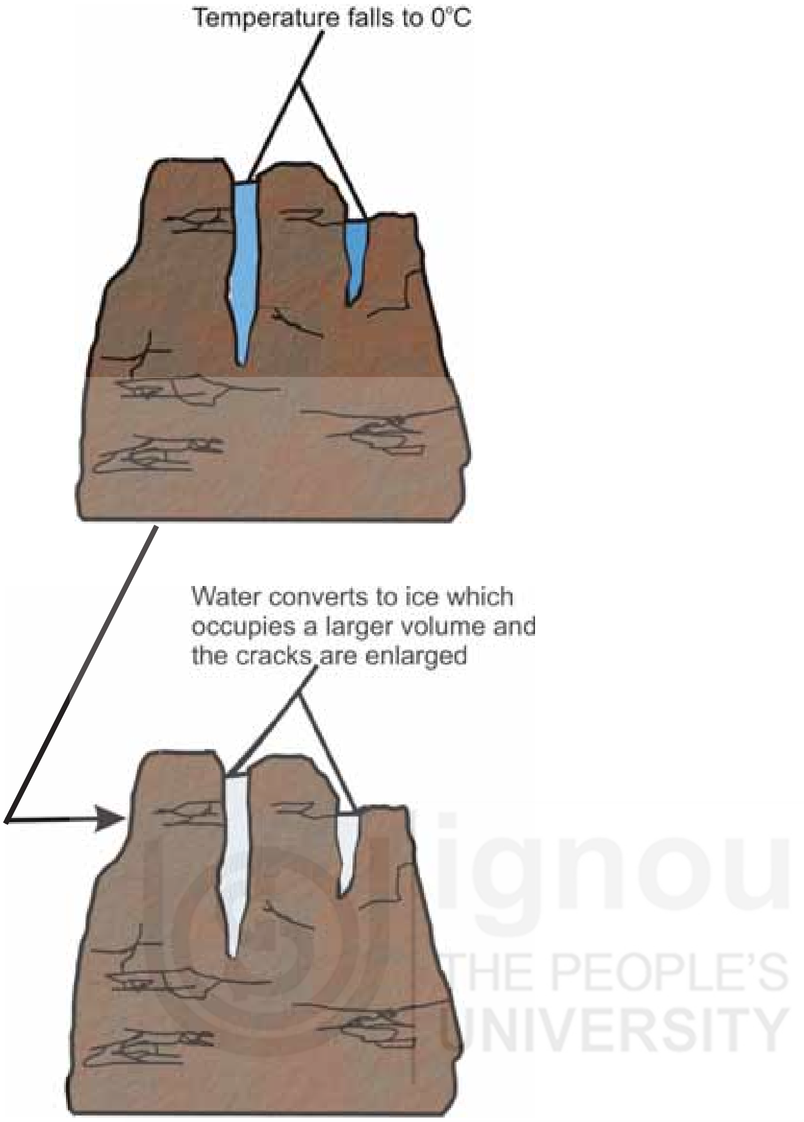
- **Freeze-Thaw:** Joints and cracks in the rocks play an important role in the frost action. Frost wedging is an important phenomenon where water episodically freezes and thaws, as in temperate climate and mountainous regions. **Frost wedging** is an efficient mechanism for widening cracks in rocks. The breakage results from expansion of the freezing water. During the day, water enters the cracks and joints, and at night, when temperature falls below 0°C, it freezes.

  On freezing its volume increases by $1/10^{th}$ of the original. By this process the rocks break and the cracks widen. As water freezes, it expands, exerting an outward force strong enough to wedge open a crack and split a rock as shown in Figs. 5.5a and b. The process is followed further and finally results in breaking of rocks into smaller pieces.

- **Frost Heaving** is the slipping of the boulders on the sloping surface. During the day water flows below the boulder. In the night it freezes and lifts the boulder a little due to increase of volume of frozen film of water. The next day when ice below melts, the boulder moves little further down the slope under the influence of action of gravity. After a period it reaches down the slope covering considerable distance as shown in Figs. 5.6a and b.

- **Hydraulic Action**: On rocky shorelines, the powerful force of breaking waves forces water into cracks and fractures in the rocks. Wave action widens the crack and hydraulic action damages cliffs and other types of coastal outcrops (Fig. 5.7).

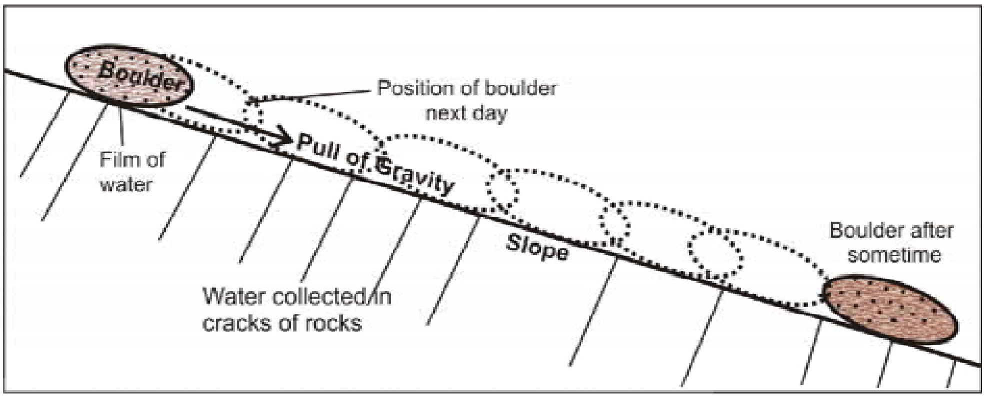
- **Action of Gravity**: It is quite important as it exposes fresh surface of rocks for weathering agents. Weathered rock material falls downwards under the action of gravity. **Rock slide** or **landslide** is the falling of the rock and weathered material downwards under the action of gravity.



(a)

(b)

Fig. 5.5: a) Sketch of disintegration of rock by frost action; and b) Effect of frost wedging on rock.



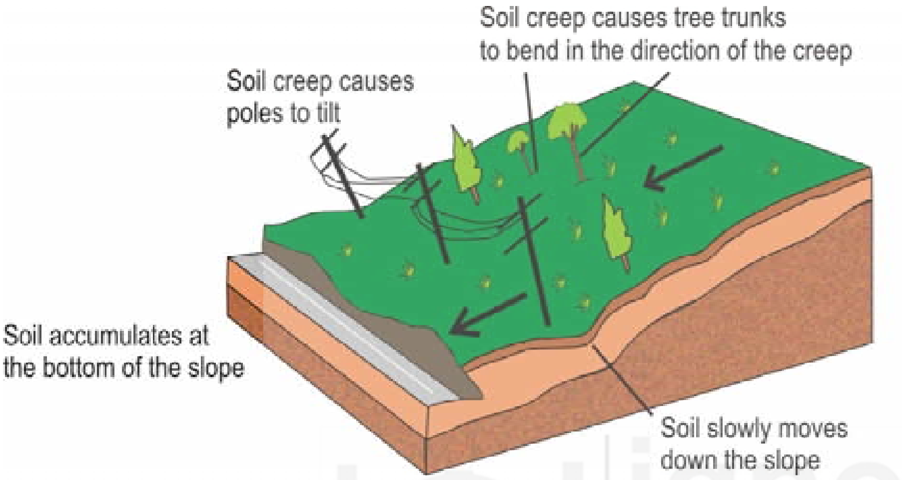
(a)

(b)

Fig. 5.6: a) Boulders slip due to melting of under ice; and b) Frost heaving example from Kashmir valley.

Fig. 5.7: Hydraulic action at rocky shoreline.

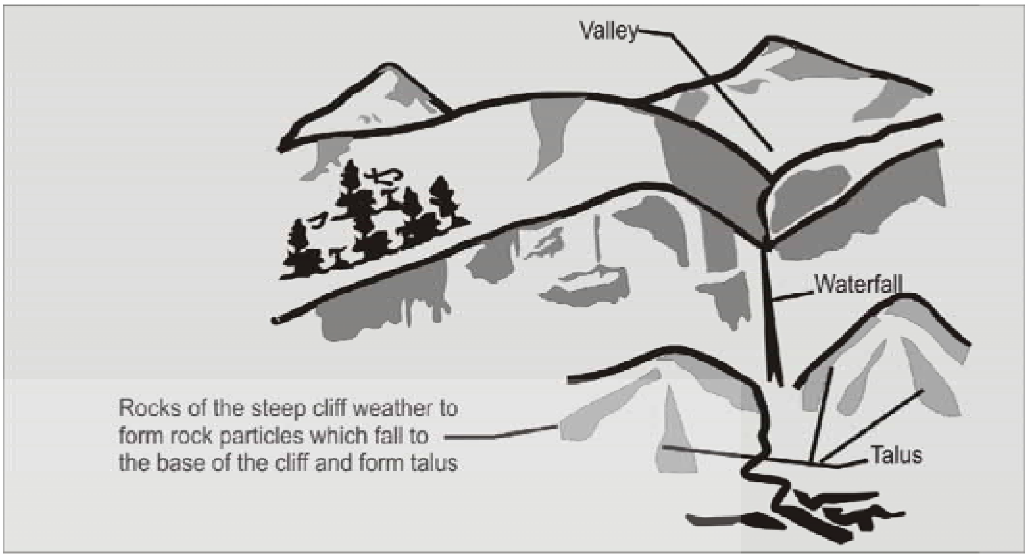
Creep involves the slow movement of weathered products downwards under the action of gravity as shown in Figs. 5.8a and b. The dislodged broken material obtained on weathering of rocks from a hill or cliff, fall under the action of gravity to the base of the hill top. It forms a conical feature which is broad at the base and tapers upwards and is called **talus** as shown in Figs. 5.9a and b. **Scree** is the mass of varying sizes and shapes of rock fragments which constitutes talus. We shall read about these features again while discussing mass wasting.



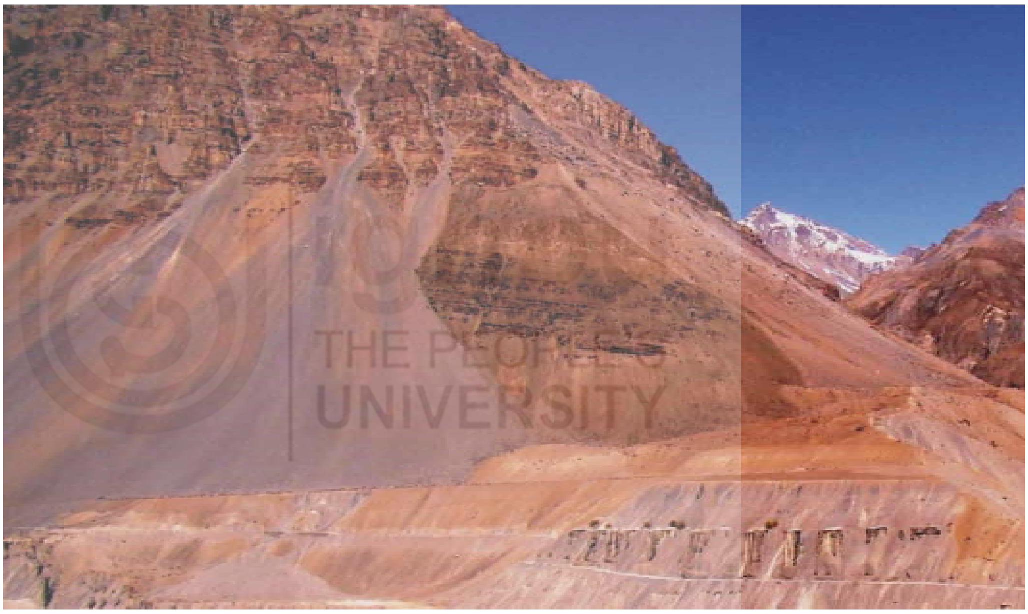
(a)

(b)

Fig. 5.8: a) Box diagram showing creep; and b) Field photograph depicting creep. Notice the bulge in the trunk in the direction of creep.
(Photo credit: Dr. Piyoosh Rautela)



(a)



(b)

Fig. 5.9: a) Sketch of the conical shaped talus; and (b) Conical shaped feature at the base of hill is talus which is composed of loose material called scree, Ladakh Himalaya.

5.3.3 Chemical Weathering

You have already been introduced to chemical weathering earlier in this section. It occurs when minerals react with air and water. In these chemical reactions, some minerals dissolve while others combine with water and atmospheric components such as oxygen and carbon dioxide to form new minerals. Chemical weathering has a special place in weathering processes as water along with other chemicals and dissolved gases may enter even in thin cracks produced by physical weathering or along bedding and joint planes. With time these cracks and joints are widened for more percolation along them leading to faster chemical weathering. In the chemical weathering, decomposition takes place by bonding with and removal of cations from solid mineral surface. Water plays an important role and is highly effective in dissolving many substances. All the chemical processes involve increase in volume. These result in development of stresses and strains in the rock and cause the rocks to crumble.

Chemical weathering involves following reactions:

- **Dissolution**: It is a chemical weathering reaction in which carbonic acid dissolves minerals like calcite, found in limestone (a common sedimentary rock). Water is very good solvent and dissolves many minerals. Limestone, dolomite, common salt and gypsum are dissolved in water. As you have read earlier, water reacts with CO_2 and forms carbonic acid, which is a weak acid but dissolves limestone quite rapidly.

$$\underset{\text{water}}{H_2O}+\underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

$$\underset{\text{limestone insoluble}}{CaCO_3}+H_2CO_3 \longrightarrow \underset{\text{bicarbonate soluble}}{Ca(HCO_3)_2}$$

  You have learnt that rocks are aggregates of minerals. If one mineral of the rock is dissolved even slightly, the adhesion of minerals is loosened and the rock tends to crumble.

- **Carbonation**: It is chemical union of a mineral with CO_2 to form carbonate. Carbonate reacts with water forming bicarbonate which is in dissolved state. Granite is the most commonly occurring rock on Earth and is weathered in the same way. Its feldspar changes to kaolin. This process is called as **kaolinisation**.

$$\underset{\text{feldspar}}{4NaAlSi_3O_8}+\underset{\text{carbonic acid}}{4H_2CO_3}+18H_2O \longrightarrow \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_8} + \underset{\text{sodium ion}}{4Na^{+}}+4HCO_3 + 8H_4SiO_4$$

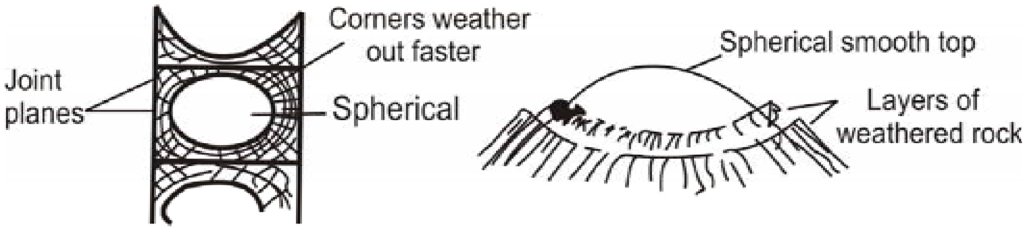
- **Oxidation**: It involves the loss of an electron from a cation in a crystal. The reaction involves chemical union with oxygen. Readily oxidised elements include iron, sulphur and chromium. Pyrite (FeS_2) on oxidation gives rise to limonite ($Fe_2O_3.nH_2O$) and free sulphur. This sulphur is mixed up with water to form sulphuric acid (H_2SO_4). It is strong acid and brings about rapid decomposition. The electrons lost by iron are gained by oxygen atoms in a process called oxidation.

$$\underset{\text{pyrite}}{FeS_2}+O_2 \longrightarrow \underset{\text{ilmenite}}{Fe_2O.nH_2O}+\underset{\text{sulphur}}{S}$$

- **Hydration**: This reaction involves the chemical union with water. For example mineral anhydrite may be converted to gypsum.

$$\underset{\text{anhydrite}}{CaSO_2}+2H_2O \longrightarrow \underset{\text{gypsum}}{CaSO_4.H_2O}$$

Spheroidal weathering: It is the result of chemical weathering. Let us discuss how it takes place. When water containing dissolved CO_2 enters a rock mass through joints and fractures, a chemical reaction takes place and there is increase in volume. Initially, corners and edges of the rock fragments are attacked giving it rounded or spheroidal appearance. Gradually, there is peeling away of layers like those of onion as shown in Fig. 5.10a and b.



(a)

(b)

(c)

Fig 5.10: a) In spheroidal weathering, the carbon dioxide rich solutions move along the joints and dissolve the rock corners and edges and deposit the weathered products in the cracks; b) Field photograph showing spheroidal weathering; inset on the upper left corner shows spherical surface; and c) Weathering rinds; notice the fresh rock in the centre.

It is important for you to distinguish between the process of exfoliation and spheroidal weathering. **Exfoliation** is a process of flaking or stripping of a rock body which occurs mainly due to physical/mechanical weathering and is product when concentric folia are developed. **Spheroidal weathering** refers to peeling of small rock bodies into onion-like layers produced mainly by chemical weathering. The term **weathering rind** is used for a discoloured, chemically altered, outer zone or layer of a discrete rock body formed by the processes of weathering. The inner boundary of a weathering rind roughly parallels the outer surface of the rock fragment in which it has developed as you can see in Fig. 5.10c.

5.3.4 Biological Weathering

You have already been introduced to biological weathering. It is the product of organisms causing weathering that is physical and chemical in character or a combination of the two. The types of organisms that can cause weathering range from bacteria in soil and rock, to plants, to animals. Biological weathering can take place by the processes listed below, let us discuss about them:

- **Movement and mixing of materials**: You might have observed burrows on shores created by burrowing organisms (Fig. 5.11a). These burrowing organisms cause mixing in the soil by their movements also known as **pedoturbation**. This movement exposes fresh surfaces to weathering processes found at distinct depths below the surface that are attacked by chemical weathering.
- **Simple breaking of particles**: Rocks can also be fractured as a result of burrowing by animals or the pressure from growing roots, known as **root wedging** (Fig. 5.11b). You might have observed the roots of trees penetrating in the cracks and joints of the hard rocks. Roots penetrate in the cracks or joints, widening and breaking them. Quarrying of material by man may also be considered as one of the factors responsible for mechanical weathering.
- **Production of carbon dioxide by animal respiration or organic decay**: You have read that during the process of respiration plants release carbon dioxide. Now let us analyse the role of released carbon dioxide in weathering processes. You have learnt earlier in this unit that carbon dioxide increases the acidity of water, which attacks and dissolves minerals in rocks by the process of chemical weathering, viz. hydrolysis, dissolution and oxidation.

  Apart from this plants and animals decay in the absence of oxygen and produce an organic product known as humus and humic acid, fulvic acid. These organic acids, though weak also help in decomposition by process of biological weathering. Weathering processes performed by microbes is studied in a branch called **Geomicrobiology.**
- **Changes in the moisture content of soils**: Organisms influence the moisture content of soils and enhance weathering. You might have observed that shade from leaves and stems, the presence of root masses and organic material increase soil moisture. Higher moisture content enhances physical and chemical weathering processes.

(a)

(b)

Fig. 5.11: Field photograph showing: a) Burrows created by sand crabs cause mixing of soil by pedoturbation (Photo credit: Dr. Benidhar Deshmukh); **and b) Roots penetrating the granite boulder. Note the physical pressure exerted by the growing roots.**

- **Bacteria, Fungi, lichens and moss**: You might be surprised to learn that fungi, lichens and bacteria also play a great role in the disintegration and decomposition of rocks. A group of bacteria has power of forming HNO_3 which is a strong acid. It attacks and alters several minerals. Fungi, lichens and bacteria during the course of their metabolic activity produce organic acids which attack minerals and cause biological weathering as shown in Fig. 5.12a.

Fig. 5.12a: Biological weathering by fungi, lichens and moss. (Photo credit: Sainandini Mishra)

5.3.5 Relative Stability of Minerals

Rates of chemical weathering vary from one mineral to other. Now, you must be curious to know that why do chemical weathering rates vary among different minerals. You can learn from Fig. 5.12b that olivine, i.e. $(FeMg)_2SiO_4$ and calcic plagioclase $Ca_2Al_2Si_2O_8$ are the least stable mineral and fastest to weather while quartz, i.e. SiO_2 is most stable mineral in the series. The relative chemical stabilities of various minerals can be used to determine the intensity of weathering. The ranking of mineral stability is referred to as **Goldich stability series**.

5.4 Productos of Weathering

You have read about processes, types and factors affecting weathering. Before discussing about the products of weathering let us understand why does a rock weather.

Weathering occurs because the conditions at Earth's surface are different from those prevailing during the formation of most igneous and metamorphic rocks and minerals. Thus, when these rocks are exposed to the surficial temperature and pressure conditions they become unstable and tend to weather.

The product of weathering is the formation of new minerals. The decomposition and disintegration of rocks results in the following products:

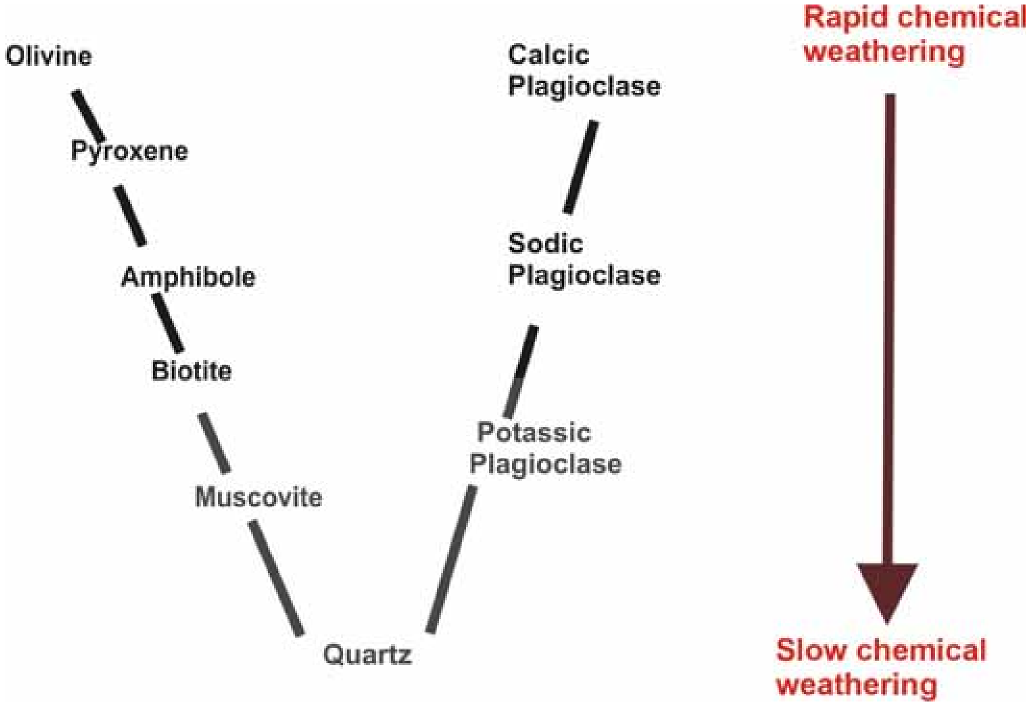


Fig. 5.12b: Relative stability of common minerals.

- **Drifted or transported soils** are the weathered products. They are transported by various agents and deposited at suitable places depending on transporting medium.
- **Residual soils** are the remainder weathered products which are left *in situ* (at the original place). Soluble constituents of the weathered products may be dissolved and carried away in solution.
- **Eluvium** is deposit of loose weathered material which has been transported and deposited by wind.
- **Alluvium** is deposit of loose weathered material which has been transported and then deposited by flowing water.
- **Diluvium** are masses of waste left after glacial action or fluvio-glacial action and are the deposits of glacial age.
- **Regolith** is loose incoherent material of almost any origin. It lies on bed rock and consists of rock wastes of all sorts. Regolith can be either transported or *in situ*.
- Watch this video to know about products of weathering

  Soil : Product of weathering

  Link: https://www.youtube.com/watch?v=y-SENU4Abv8

You have learnt in this section about the physical, chemical and biological weathering processes. In the next section we will discuss in detail about the products of weathering, i.e. soil. Before going to the next section spend about five minutes to check your progress.

SAQ 1

a) Define weathering.

b) Differentiate between exfoliation and spheroidal weathering.

c) How is CO_2 important in chemical weathering?

d) What is the difference between drifted and residual soil?

5.5 SOIL

You have read that disintegration and decomposition of rocks takes place and in the process gives rise to weathering residues which may be transported or deposited *in situ*. Soil is an important resource that provides food for world's population. The word *'Soil'* has come from Latin word '*Solum*' which means 'the ground'. Geologists use the term soil to describe layers of material derived from weathering of rocks. Soil material undergoes additions of new materials, losses of original materials, and modification through physical and chemical reactions. Organic matter called **humus** is an important component of soil. It consists of the remains and waste products of the many organisms that live in soil.

Soil may be defined as the naturally deposited unconsolidated layers or soil horizons of variable thicknesses covering the Earth's surface. Their chemical, physical, biological and mineralogical properties are capable of supporting plant growth. Soil is a product of decomposition and chemical and physical weathering forces acting upon native rocks, vegetation, and animal matter over a long period of time.

Pedosphere is the outermost layer/ skin of the Earth that exists at the interface of atmosphere, lithosphere, hydrosphere and biosphere as shown in Fig. 5.13. The dynamic interaction between the atmosphere (air in and above the soil), biosphere (living organisms), lithosphere (unconsolidated regolith and consolidated bedrock) and the hydrosphere (water in, on and below the soil) gives rise to pedosphere. **Pedology** is the science dealing with study of soil.

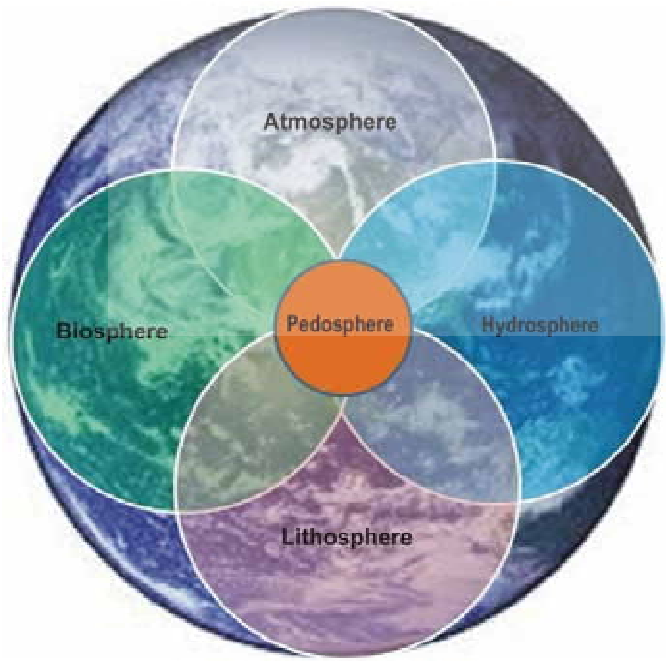


Fig. 5.13: Pedosphere is thin skin of soil on Earth's surface that exists at the interface of atmosphere, lithosphere, hydrosphere and biosphere.

5.5.1 Factors and Processes of Soil Formation

Let us familiarise with the factors responsible for the formation and development of soil.

- **Parent material**: This includes the solubility and stability of constituent minerals, the sizes of grains and the patterns of fragmentation such as joints and cleavage in bedrock.
- **Climate**: It includes rainfall, temperature humidity, aridity and wind and their seasonal patterns of variation.
- **Biota**: The activity of living plants and animals and the decomposition of their organic wastes and residue have profound influence on soil formation as well as soil profile development.
- **Topography***:* It influences soil formation primarily through its relation with water temperature, soil erosion and climate. Do you think whether the steep or gentle slope and the rocks on hills facing the Sun or not will have any difference in the process of soil formation? We have already discussed earlier about the effect of topography. Temperature can accelerate or retard weathering process.
- **Time***:* Soil forming processes take time to show their effects.

We have discussed the factors involved in the transformation of a parent rock to a soil material. This was initially put forward by Dokuchaev in 1889 in the form of equation given below:

S = f (Cl, O, R, P, T, ……..)

where,

S = Soil formation

f = function

Cl = Climate

O = Organisms/ biota,

R = Relief/topography

P = Parent material

T = Time

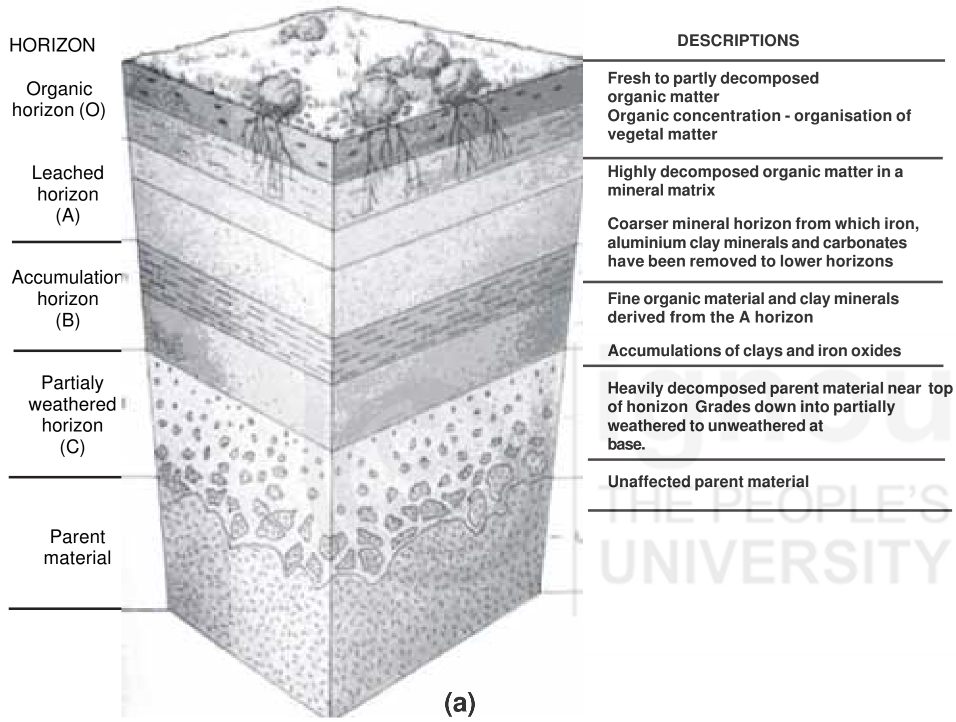
Jenny in 1941 grouped climate and organism/biota as **active factors** and relief/topography, parent material and time as **passive factors**.

All the above factors are important and play their role and their collective effect is reflected in the type of soil produced.

As the soil ages and matures, the materials are added or removed/ subtracted from it. The addition of humus, for instance, provides a source of nutrients and encourages further plant growth. Subtraction causes rainwater to remove material as it percolates down through the ground. This causes soil to undergo **transformations**. Soil transformations mostly involve chemical weathering of feldspar and other minerals to form clays. **Translocations** are lateral and vertical movements of materials within the developing soil. Water acts as an important agent of translocation and aids transportation of dissolved salts. Water selectively removes some materials as it percolates down through the soil after rainfall. This process is called **leaching**. It is the transfer in solution of organic matter and other elements from upper to lower soil levels.

5.5.2 Soil Profile

You might have observed the horizontally layered soil horizons while travelling in a hilly terrain or along a road cutting. The vertical section through the soil – subsoil – bedrock sequence is termed as **soil profile**. The composition and appearance of a soil is reflected through their nature. You know that soil is the mixture of mineral matter (detritus) and organic matter (humus) that lies between the Earth's surface and unweathered bedrock or parent rock. A simple soil profile may be broadly divided into the following horizons as shown in Fig. 5.14a.



(a)

(b)

Fig. 5.14: a) Soil profile showing different horizons; and b) Field photograph showing soil profile in a granitic terrain.

'O' horizon is the topmost layer of soil profile. It is composed of accumulated organic matter and the concentration of humus tends to make it darker near the surface.

'A' horizon is present beneath the 'O' horizon, and is also known as **topsoil**. It has usually sufficient mineral matter, humus and organic material to support vegetation and chemical weathering is active. The upper part of the 'A' horizon contains most of the organic matter. The lower part of the 'A' horizon has less organic matter and has suffered maximum leaching. It is also called **leached zone** or **zone of eluviation**.

'B' horizon is present below the 'A' horizon and is comparatively less weathered. Roots of larger plants reach this horizon. 'B' horizon is largely enriched in clay and/or iron and aluminium hydroxides. This horizon is termed as **zone of accumulation** or **zone of illuviation**.

'C' horizon consists of slightly weathered bedrock grading into unweathered bedrock.

Bed rock or **substratum** is little or almost unweathered parent rock called as '**R**' **horizon (Fig. 5.14c)**.

5.5.3 Classification of Soils

There are different kinds of soils which are classified based on its genesis, texture and composition, as mentioned below. Let us discuss in detail about the classification of soil.

A) Genetic-On the basis of mode of formation

1. ***In situ* soils:** These are found at the place of formation. They are of two types:
   - **Residual type**: This type of soil has been formed at same place where it is found showing similar composition and connection with the parent rock below.
   - **Cumulose type**: It is formed by accumulation of organic matter. They are best formed in marshy conditions, e.g. peat.
2. **Transported/Drifted soils**: These are the soils which have been transported and deposited away from the parent body. These are of the following types:
   - **Colluvial** or **eluvial soil** is fragmental in nature, formed by gravity at the base of the hill.
   - **Alluvial soil** is fertile soil formed by riverine action.
   - **Glacial soil** is produced by glacial action.
   - **Aeolian soil** is formed by wind action producing sand, loess, etc.
   - **Lacustrine soil** is formed in the lakes and is generally rich in organic matter.
   - **Marine soil** is formed by sea action on coastal regions.
   - **Volcanic soil** is formed by weathering of products produced by volcanic action.

B) On the basis of texture and composition

- **Sandy soil**: It is sandy in nature, with very little clay material and is highly porous.
- **Loamy soil**: It comprises equal amount of sand and clay.
- **Clayey soil**: In this type of soil, clay minerals predominate.
- **Peat soil***:* It has very little clay and is mostly constituted of decomposed vegetal matter.
- **Podzol soil**: It is grey type of sandy subsoil with very little iron compounds and humus.
- **Lateritic soil***:* It is brownish in colour constituted of hydroxides of iron, aluminum and some oxides of manganese.

C) USDA Classification in Soil Taxonomy

In 1951 the Soil Survey Staff of the U.S. Department of Agriculture began a cooperative effort with soil scientists in US and other countries to develop new comprehensive classification scheme. This has been in use in US along with other 55 nations since 1965. Each of the world's soils is assigned to one of 12 types, largely on the bases of soil properties. Presently, the soil scientists in the world commonly follow the USDA classification (Table 5.1).

5.5.4 Soils of India

Geographical distribution of commonly recognised soil types of India is shown in Fig. 5.15. Characteristic features and regional distribution of common Indian soils have been tabulated in Table 5.2.

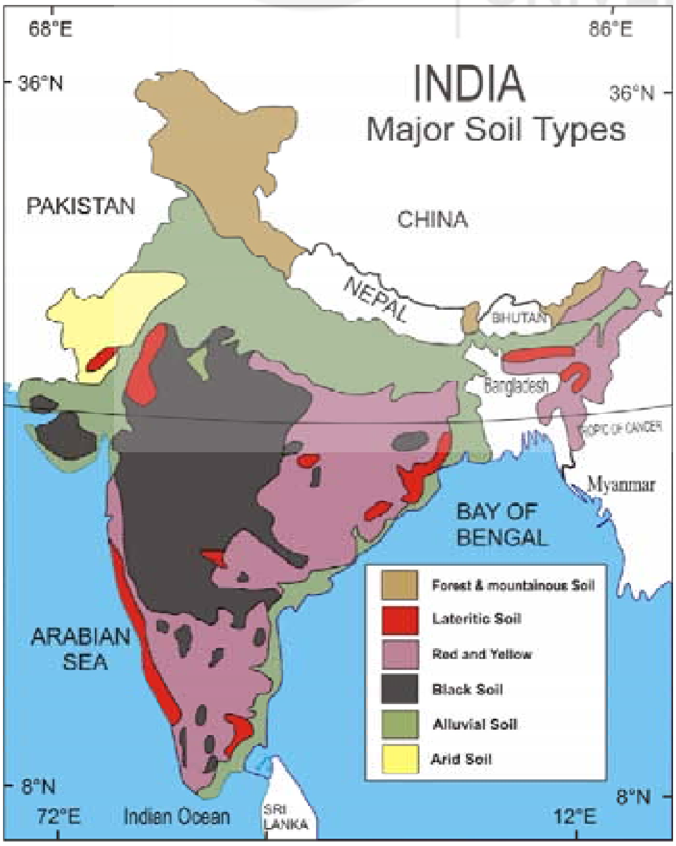


Fig. 5.15: Major soil types of India and their geographical distribution.

Table 5.1: USDA classification: Twelve recognised soil types

Sl. No.	Soil Type	Description
1.	Alfisols	Soils of humid and subhumid climate with a subsurface horizon of clay accumulation, common in forested areas
2.	Andisols	Soils formed from volcanic ash and contain compounds rich in organic matter and aluminium
3.	Aridisols	Soils formed in dry climates, low in organic matter and often having subsurface horizons with soil accumulation
4.	Entisols	Soils lacking subsurface horizons because the parent material accumulated recently
5.	Gelisols	Weakly weathered soils formed in areas that have very cold or permafrost conditions
6.	Histosols	Soils with a thick upper layer, very rich in organic matter and contain relatively little mineral material
7.	Inceptisols	Soils with weakly developed subsurface horizons because the soil is young or the climate does not promote rapid weathering
8.	Mollisols	Soils of semiarid and subhumid mid-latitude grasslands that have a dark, organic-rich A-horizon
9.	Oxisols	Very old, highly leached soils with subsurface accumulations of iron and aluminium oxides, commonly found in humid tropical environments
10.	Spodosols	Soils formed in cold, moist climates that have a well-developed B-horizon with accumulation of aluminium and iron oxides, formed under pine vegetation in sandy parent material
11.	Ultisols	Soils with a subsurface horizon of clay accumulation, highly leached, commonly found in humid tropical and subtropical climates
12.	Vertisols	Soils that develop deep wide cracks when dry, due to high clay content and not highly leached

Table 5.2: Characteristic features and regional distribution of common Indian soils

Type	Main features	Distribution
Alluvial Soil	It is of following two types: **Khaddar** – newer deposit, light in colour, siliceous in composition. **Bhagar** – the older alluvium, dark in colour, composed of lime nodules and has clayey composition	Ganga and Brahmaputra river valleys; deltas of Godavari and Krishna; plains of Uttar Pradesh, Uttarakhand, Punjab, Haryana, West Bengal and Bihar; Coastal strip of peninsular India
Desert Soil	Derived in the dry climatic conditions with high temperature, faster evaporation. Soil lacks humus and moisture. Contains high percentage of soluble salts; rich enough in phosphate though poor in nitrogen	Rajasthan, northern Gujarat and southern Punjab
Black Soil/ Regur Soil	Black Soil/Regur Soil is derived from basalts of Deccan trap, black in colour due to presence of titanium, iron. Consists of calcium and magnesium carbonates; high quantities of iron, aluminium, lime and magnesia and poor percentage of phosphate, nitrogen and organic matter	Maharashtra and Malwa plateaus, Kathiawar peninsula, Telengana, Rayalasema region of Andhra Pradesh and northern part of Karnataka
Mixed Red and Black Soil	Poor in lime, potash and iron oxide. They are thin and infertile in uplands but are fertile in the valleys and plains	Parts of Peninsular India
Red and Yellow Soil	Mainly formed due to decomposition of ancient crystalline rocks like granites and gneisses. Poor in nitrogen, phosphorus, humus but rich in potash. Siliceous and aluminous in nature. Clay fraction of the red soils generally consists of kaolinitic minerals	Parts of Orissa, Chhattisgarh, eastern parts of Deccan plateau, southern states of Kerala, Tamil Nadu and Karnataka and Chhota Nagpur plateau (Jharkhand)

Type	Main features	Distribution
Lateritic Soil	Lateritic Soil is the result of intense leaching due to heavy rain. Composed mainly of hydrated oxides of iron and aluminum; loss of silica from the soil profile	Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, and hilly areas of Odisha and Assam
Mountain soil	Coarse grained, loamy and silty. It is acidic with low humus content	Hilly and mountainous areas, coniferous forest belt of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Sikkim

In this section, we have discussed about soil profile, factors affecting soil formation, classification of soil and also geographical distribution and characteristics of soils of India. In the next section, we would read about mass wasting.

5.6 MASS WASTING

You would have observed slopes of the hills in the mountainous terrains exposed at the cuttings along the railway tracks and roads. You would have also realised that how important it is for hill slopes to be stable to avoid any hazard or mishaps. Gently sloping hill sides and cuttings are generally safe and stable whereas those with steep gradient (slope) are often unstable facilitating **landslides** synonymous to mass wasting. Mass wasting is a set of processes that move weathered rock, sediment and soil down a slope under the action of gravity. Recollect that you have read about this earlier in this unit. **Mass wasting** may be defined as the movement of rock and soil down a slope under the influence of gravity. It includes all the processes by which weathered and unweathered Earth materials move downslope under the influence of gravity. They may also rest at foothills to form talus. Once these materials reach stream channels and rivers, they are efficiently transported across the continents all the way to ocean.

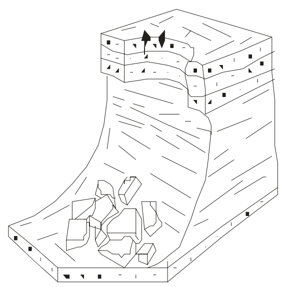
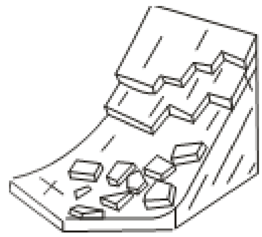
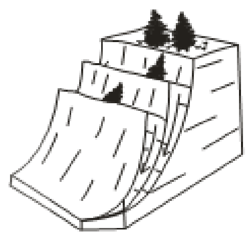
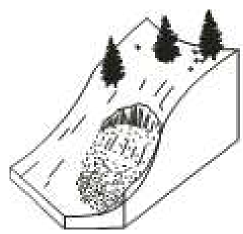
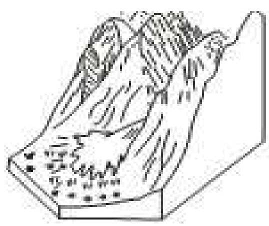
- Watch this video to know about Landslide its types and causes
  Link: https://www.youtu.be/c173TU0hjQk

5.6.1 Types of Mass Wasting

Mass wasting is classified on the basis of rate of movement and type of material which slides down the slope as shown in Fig. 5.16. It is more generalised term and includes almost all types of slides and flow. Some of the important types and processes involved in mass wasting are given in Table 5.3.

Rockfall and debris fall, rockslide and debris slide and slump are generally small-scale processes seen on cliffs and steep slopes where rock fragments both small and large, fall and slide downward. Both mud and debris flows result from heavy rains in areas with an abundance of unconsolidated sediments. As we have discussed earlier, soil creep is the slow,

Table 5.3: Types of Mass wasting

Process	Characteristics	Fig. 5.16
Rockfall and debris fall	Rockfall occur when an accumulation of consolidated rock fragments are dislodged and falls through the air or free falls vertically under the influence of gravity, rapidly from a cliff or by leaps down a slope. Debris falls are similar to rockfall except that they involve a mixture of soil, regolith, vegetation and rocks. They are commonly referred to as **landslide** (see Fig.5.16a).	 **(a) Rockfall**
Rockslide and debris slide	Rockslide results when a slope fails along the plane of weakness (see Fig.5.16b). Debris slide is characterised by unconsolidated rock, debris and regolith (see Fig. 5.16b). While rock slide lacks typical debris; usually, it consists of blocks of rock in a chaotic mass. The rapid sliding descent of a rock mass down a slope commonly forms heaps and is confused irregular masses of rubble at the base of the mountain or hill.	 **(b) Rockslide**
Slump	Slump is the sudden downward slipping of rock block or regolith along a curved surface of rupture. The movement creates a scarp facing downslope (see Fig. 5.16c). Slump is particularly common in places where slopes are steep and cliff such as by erosion at their bases as along stream banks and coastal cliffs.	 **(c) Slump**
Debris flow	The rapid downslope movement of debris flow carrying clasts ranging in size from clay particles to boulders and often a large amount of woody debris. It develops when the water accumulates rapidly in the ground during heavy rainfall or snow melt. It commonly forms an apron like or tongue like area, with a irregular surface (see Fig. 5.16d).	 **(d) Debris flow**
Mudflow	Mudflow is a debris flow which is principally composed of mud and is saturated with water. It can travel several tens of kilometers from their source (see Fig. 5.16e).	 **(e) Mudflow**

down-slope migration of soil under the influence of gravity. Curved tree trunks, cracks in slopes and tilted power poles are indicators of creep as shown in Figs. 5.8a-b, 5.16 a-e and Fig. 5.17.

Fig. 5.17: Field photographs of: a) Rockfall and debris fall; b) Rock slide; c) Debris Slide; d) Slump; e) Mudflow; and f) Soil creep. (Photo credit: a,b d,e of Dr. Piyoosh Rautela, c) Dr. Rahul Varma)

Avalanches, lahars and submarine landslides are special types of mass wasting processes. **Avalanche** is a fast-flowing, fluidised mass of snow, ice, air and occasionally some regolith that cascades down a mountain side due to collapse of a snowfield. **Solifluction** is a type of creep that occurs in icy regions, when the surface layers of soil alternately freeze and thaws causing the soil to ooze downhill, carrying broken rocks and other debris with it. A

lahar is a mudflow composed of **pyroclastic ash** (fine grained material derived during volcanic eruption) and water that flows down the slope of a volcano. **Submarine landslides** are vast debris flows that take place beneath the seas and oceans and can take away an island in a single event.

5.6.2 Factors Responsible for Mass Wasting

Now, you would be familiarised with the factors responsible for mass wasting. The factors which govern the possibility of mass wasting and determine the safety and stability of hill slopes, cuttings and highways, are as mentioned below:

- **Nature of rocks occurring along the slope or cutting walls**: You might have observed that the hill slopes with loose unconsolidated material is unstable as compared to massive hard and compact rocks (like granite, gabbro, sandstone, marble, gneiss, quartzite). The stability of slope varies in both the cases.
- **Geological structure of the country rocks**: It is well recognised that the presence of fault, shear zones and other planes of weakness effectively reduce the strength of any rock.
- **Prevailing ground water conditions along the slope or cutting wall**: You might be aware of the lubricating action of water. The presence of water increases landslides thus, affecting stability of the slopes. Hence, ground water conditions and water table of the area should be carefully observed to ascertain stability of slopes and highways. Water increases mobility of the materials causing landslides appreciably during the rainy season.

5.6.3 Causes of Mass Wasting

The causes of mass wasting are as follows:

- earthquake shocks
- blasting for quarrying or construction, etc.
- absence of surface drainage, increasing water percolation and ultimate sliding
- presence of more joints and cracks in the rocks
- steepening of slope for various purposes
- slope saturated with water because of bad drainage
- increased height of slope because of quarrying, mining, etc.
- extra load of dams, buildings, townships, etc. placed on slopes.

Mass wasting landslide can be hazardous if humans (or their buildings and roads) are in the way. Anthropogenic activities may reduce the stability of regolith and rock, leading to mass wasting.

- Watch this video to know about mitigation measures
  Landslides: Mitigation measures
  Link: https://www.youtu.be/BcUVeL43x7c

You have learnt in last two sections about the mass wasting. In the next section we will briefly discuss about erosion. Before going to the next section spend about five minutes to check your progress.

SAQ 2

a) Which soil covers the maximum area in Maharashtra and Gujarat?

b) What is soil creep?

c) List the causes of mass wasting.

d) What is the difference between illuviation and eluviation?

5.7 EROSION

We have read that weathering and erosion are closely related, in section 5.3. In weathering, disintegration and decomposition of rocks takes place. The weathered material is removed by different external geological agents like wind, river, glacier, underground water, etc. This process of weathering followed by the removal of weathered material is known as erosion.

Thus;

Weathering + Transportation = Erosion

Erosion exposes fresh surface for the weathering and other agents to work upon the newly exposed surface. By the process of erosion original surface is lowered.

Denudation refers to the end result of **weathering and erosion**. Its ultimate effect results in the lowering of uplifted surfaces.

5.8 SUMMARY

The Earth is subjected to various forces which act externally and internally. Let us summarise what we have learnt in this unit:

- The external or exogenic geological processes comprise erosion, transportation and deposition of the eroded materials. The internal or endogenic geological processes include earthquakes, volcanoes and mountain building.
- Weathering refers to the natural processes of disintegration and decomposition of rocks. Physical, chemical and biological weathering may work in harmony to breakdown the rocks exposed on the Earth's crust.
- Four factors that control rates of weathering are: nature of parent rock; presence and absence of soil; climate and the length of exposure time.
- Physical weathering involves the mechanical breakdown of minerals and rocks by a variety of processes such as temperature, pressure release, abrasion, freeze-thaw, hydraulic action and action of gravity.
- Chemical weathering is generally more effective of the three types of weathering. It involves reactions like dissolution, carbonation, oxidation and hydration.
- Biological weathering is affected by factors like movement and mixing of materials by organisms, production of carbon dioxide by animal respiration or organic decay and changes in the moisture content of soils and presence of microorganisms.

- The products of weathering are transported soils and residual soils.
- Soils are admixture of disintegrated and decomposed organic material, which is capable of supporting vegetation. Different layers are reflected in the cross section of matured soil profile, each having its own peculiar characteristic.
- Soils can be classified based on texture and composition. The commonly followed USDA classification recognises twelve soil types.
- Mass wasting is broadly classified as rockfall and debris fall, rockslide and debris slide, slump, soil creep, debris flow and mudflow based on the rate of movement and type of material.

5.9 ACTIVITY

1. Now let us perform an experiment. Get cubes of common salt (NaCl) from market. Put them in a glass of water and shake for a few seconds. Then drain the water and observe the broken and dissolved corners of the pieces of salt and compare them with their original size and shape. Think about the changes you observe and what is this phenomenon?
2. Take few small iron nails. Wrap them in a moist paper and then in a plastic sheet. Place them in a closed container for two weeks. When you check them after two weeks you will find that the nails have undergone rusting. Can you explain the reason of rusting?

5.10 TERMINAL QUESTIONS

1. How is physical weathering different from chemical weathering?
2. Discuss the factors affecting weathering.
3. Draw a well labelled diagram showing different horizons of soil profile. Give a brief description of each horizon.
4. Define mass wasting. Also give their broad classification.

5.11 REFERENCES

- Fletcher, C. (2011) Physical Geology, The Science of Earth, John Wiley & Sons, 679p.

5.12 FURTHER/SUGGESTED READINGS

- Dutta, A.K. (2010) Introduction to Physical Geology, Kalyani Publishers, Ludhiana, 250p.
- Mahapatra, G.B. (2013) A Textbook of Geology, CBS Publishers, New Delhi, 366p.

5.13 ANSWERS

Self-Assessment Questions

1. a) Weathering refers to the natural processes of disintegration and decomposition of rocks. It includes activities whereby the rocks at or near the surface, break, decay or crumble.

b) Exfoliation takes place mainly by physical weathering whereas spheroidal weathering is produced by chemical processes.

c) Water is a good solvent. CO_2 forms carbonic acid when it reacts with water. Carbonates are rapidly dissolved in it.

$$H_2O + CO_2 \rightarrow \underset{\text{(carbonic acid)}}{H_2CO_3}$$

$$\underset{\text{(limestone-insoluble)}}{CaCO_3 + H_2CO_3} \rightarrow \underset{\text{bicarbonate (soluble)}}{Ca(HCO_3)_2}$$

d) Weathered material is transported by various agents and is deposited at suitable places depending on transporting medium giving rise to transported soils. On the other hand when the soluble constituents of the weathered products are dissolved and carried away in solution, the remainder that may be left *in situ* gives rise to residual soils.

2. a) Black soil.

b) Creep is a type of mass wasting. It is very slow movement under the action of gravity.

c) Causes of mass wasting are as follows:

- earthquake shocks
- blasting for quarrying or construction, *etc.*
- absence of surface drainage, increasing water perculation and sliding
- presence of more joints and cracks in the rocks
- steepening of slope for various purposes
- slope saturated with water because of bad drainage
- increased height of slope because of quarrying, mining, *etc.*
- extra load of dams, buildings, townships, etc. placed on slopes.

d) Eluviation occurs in the 'A' Horizon also known as the Zone of Leaching. It is the process of removal of materials from soil horizons. Illuviation occurs in the 'B' Horizon also known as the Zone of Accumulation. It is the deposition in an underlying soil layer of colloids, soluble salts, and mineral particles which have been leached out of an overlying soil layer.

Terminal Questions

1. Please refer to the subsections 5.3.2 and 5.3.3.
2. Please refer to the subsection 5.3.1.
3. Please refer to the subsection 5.5.2 and Fig. 5.14a.
4. Please refer to the section 5.6.

UNIT 6

GEOLOGICAL WORK OF RIVERS

Structure

6.1 INTRODUCTION

We have read about the types and mechanism of weathering processes in Unit 5 Rock Weathering. In the next three units of this block we will get acquainted with the work done by various geological agents sculpturing the Earth's surface, namely river, wind, underground water, glacier, ocean and the resulting landforms. Can you imagine that these processes started operating much before the life originated on Earth and will continue to do so? Let us explain this with the help of an interesting analogy. The feature or landscape which we see today is like a small clipping of a long film. You can describe plot of the entire film with the help of a short clip of the film. Similarly, a landscape feature you see today can help you to analyse and describe the processes acting on the Earth in the past.

Rivers are the dominant agents of erosion on our planet. As the river flows, it picks up weathered rock debris and carries it to the ocean. It does an enormous amount of work by eroding and transporting sediments and dissolved compounds and ions toward the ocean.

Let's now discuss the geological work carried by river in this unit.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define geological agents and their functions;
- ❖ list the stages of river, drainage systems and patterns;
- ❖ identify the types of sediment load and processes of transportation;
- ❖ explain types, processes and factors affecting fluvial erosion;
- ❖ discuss erosional landforms developed due to geological work of rivers; and
- ❖ describe depositional landforms formed by geological action of rivers.

6.2 WHAT ARE GEOLOGICAL AGENTS?

You have learnt that the dynamism of our planet Earth is the manifestation of exogenic (external) and endogenic (internal) processes in the previous block. The changes brought about by these processes are marked by the shaping of beautiful landscapes and landforms on Earth's surface. Certain geological/ geomorphic agents function to bring about gradational changes in landforms. **Geomorphic agent** is a geological agent that is able to alter the surface of our planet. It is powered by Sun, Earth's gravity and climatic parameters. These agents may be in any state of matter, e.g. solid like glaciers, liquid like rivers, lakes, underground waters and oceans or gas like winds or even the combination of these agents. Each geological agent functions in its own way developing characteristic erosional and depositional landforms.

Geomorphology is the branch of geology which deals with the systematic study of landforms and their interpretation which are the records of the past history of Earth.

Let us look at the three basic functions performed by these agents.

- **Erosion** as you have already learnt, is the breaking down or disintegration of rocks due to the physical forces associated with the natural agencies, followed by removal of the dislodged rock fragments and particles away from the site. Weathering greatly assists in the erosion of rocks and other deposited materials. The word **erosion** has been derived from a Latin word, 'erodere' which means to gnaw. It is a dynamic process which involves the removal of geomaterials from the rocks and other deposited materials.

- **Transportation** is the process of removal of dislodged and disengaged materials from the site of their formation by various geological agents.

- **Deposition** is a process of accumulation and dropping down of the transported materials, due to the loss of the capacity of that particular agent to bear the load further.

Now in this unit we will read more about erosional, transportational and depositional processes and the resulting landforms from the geological works done by river.

6.3 TYPES AND STAGES OF RIVER

Rivers are the bodies of running water in their natural channels carved by themselves on the surface of the Earth. The term **running water** applies to any surface water that moves from higher to lower areas in response to gravity. Small rivers are often called as **streams**. A **river system** is a network of connecting channels or streams through which water precipitated on the surface, is collected and funnelled back to the ocean.

Thalweg is the line running along the channel and connecting deepest part of a stream. It denotes a line of fastest flow of river. **River/ stream capacity** expresses the total potential weight of sediment load which varies with particle size. **River discharge** is the amount of water passing a given point during a specific interval of time. It is usually measured in cubic meters per second. **River/ stream competence** refers to the weight or size of the largest particles that can possibly move along the bed. **Stream Gradient** is the steepness or slope over a specific length of a stream and determines its velocity.

A good way to appreciate the important role played by streams in transporting water and sediment downslope is to sit beside it and closely observe it.

Let us read about the sources of water in rivers, which include:

- run off during precipitation;
- seepage and springs from underground; and
- melting of snow and glaciers.

Runoff includes the surface water flow, both over the slopes of the land and in stream channels. Before studying about the geological work of rivers let us first discuss about the characteristics of rivers such as their types and stages.

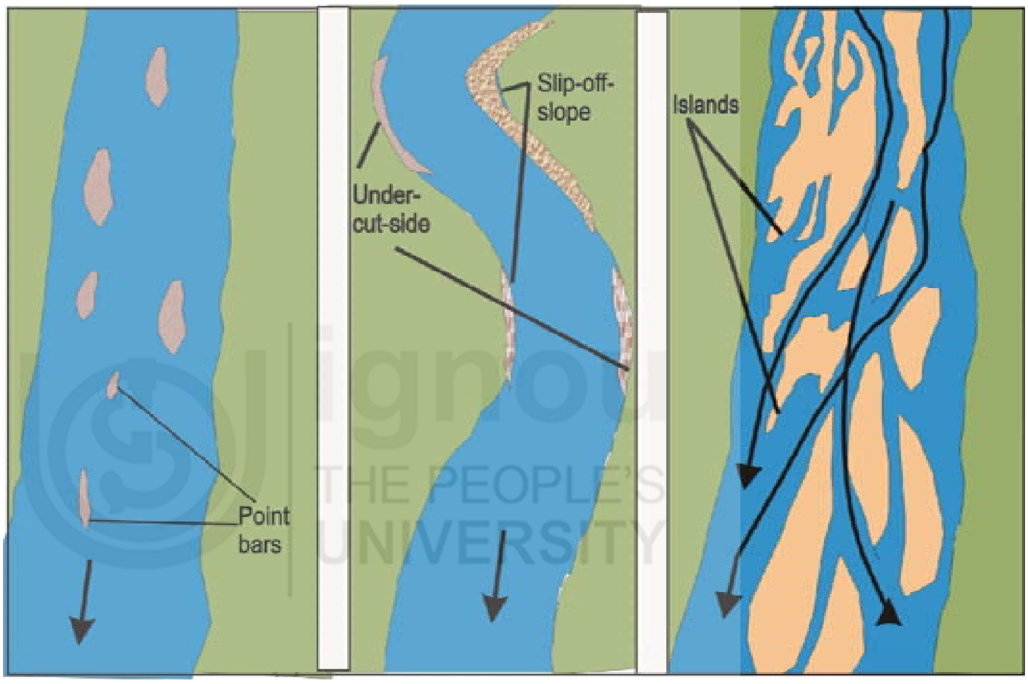
6.3.1 Types of River Channels

Let us recognise the three types of river channels as shown in Fig. 6.1.

i) **Straight Channel**: They are rare and usually found where there is same structure and parallel disposition of hard and soft rocks on the underlying topography, which forces the channel to be straight. When the velocity of the stream is low, the sediment can be deposited to form a **point bar** Fig. 6.1a.

ii) **Meandering Channel**: It is the characteristic of a river that is free to travel across a valley floor. They develop most readily on low gradient slopes composed of easily eroded sediments. Rivers in mature stage often show such sinuous channels, of which the outer curve is important due to relatively free water flow and the inner side due to restricted flow sheds off some of its load, called **slip-off-slope**. When you have a look at the transverse section it will show sloping surface from cut-off to slip-off side. Hence, you can observe both erosion and deposition in the case of meandering rivers as shown in Figs. 6.1b and 6.14d.

iii) **Braided Channel**: It is formed when a stream contains more sediment than it can readily transport. It is the stream that divides into branching and intertwining subchannels separated by islands or sandbars. It is also characteristic of mature stage of river development where erosion and deposition both are going on as shown in Figs. 6.1c and 6.13.



(a) (b) (c)

(d)

Fig. 6.1: Types of river channels: a) straight channel; b) meandering channel; c) braided channel; and d) Aerial photograph of meandering river.

6.3.2 Stages of River

Geological action of river is usually known as **'fluvial cycle of erosion'**. The cycle begins on recently uplifted landmasses with reference to sea level. As the land rises, the rivers are originated and their geological work starts. There are four distinct stages in the development of the river systems (Fig. 6.2).

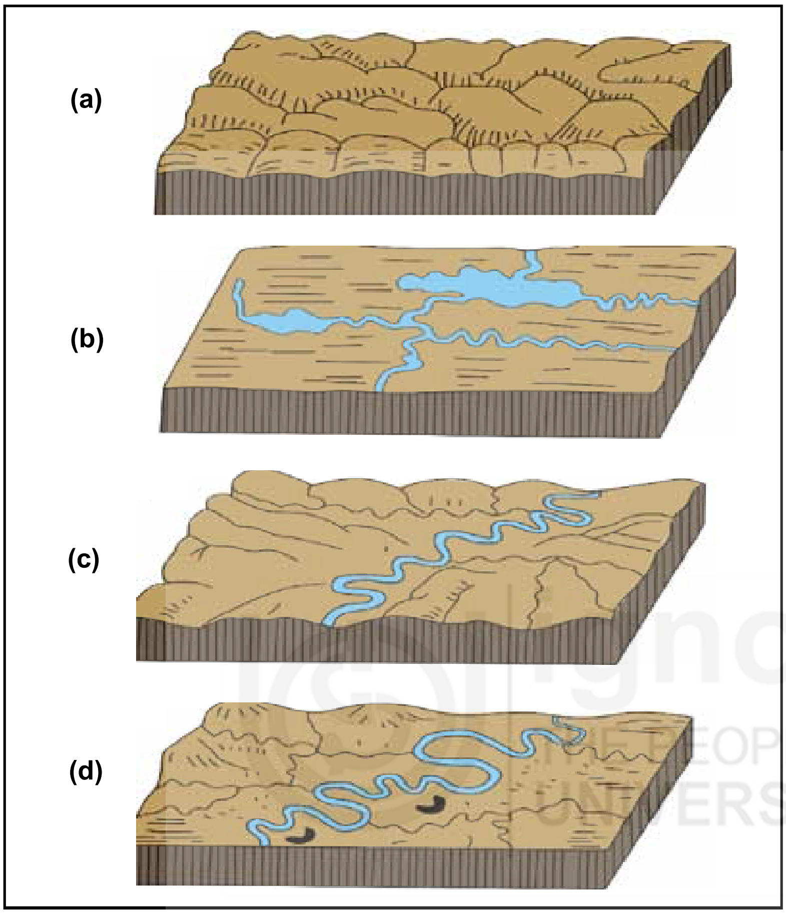


Fig. 6.2: Stages of fluvial cycle of erosion: a) Initial stage; b) Youth stage; c) Mature stage; and d) Old stage.

The stages may be compared with stages of human life:

i) **Initial Stage**: It is the first stage similar to an infant. In this stage, the river water follows along the interconnected depressions available on the surface of the Earth (Fig. 6.2a), just as an infant does as mother wants. Initially the rate of uplift far exceeds the rate of erosion. The gradient is quite high and the streams are turbulent.

ii) **Youth Stage**: In this stage, the river and its tributaries are established. The river has sufficient energy to hit/erode any obstruction on its course and is characterised by intensive bottom erosion and steep gradient. It makes V-shaped valleys (Fig. 6.2b). The slopes are dominated by numerous rills and gullies rather than big streams. The lengthening of **longitudinal profiles** takes place through **headward** erosion of tributaries which is important in this stage. Waterfalls, gorges and canyons are commonly formed. This stage is comparable to a youth's activity, who tries to remove any hurdle in its way. **Headward erosion** is the tendency for stream channel to lengthen upslope as a result of greater erosion at valley headwaters.

iii) **Mature Stage**: In this stage, erosion takes place through **lateral cutting** and **valley widening**. It is the main action, instead of **valley deepening**. **Lateral cutting** or sideways erosion widens the river channel. Meandering of rivers takes place and ox-bow lakes and flood plains are produced (Fig. 6.2c).

You will read about terms like water falls, gorges, canyons meandering, ox-bow lake, flood plain, braided, delta, etc. further in this unit. Rivers often become braided, as it off loads the material it had eroded earlier (Fig. 6.2c). Infact, it is essentially the stage where the river begins the deposition but simultaneously erosion also takes place, e.g. as noticed in meandering and braiding of a river. You can again compare this stage with human life as with age people become more flexible.

iv) **Old Stage**: The old stage is characterised by further decrease in channel gradient, almost total absence of valley deepening, decrease in the number of tributary streams and flattening of valleys (Fig. 6.2d). In this stage the downcutting stops and practically lateral erosion too has no scope. The eroded material that river was carrying is dropped, in the same way as an old person likes to continue further whatever he has gathered and does not venture for any new activity. The valley becomes nearly flat forming plains and ultimately the river meets lake or sea sluggishly forming a delta. Frequently, the river is over flooded and builds up flood plains on both sides.

6.4 DRAINAGE SYSTEMS AND PATTERNS

Drainage systems refers to the origin and development of streams through time while **drainage patterns** means spatial arrangement and form of drainage system in terms of geometrical shapes in the areas of different rock types, geological structure climatic conditions and denudational history.

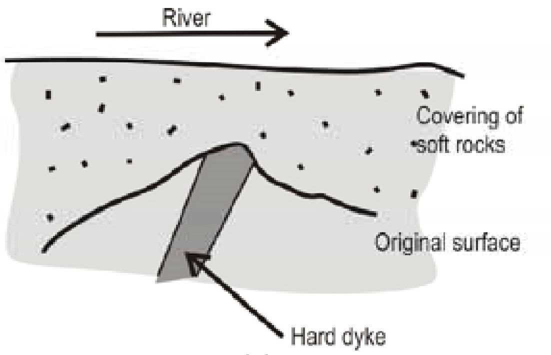
6.4.1 Drainage Systems

Let us discuss the types of drainage systems.

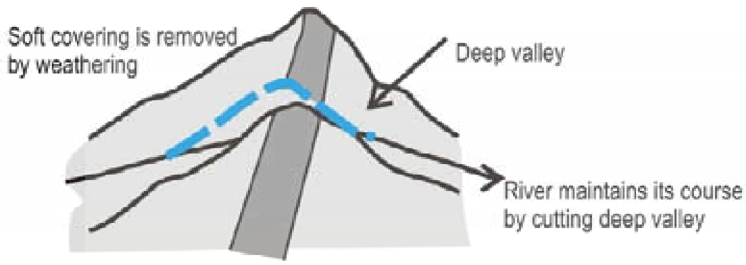
We have discussed that drainage system refers to the origin and development of streams through time.

Following five types of drainage systems have been recognised:

i) **Superimposed streams**: It means something imposed or placed on. Superimposed stream means a river which, flowing on a definite geological formation and structure, has inherited the characteristics of its previous form developed on upper geological formation of entirely different structural characteristics. A river flowing on the covering of soft rocks over harder rocks cuts the soft rocks and reaches to hard rocks and maintains its course as shown in Fig 6.3. Most of the rivers of the Deccan traps region in Peninsular India are superimposed because new drainage system was evolved on the new surface formed due to cooling and solidification of lavas in later part of geological history. Thereafter these rivers were superimposed on the lower formation after the removal of lava cover.

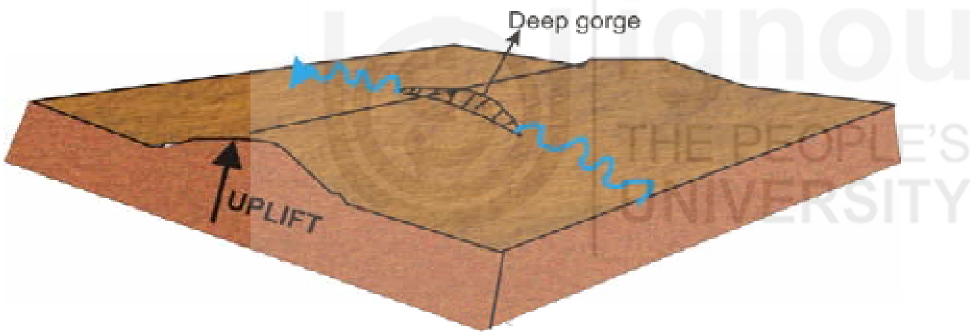


(a)



(b)

Fig. 6.3: Sketch of superimposed drainage: a) River flowing over the soft rocks; and b) River cuts deep valley through soft rocks and maintains its course.



(a)

(b)

Fig. 6.4: a) Diagram showing antecedent drainage pattern; and b) Chyom River as example of antecedent river from West Siang district; Arunachal Pradesh. (Photo credit: Dr. Kakoli Gogoi)

iii) **Consequent streams**: They are the first streams to be originated in a particular region. The consequent streams have their courses in accordance with the initial slope of land surface. River flows through the existing surface relief in the direction of general slope of the area and hence it derives the name 'consequent' as shown in Fig. 6.5a. Most of the streams draining the coastal plains of India are examples of consequent streams.

iv) **Subsequent streams**: They run through some secondary local depression on the sides of main consequent valley and often meet them obliquely. They are generally controlled by the lithology of rock formation as shown in Fig. 6.5b. For example the Asan River, a tributary of the Yamuna River and Song River, a tributary of Ganga River in the Dehradun valley are examples.

v) **Obsequent streams**: These are small tributaries flowing opposite to the original consequent stream. They generally meet subsequent rivers at right angles and depend on the local gradient as shown in Fig. 6.5c.

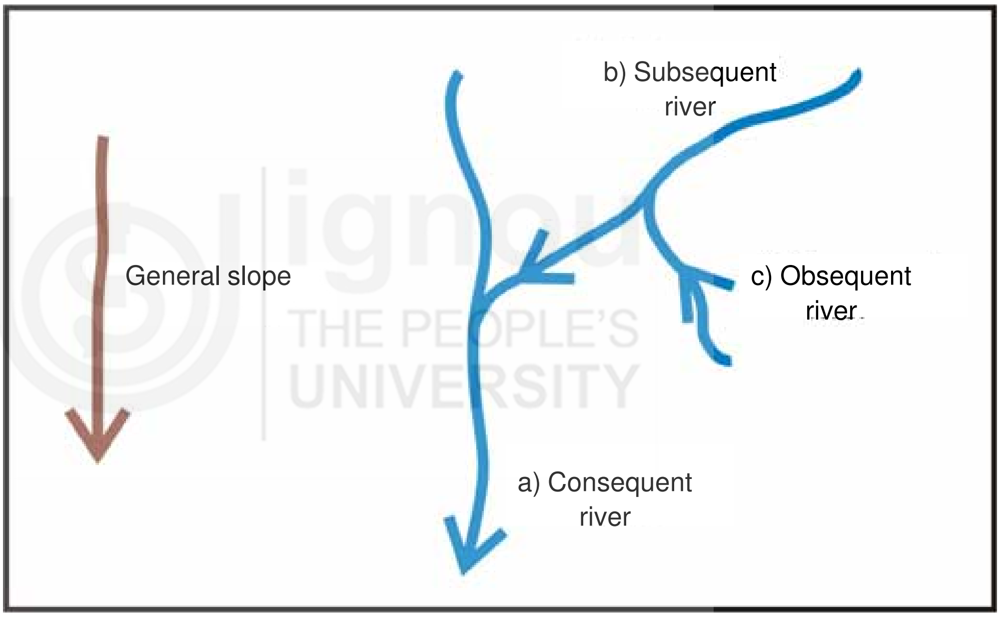


Fig. 6.5: Diagram showing: a) Consequent river; b) Subsequent river; and c) Obsequent river.

6.4.2 Drainage Patterns

The drainage pattern of the rivers comprises the network of tributaries in the headwater region that collect and funnel water and sediments to the main stream. We have discussed in the earlier section that drainage patterns means spatial arrangement and form of drainage system in terms of geometrical shapes in the areas of different rock types, geological structure, climatic conditions and denudational history. Thus the location, number and flow directions of different streams of a particular region depend on the nature of slope, structural control, lithological characteristics, tectonic factors, climatic conditions, vegetal characteristics etc. The streams within a drainage basin form certain patterns, depending on the slope of land, underlying rock structure as well as the climatic conditions of the area. Let us read some common drainage patterns as shown in Figs. 6.6a to f.

i) **Dendritic drainage pattern**: It is characterised by irregular branches of the main river quite similar to the branches of a tree. The rocks over which it flows are tectonically undisturbed as shown in Fig. 6.6a. The pattern develops in a variety of structural and lithological environments such as in mountainous and hilly areas, e.g. Himalayas or extensive plateau surfaces like Deccan plateau.

ii) **Parallel drainage patterns**: It develops on steep slopes where the tributaries and main river flow parallel to each other as shown in Fig. 6.6b. Many rivers taking their sources from the western flanks of Western Ghats drain with straight courses towards west to empty into the Arabian Sea.

iii) **Trellis drainage patterns:** It develops on folded or tilted strata often at right angles to the main stream as shown in Fig. 6.6c.

iv) **Rectangular drainage pattern**: This pattern is commonly found in homogeneous igneous and metamorphic rocks in which tributary streams display right-angled bends that follow joints and faults as shown in Fig. 6.6d. **Joint** is a fracture in a rock along which there is no observable relative movement. **Fault** is a fracture in rock along which there has been an observable amount of displacement.

v) **Radial drainage pattern**: It is also known as centrifugal pattern as it radiates in all the directions like the spokes of a wheel. It is obvious that dome structures, volcanic cones, batholiths residual hills, mesas and butte favour the development of radial pattern as shown in Fig. 6.6e. For example the local upland situated to the south west of the Ranchi city has given birth to radial drainage pattern wherein the South Koel, the Subarnarekha, the Kanchi and the Karo rivers take their sources and radiate in different directions.

vi) **Annular drainage pattern**: It is characterised by a radiating circular pattern and is found on the top of domes and basins which have alternating beds of strong or resistant and weak rocks encircling the rock body as shown in Fig. 6.6f.

6.5 FLUVIAL EROSION

The geological works of fluvial or rivers are called three-phase work comprising erosion, transportation and deposition. The fluvial landforms are divided into two major groups, e.g. (1) erosional landforms, and (2) depositional landforms. The landforms resulting from progressive removal of the bedrock mass are called erosional landforms, e.g. various types of valleys – broad and flat, mature and old (viz. gorges, canyons, broad and flat, mature and old), potholes, rapids and waterfalls, terraces, meanders etc. The landforms shaped by deposition of different types of eroded materials become depositional landforms such as alluvial fans and cones, natural leeves, flood plains, terraces, deltas etc.

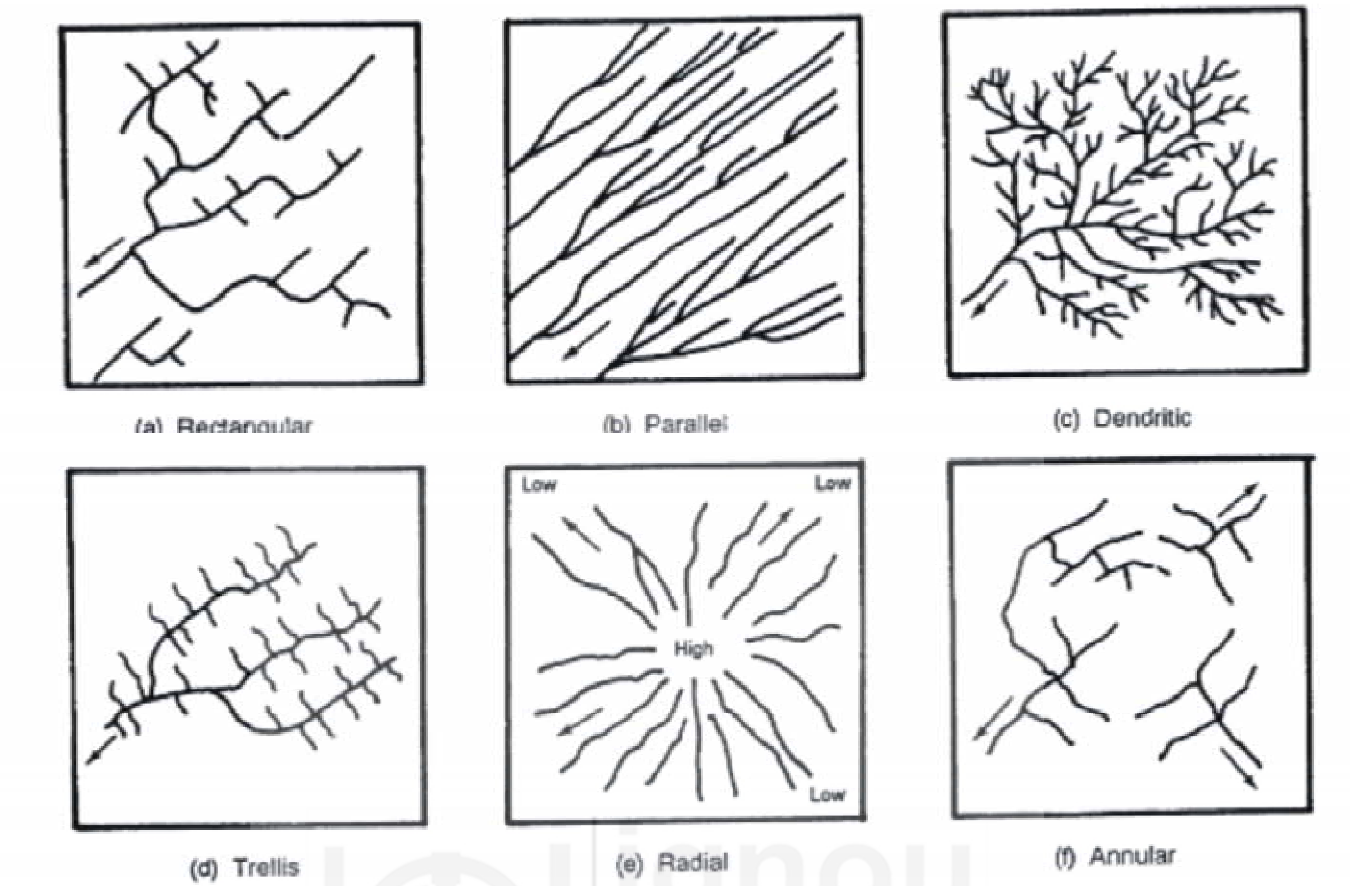


Fig. 6.6: Common drainage patterns: a) Rectangular; b) Parallel; c) Dendritic, d) Trellis; e) Radial; and f) Annular.

Now we will discuss the types of fluvial erosion.

6.5.1 Types of Fluvial Erosion

Fluvial or fluviatile erosion is defined as the removal of sediment from the surfaces of a stream channel. It can occur in three ways:

i) **Vertical Erosion**: This refers to downcutting and thereafter deepening by the river.

ii) **Lateral Erosion**: This is the type of erosion taking place along the river banks. The current of a stream follows the outer side of curves or bends in the channel and lateral erosion takes place. Lateral erosion and subsequent valley widening becomes more active and significant during mature stage of river development than vertical erosion and valley deepening.

iii) **Headward Erosion**: 'Head' refers to mouth of the river. Headward erosion is the tendency for stream channel to lengthen upslope as a result of greater erosion at valley headwaters. River Capture or River Piracy is an example of such erosion. This occurs when headward erosion breaches a drainage divide, intersects another channel and captures its flow.

Let us understand river piracy with the help of Fig. 6.7. A tributary of River '**1**' has greater gradient and carries out headward erosion. After sometime when it reaches River '**2**' then water of River '**2**' is diverted to River '**1**'. This

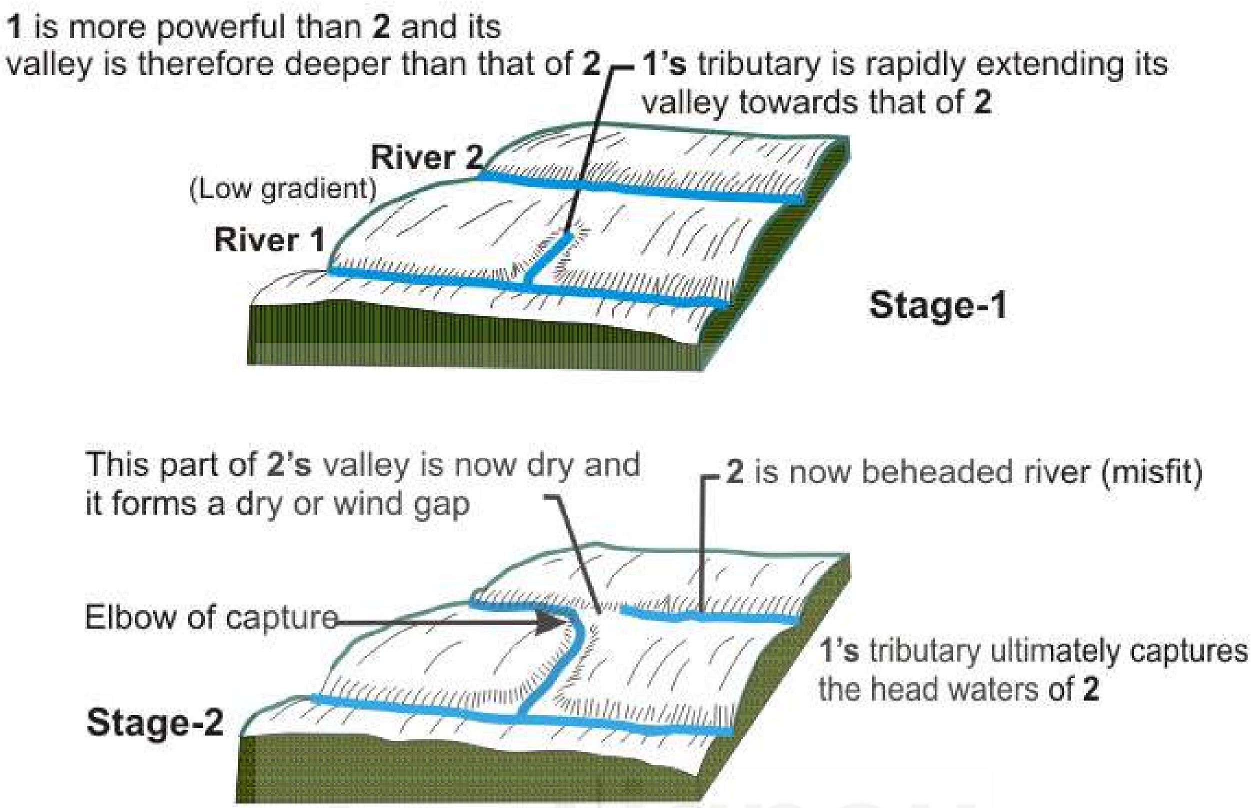


Fig. 6.7: Diagram depicting the stages of river capture or river piracy.

happens because the gradient of River '**1**' is steeper and overpowers the slow flowing River '**2**'. The bend where the diversion takes place is known as **elbow of capture.** The remaining part of River '**2**' becomes thin and is called '**misfit**'. The misfit or underfit stream is the lower course of captured stream. The dry part of the beheaded channel just below the elbow of capture is called **wind gap** also known as **col**. Indian examples of river capture is the River Bhagirathi of the River Ganga. Another interesting example of river capture is the case of Palar River which has been captured by the River Kaveri.

Now let us read about the processes of fluvial erosion.

6.5.2 Processes of Fluvial Erosion

River erosion involves both mechanical and chemical erosion. Mechanical erosion comprises corrosion or abrasion, hydraulic action and attrition while chemical erosion involves corrosion or solution and carbonation.

Let us discuss these four processes.

i) **Corrasion or abrasion**: It is the mechanical wear and tear of the rocks on the sides and floor of the river valley. It can occur through the impact of erosional tools or rock particles (boulders, pebbles, cobbles etc.) carried in the current of water, striking against the exposed bedrock of the channel. The erosional mechanism of abrasion operates in two ways:

- vertical erosion leading to erosion and deepening of valley floors,
- lateral erosion leading to erosion of valley walls and its widening.

ii) **Hydraulic action**: It is the thrust of the water body itself. It enhances the mechanical loosening and removal of broken rocks through its water force.

iii) **Attrition**: It is the breaking away of the transported material by striking or mutual impact with one another. In other words it is the mechanical tear and wear of the erosional tools within themselves. The boulders, cobbles, pebbles, etc while moving with water collides against each other and thus are fragmented into finer particles.

iv) **Corrosion or Solution**: You might have seen caves in limestone rocks. The caves are formed when limestone comes in contact with water containing carbon dioxide. **Corrosion** or **solution** is the chemical processes of rock erosion by river water. River water is capable of dissolving matter from minerals of a rock in the presence of some aiding substances such as alkali matter and gases like carbon dioxide.

It is important for you to comprehend that chemical weathering; abrasion and hydraulic action are so intimately interrelated. It is unwise to think of pure hydraulic action without chemical erosion and abrasion.

6.5.3 Factors Affecting Fluvial Erosion

Erosion by a river in a given time depends on following factors:

- volume of discharge and velocity of flow which influences the quantity of energy
- character and size of the sediments, which are termed as its load
- rock type and geologic structures
- infiltration capacity of the area it drains
- vegetation which affects stability and permeability of the soil

Now let us read about the landforms resulting due to fluvial erosion.

6.6 EROSIONAL LANDFORMS

You have read about the types, processes and factors affecting fluvial erosion. Now let us discuss the erosional features and landforms resulting from fluvial activity.

6.6.1 River Valleys

The valleys carved out by the rivers are significant erosional landforms. The shape and dimension of fluvially originated valleys change with the advancement of the stages of fluvial cycle of erosion. Rivers erode beds and banks of valleys along their journey to lake or sea. The cross-sectional profiles of the valley formed in the initial and youthful stage of fluvial cycle are characteristically 'V' shaped as shown in Fig. 6.4a and 6.8a. The valley is very deep and narrow. Such types of V-shaped valleys are the result of accelerated rate of downcutting (vertical erosion and valley deepening). They are further transformed into very broad and shallow valleys having concave valley side slope of very gentle gradient during old stage. V-shaped valleys are divided into two types (1) gorges and (2) canyons.

6.6.2 Gorge and Canyons

Gorge and canyons are very deep and narrow valleys having very steep valley side slopes or in other words wall-like steep valley sides. Gorges and canyons have steep and high valley walls as compared to their width. Slightly larger gorges are called as **canyons**. One of the most famous examples is the Grand Canyon formed by Colorado River as shown in Fig. 6.8b.

6.6.3 Waterfalls

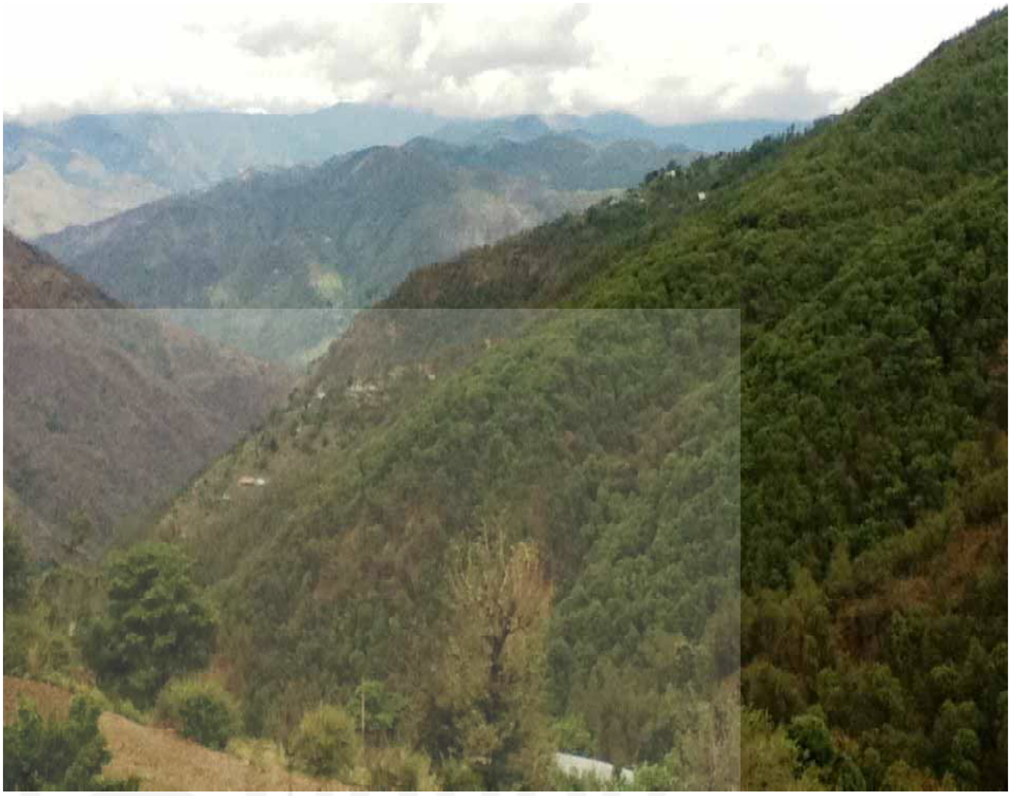
Waterfalls are caused because of sudden descent or abrupt break in longitudinal course of rivers due to several factors, e.g. variation in the relative resistance of rocks difference in topographic relief, fall in the sea level and Earth movements. When harder rock comes in the path of the rivers waterfalls are often formed. The soft rocks are rapidly eroded and protruding hard rock produces obstruction in the path of the river. As a result of this, water descends down rapidly under the action of gravity, further eroding the soft rocks by hydraulic action (Fig. 6.9a and b). **Rapids** are of much smaller dimension than waterfalls. **Knickpoint** is the place where the stream profile steepens abruptly causing a vertical drop. This feature is found in all waterfalls. There are numerous waterfalls in the Himalayan region.

6.6.4 Potholes and Plunge Pools

Potholes are kettle-like smooth, rounded, bowl or cylindrical shaped depressions formed on the river bed of the river valleys. They are caused by mechanical abrasion and downcutting by rock fragments trapped in whirling currents (Fig. 6.10). The depth of a pothole is far more than its diameter. Potholes of much bigger size are called plunge pools. Plunge Pool is produced on the river bed mostly because of hydraulic action where the water falls from height and cause bedrock erosion. Depressions are produced where water is filled up, for example, at the base of the waterfall (Fig. 6.9 b).

6.6.5 River Terraces

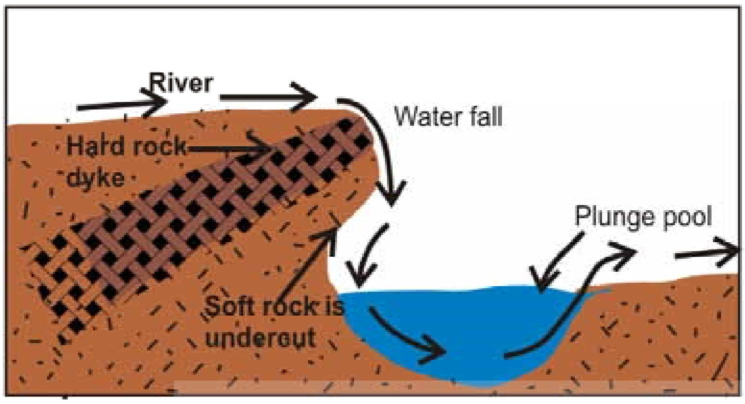
The narrow flat surfaces on either side of the valley floor are called river terraces which represent the level of the former valley floors and the remnants of older flood plains. River terraces are generally formed due to dissection of fluvial sediments of flood plains deposited along a valley floor. Terraces are divided into (1) paired terraces and (2) unpaired terraces. **Paired terraces** are formed due to rapid vertical erosion resulting into the occurrence of terraces on both the sides of the river valleys. **Unpaired terraces** are formed due to simultaneous vertical erosion (valley deepening) and lateral movement of the channel.



(a)

(b)

Fig. 6.8: a) Field photograph showing V-shaped valley and gorge, Kumaon Himalayas; and b) Panoramic view of Grand Canyon which is a steep-sided canyon carved by the Colorado River in Arizona, United States. (Photo credit: Prof. R. N. Tiwari)



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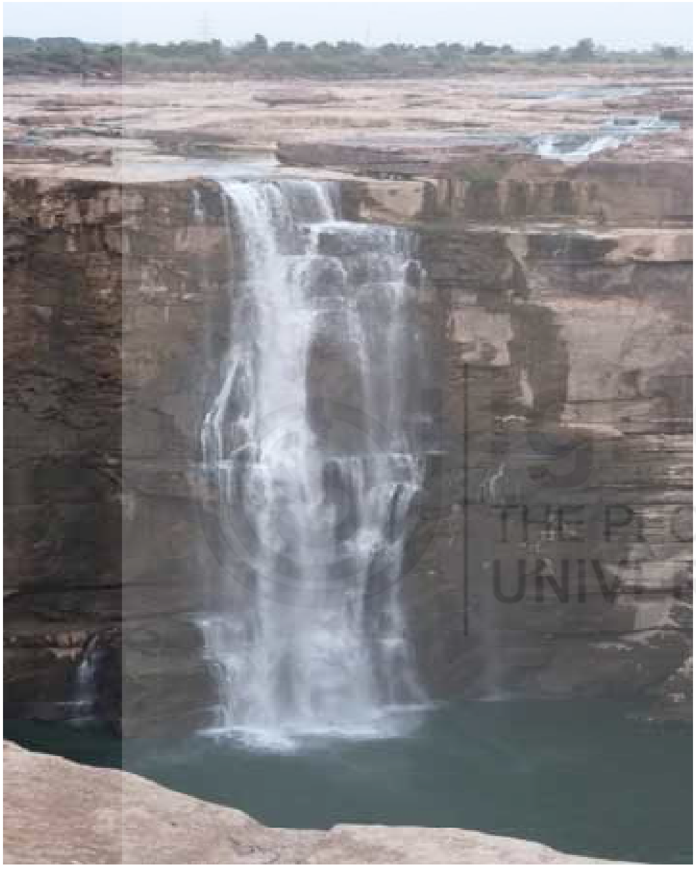


(b)

Fig. 6.9: a) Sketch showing waterfall and plunge pool; and (b) Waterfall in Vindhyachal mountains.

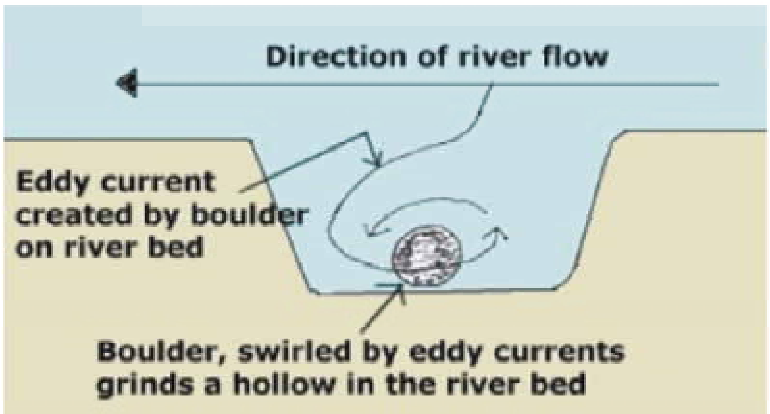


Fig. 6.10: Formation of potholes.

In the previous sections we have studied about the erosional landforms formed by geological work by rivers. Before going to the next section spend 5 minutes to check how you are progressing.

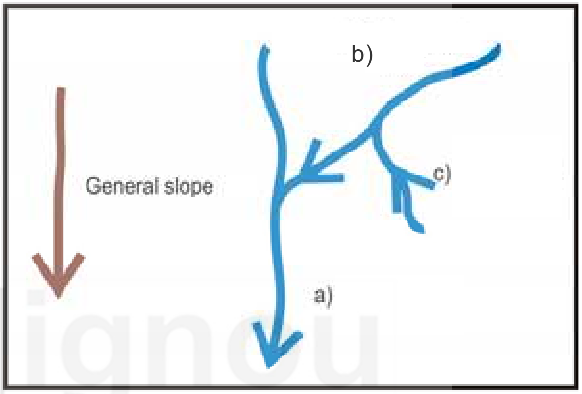
SAQ 1

a) Name three types of fluvial erosion.

b) What is a braided river?

c) Distinguish between drainage system and drainage pattern.

d) The figure given below shows three types of drainage systems. Fill in the blanks at (a), (b) and (c). Please provide explanation to your answers for (a), (b) and (c).



6.7 SEDIMENT TRANSPORT

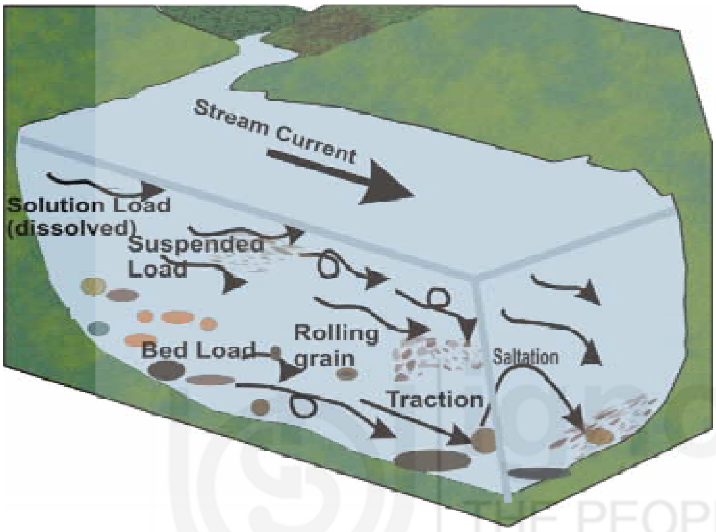
You might have observed that the rivers possess a unique feature of transporting sediments and debris produced by erosional activity. Transportation by river depends on velocity, volume and density of the river water and the density of transported material. Running water is the major cause of erosion, not only because it can abrade and erode its channel, but also because of its enormous power to transport loose sediment produced by weathering. The flowing water is a fluid medium by which loose, disaggregated regolith is picked up and transported to the ocean. **Regolith** is the blanket of soil and loose rock fragments overlying the bedrock.

6.7.1 Types of Sediment Load

River carries sediment load that may be transported as, suspended load, dissolved load and bed load as shown in Fig. 6.11a.

- **Suspended load** consists of fine particles that are carried along in suspension in a stream. The size of these particles depends on their density and the velocity of the stream but their mass is such that it moves in suspension, until its velocity is checked. The suspended load is the most obvious, and generally the largest, fraction consisting of the smallest particles of silt and clay, which are kept suspended above the channel's bed by fluid turbulence. It is the suspended load of streams and rivers that gives murky appearance to the water which you can notice in Fig. 6.11b.

- **Dissolved load** consists of soluble ions that have entered the water as a result of chemical decomposition of rocks and soil together with the amount contributed by underground water and rain water. Because the dissolved load of a stream is invisible, it is commonly overlooked, but it is an important part of the total sediment load.
- **Bed Load** consist of large or dense particles that remain on stream bed most of the time that they are transported by water (Fig. 6.11b). The bed load of larger particles, mostly sand and gravel, cannot be kept suspended by fluid turbulence so that it is transported along the bed. However, some of the sand may be temporarily suspended by currents that swirl the stream bed and lift grains into the water.



(a)

(b)

Fig. 6.11: a) Sediment load consists of suspended load, bed load and dissolved load. Bed load moves by traction, rolling and saltation; and (b) Suspended load gives murky or muddy appearance to water. Also notice boulders lying as bed load.

The grains move forward with the water, but also settle and finally come to rest and then again move by the same process of intermittent bouncing and skipping, a phenomenon known as **saltation** (Fig. 6.11a). Particles too large to be even temporarily suspended are transported by traction; that is, they simply roll or slide along a channel's bed. Bed load move by sliding or rolling called **traction**, or jumping known as saltation which results due to collision between particles as shown in Fig. 6.11a.

6.7.2 Transport Mechanism

Let us learn about the ways how bed load can be transported by:

a) **Traction:** Some of the heavier material which cannot be lifted is pushed ahead by force of water.

b) **Rolling**: By this the boulders, pebbles roll down due to force of water and become rounded. The heaviest particles will be moved down the river by rolling along the bottom of the channel.

c) **Saltation**: It is temporary hydrodynamic lifting and subsequent push of heavier pebbles and their transportation in short skips and bounces by the moving water.

6.8 DEPOSITIONAL LANDFORMS

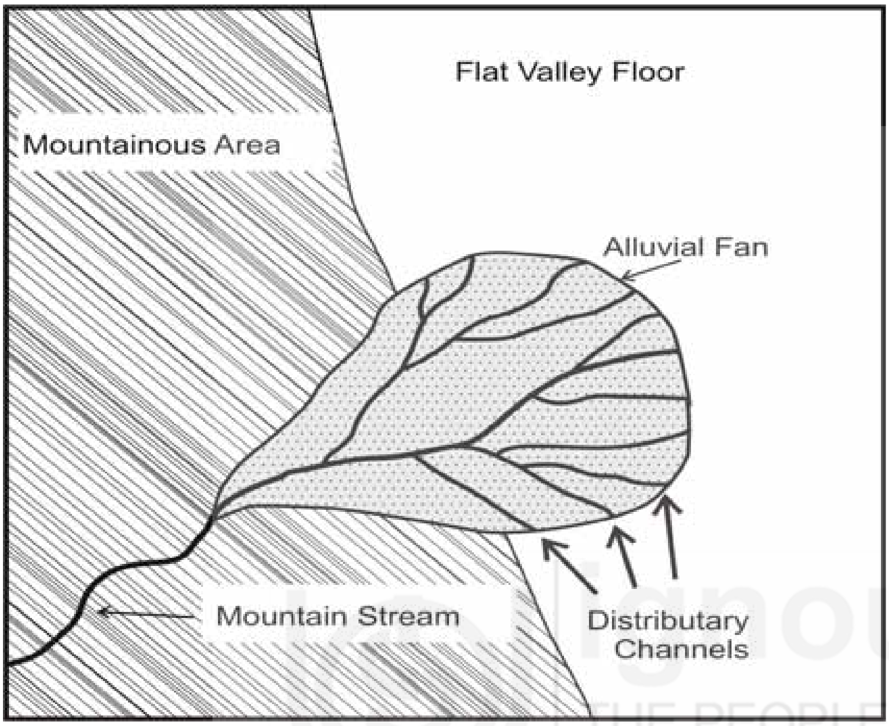
We have discussed about the fluvial erosion and the resulting landforms. Now let us read about the process of deposition by rivers called as **fluvial or fluviatile deposition**. Deposition of sediments takes place where velocity of river is checked. Before discussing the depositional landforms resulting from fluvial activity, let us read the conditions under which the material transported by river is deposited:

- reduced gradient of the river channel;
- river bed becomes wide;
- reduction of the velocity of water current;
- river divides into two or more channels;
- water sinks into the gravels;
- reduction of water volume by evaporation;

Now we will study about different depositional landforms also known as constructional landforms developed by river.

6.8.1 Alluvial Fans and Cones

When a river abruptly falls on plain from mountain, the deposition takes place at the base of the foothills resulting in the formation of **alluvial fans** and **cones**. They are so named because of their resemblance to fans and cones. The thickness of the fans and cones is maximum at the place of deposition as it widens and thins out at great distances. Alluvial fans are semicircular, gently sloping cone of channel sediments as shown in Fig. 6.12a. The sediments are deposited when a high-gradient stream leaves a narrow canyon and enters a flat plain or valley floor. The decrease in gradient causes a drop in flow velocity and hence stream loses its capacity to carry load. This results in deposition of fan shaped cones of alluvial sands and gravels ranging from a few meters to many kilometers in extent. The union of several such fans makes a more or less continuous plain in front of the mountain. Such plains are called **piedmont alluvial plains**. If the water is absorbed by sediments, the deposits cannot spread out and in that case a more or less conical structure is formed which is called **alluvial cone and fan** (Fig. 6.12b). Indian examples of alluvial fans are the Kosi fan and Gandak fan.



(a)

(b)

Fig. 6.12: a) Cross section showing alluvial fan; and (b) Alluvial fan formed by a tributary in the Nubra river in Ladakh. (Photo credit: Dr. Rakesh Chandra)

6.8.2 Braided Rivers

You have already read about braided river in the earlier subsection 6.3.2. Braided river has a channel which is anatomising into an interlacing network of channels, which then rejoin in a pattern resembling braids of hair (Fig. 6.13). A **braided stream** has an intricate network of dividing and rejoining channels separated from one another by sand and gravel bars. If you view from above, the channels resemble the complex strands of a braid. Braided rivers are very efficient in moving a large amount of coarse materials that are in the bed load. **Alluvial terrace** is the elevated, shelf-like surface upon which the stream formerly flowed. It is typically an ancient flood plain remnant, which is abandoned as the stream cut downward and establishes a course at a lower level. Braided channels develop when the sediment supply exceeds the transport capacity of running water, resulting in the deposition of sand and gravel bars. During high-water stages, the bars are submerged, but when the water level is low, they are exposed and divide a single channel into multiple channels. Braided streams have broad, shallow channels and are characterised as bed load transport streams because they transport and deposit mostly sand and gravel. Braided channels are common in arid and semiarid regions with sparse vegetation and surface materials that are easily eroded.

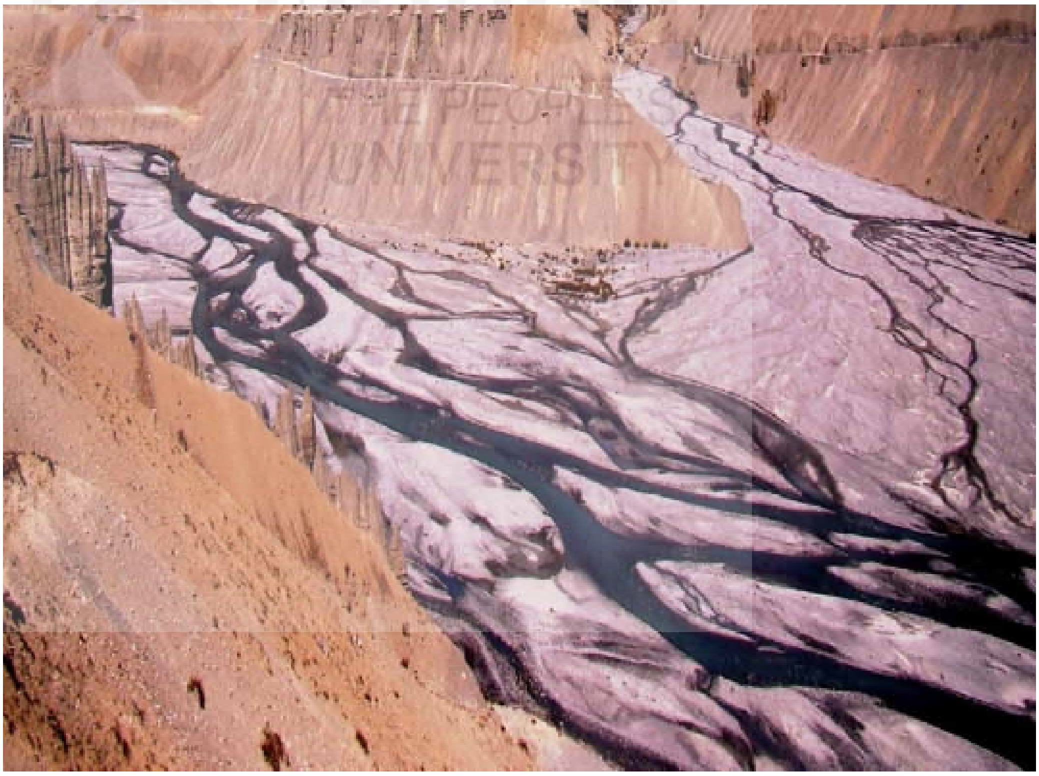


Fig. 6.13: Braided river channel, notice the alluvial terraces.

6.8.3 Meander Deposits

The word '**meander**' is derived from *Maiandros* (now Menderes) River in Turkey, known in ancient times for its winding and serpentinuous (i.e. snake like) course. **Meandering streams** have a single sinuous channel with broadly looping curves referred to as meanders as often seen on flood plains. Channels of meandering streams are semicircular in cross section along straight reaches, but markedly asymmetric at meanders, where they vary from shallow to deep across the meander. In the mature stage of the river commonly the gradient becomes very low as often seen on the flood plains. The river flows in a zigzag path, which is called **meandering** (as shown in Figs. 6.14a, b and c). The deposition takes place on convex banks of the meanders, where the relative velocity of the river water is reduced which causes the channel to block. Then **ox-bow lake** is formed which is also called as **'horse shoe lake'** because of its shape. Many river valleys with meandering channels are marked by crescent-shaped ox-bow lakes, which are simply cutoff meanders. Ox-bow lakes may persist for a long time, but they eventually fill with organic matter and fine-grained sediments carried by floods (Fig 6.14a, b and c). **Point bar** is low, crescent-shaped deposit of sand and gravel developed on the inner bank of a meander where the water velocity is low. When it erodes on the outer side of the channel it is referred to as **undercut**. **Slip off side** are the deposits formed on the inner side of the channel where running water velocity is relatively lower. The deeper side of the channel is known as the **cut bank** because greater velocity and fluid turbulence erode it.

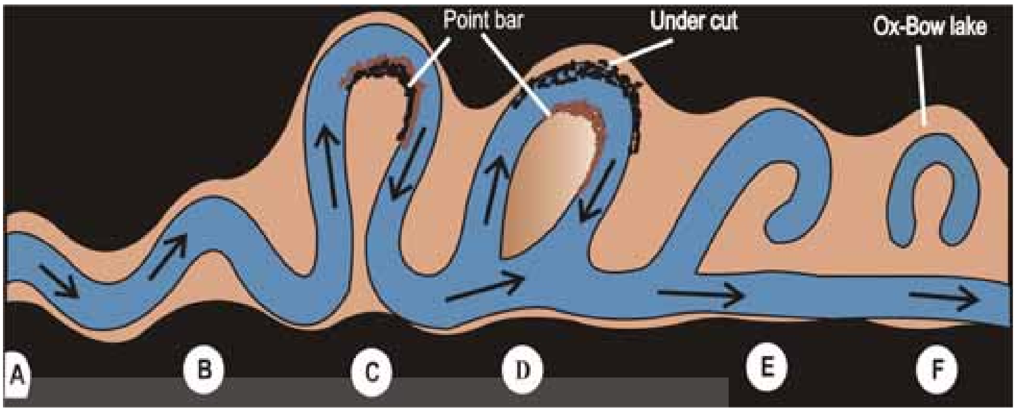
6.8.4 Flood Plains and Alluvial Deposits

The flood plain is an important site of sediment storage within a fluvial system. During the floods water is filled up in large areas on the banks and sides of the rivers. When water in a river exceeds its carrying capacity, the water spills out of the river valley and spreads over the adjoining areas, **flood** is said to have occurred. **Flooding** is the over flow of water from steam channel onto adjacent land that is usually dry. It is a natural process in all river systems and has taken place in all geologic times. The river channels periodically receive more water than they can accommodate, so they overflow their banks and spread across adjacent low-lying, relatively flat areas which form the **flood plains.** Flood plain sediments might be sand and gravel that accumulated when meandering streams deposited a succession of point bars as they migrated laterally (Figs. 6.14 and 6.15a). The deposition of suspended material, i.e. fine material gives rise to thick deposits and they are known as alluvial deposits, e.g. thick alluvial deposits of rivers Ganga and Yamuna cover large areas of U.P., Bihar and West Bengal. They have given rise to very rich fertile plains. You can observe polygonal mud cracks (Fig. 6.15b) on the flood plains during the period of desiccation.

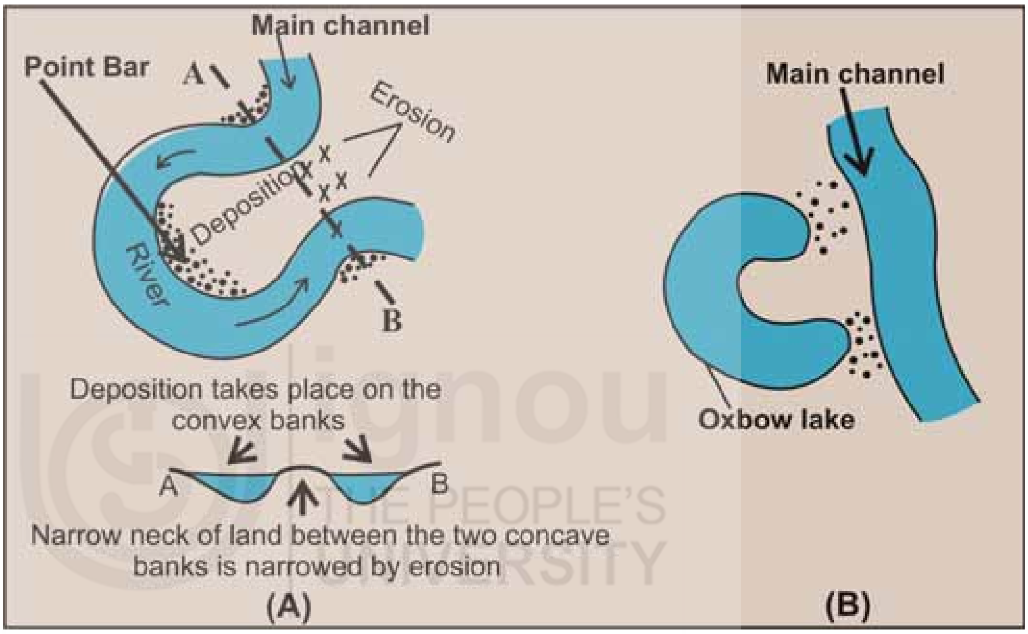
The successive floods build up **natural levees**, ridges of coarse material that confine the stream within its banks between floods, even when water levels are high as shown in Fig. 6.15. These are the raised parts of the banks and are known as **levees**.

6.8.4 Delta

Most of the material carried by rivers is finally deposited into sea or lake. The deposited materials build up a large, flat-topped deposit giving rise to low swampy plain known as **delta**. Delta is the nearly flat triangular or fan-shaped



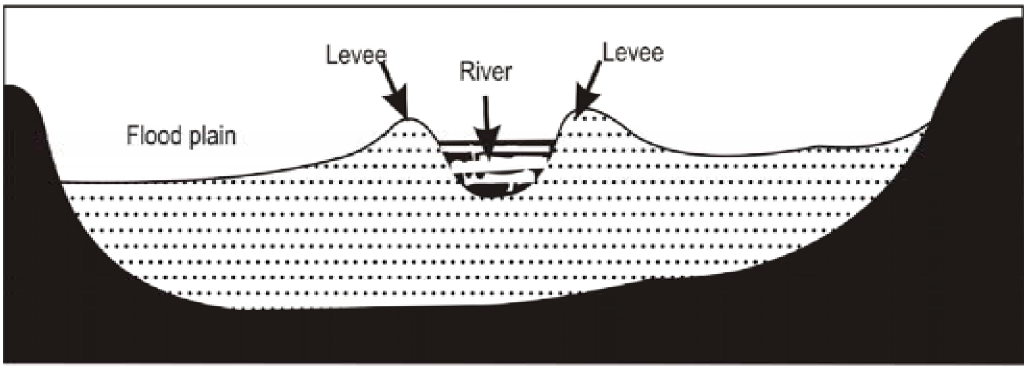
(a)



(b)

(c)

Fig. 6.14: a) Stages of meandering river gradually increasing curvature to form ox-bow lake (horse shoe lake): b) Ox-bow lake is formed due to faster erosion on concave banks and deposition on convex banks called point bars. You can see the two stages of formation of ox-bow lakes in (a) and (b); and c) Aerial photograph of a meandering river migrating across the flood plain of a river Brahmaputra with numerous ox-bow lakes, marked with arrows.



(a)

(b)

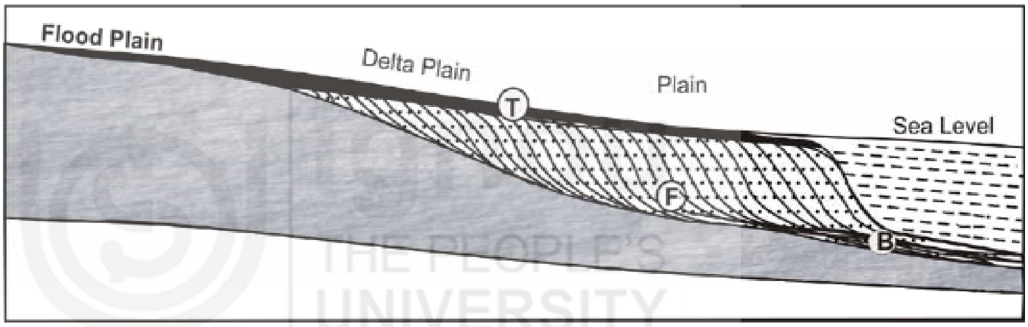
Fig. 6.15: a) Cross section showing flood plains, alluvium and levees; and b) Mud cracks on the flood plain.

plain at the mouth of the river resembling greek letter Δ as shown in Fig. 6.16a. We owe the name delta to Greek historian Herodotus. The roughly triangular shape consisting of the sediment deposit at the mouth of the River Nile prompted him to name it after the Greek letter '$\triangle$' delta. The main river channel divides into several channels (due to sediment deposition) which are known as **distributaries** as shown in Fig. 6.16b. In a delta, three layers of sediments are prominently found as shown in Fig. 6.16c. Materials deposited on the top of delta are typically sand, make up horizontal **topset beds**. Downstream, on the outer front of the delta, fine-grained sand and silt are deposited to form gently inclined **foreset beds. Bottomset beds** form base of the delta and they have gentle inclination towards sea and are made up of fine grained material. Geologists have identified three main types of marine deltas, depending on the relative importance of stream (or river), wave and tide processes:

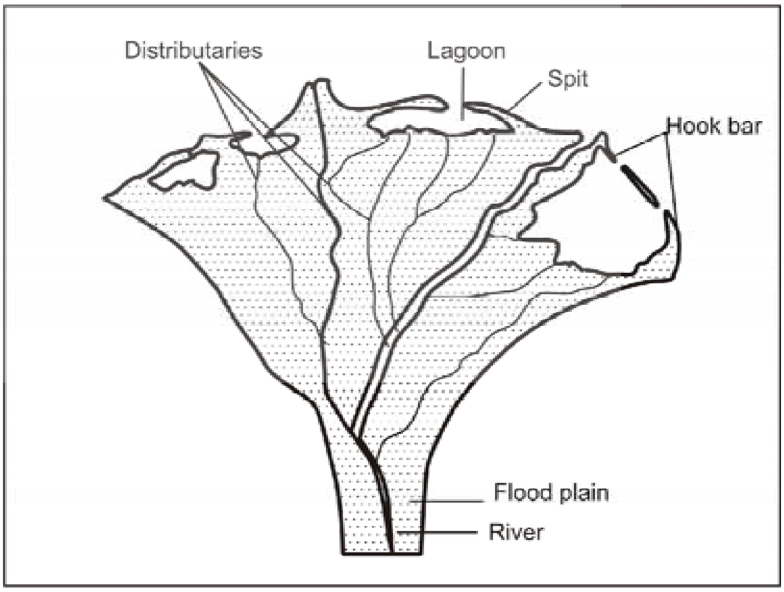
- **Stream-dominated deltas** have long finger-like sand bodies; each deposited in a distributary channel that progrades seaward.
- **Wave-dominated deltas** have distributary channels, but the seaward margin of the delta consists of islands reworked by waves and the entire margin of the delta progrades.

- **Tide-dominated deltas** are continuously modified into tidal sand bodies that are parallel to the direction of tidal flow.

(a)



(b)



(c)

Fig. 6.16: a) Triangular shaped Sunderban delta formed by the River Ganga, as seen in the satellite image (source: www.flashearth.com)**. You can see the distributary channels; b) Cross section through a delta showing top set beds (T), foreset beds (F) and bottom set beds (B); and c) Diagram showing triangular delta and distributary channels**

In the previous sections we have studied about the depositional landforms formed by the geological work done by river. Before going to the next section let us spend 5 minutes to check your progress.

SAQ 2

a) Enumerate the types of sediment load carried by river?

b) Define saltation.

c) What are ox-bow lakes?

d) What are natural leeves?

6.9 SUMMARY

The landscape of the Earth is sculptured by various geological agents namely, wind, water (including river, groundwater and sea/ocean) and glacier. In this unit we have learnt about the geological work done by river (Table 6.1). Let us summarise what we have learnt in this unit:

- Geological agents function in such a way that results in the development of erosional and depositional landforms. Erosion is the breaking down or disintegration or dissolution of rocks due to the physical/ chemical forces associated with the natural agencies. Transportation is the process by which the weathered materials are removed from the site of their formation by various geological agents. Deposition is the process which involves accumulation of the transported materials.

- River valleys have characteristic 'V' shape which develop during initial and youth stages. River channels are of three types-straight, meandering and braided. The fluvial cycle begins on recently uplifted landmasses which include four stages *viz.*, initial, youth, mature and old. The four processes that affect river erosion are hydraulic action, attrition, corrasion or abrasion and corrosion or solution. These manifests in landformal features viz. pot holes, gorges, canyons, waterfalls, river capture or piracy.

- River sediment load is transported as suspended load, dissolved load and bed load. Bed load move by sliding or rolling-called traction or jumping known as saltation.

- The depositional landforms formed by river action are like alluvial fans, braided rivers, meander, delta and flood plains.

Table 6.1: Summary of geological work done by river

Geological activity		Activity
EROSION	Erosional Processes	Corrosion/ Solution activity, Hydraulic action, Corrasion/ Abrasion, Attrition
	Erosional Landforms	River valley, V-shaped valley, Potholes, Gorge, Canyon River capture Water fall
TRANSPORTATION	Transportational Processes	Solution, Suspension, Traction, Rolling, Saltation
DEPOSITION	Causes of Deposition	Reduction of gradient and volume, River bed widening, Obstruction, Meandering, Sinking into gravels
	Depositional Landforms	Alluvial fans and cones, Braided and Meander river deposits, Ox-bow lake, Flood plains, Alluvial deposits, Levees, Delta, Bar, Spit, Hook

6.10 ACTIVITY

In whatever region you are residing, visiting or working, there is always an opportunity to observe, interact and enjoy the nature around you.

1. Download Google Earth or similar software in your computer at home or internet cafe. Now visualise rivers flowing in mountains and plains in the Google Earth and try to identify the variations in their channels and different kinds of erosional and depositional landforms about which you have studied in this unit.

2. Try to identify landforms present in your region in the google earth images.

6.11 TERMINAL QUESTIONS

1. Describe the fluvial erosional landforms. Draw well labelled diagram wherever required.

2. Discuss the types of river channels.

3. Elaborate the four stages of a river.

4. List the depositional landforms of a river and discuss meander and flood plain deposits.

5. Illustrate river piracy with the help of a well labelled daigram.

6.12 REFERENCES

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6.13 FURTHER/SUGGESTED READINGS

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- Mahapatra, G.B. (2013) (Reprinted), A Textbook of Geology, CBS Publishers, New Delhi, 366p.
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6.14 ANSWERS

Self-Assessment Questions

1. a) Braided are the rivers where river branches out by bars (sand bars) in several streams. They are produced when river is heavily loaded and gradient is low.

   b) Vertical, Lateral, Headward,

   c) Drainage systems refers to the origin and development of streams through time while drainage patterns mean/means spatial arrangement and form of drainage system in terms of geometrical shapes in the areas of different rock types, geological structure climatic conditions and denudational history.

   d) a) Consequent (b) subsequent (c) obsequent

   The consequent streams have their courses in accordance with the initial slope of the land surface. Subsequent streams often meet them obliquely. Obsequent streams are small tributaries flowing opposite to the original consequent stream.

2. a) Suspended, dissolved and bed load.

   b) Saltation is temporary hydrodynamic lifting of heavier pebbles and their transportation in short skips and bounces by the moving water.

   c) The ox-bow lakes are formed when the deposition takes place on convex banks of the meanders and concave banks are eroded. The river in its abandoned path leaves behind a crescent shaped water filled loop known as ox-bow lake.

   d) Natural levees are the successive flood that builds up the ridges of coarse material which confine the stream within its banks between floods, even when water levels are high.

Terminal Questions

1. Refer section 6.7. Describe erosional landforms like–river valleys, gorge and canyons, waterfalls, potholes and plunge pools and river terraces.
2. Refer subsection 6.3.1. Discuss the three types of river channels– braided channel, meandering channel and straight channel.
3. Refer subsection 6.3.1. Elaborate on the four stages of river–initial stage, youth stage, old stage and mature stage.
4. Refer to the section 6.8 and thereafter subsections 6.8.3 and 6.8.4.
5. Refer Fig. 6.7.

UNIT 7

GEOLOGICAL WORK OF WIND AND UNDERGROUND WATER

Structure

7.1 INTRODUCTION

We have learnt about the geological agents and their role in sculpturing the Earth's surface, in the previous unit. Now in this unit we will read about the geological work done by the agents, namely wind and underground water. Wind is a powerful tool of erosion and deposition in the areas where conditions are arid or semiarid. Particularly in deserts sand storms is a regular phenomenon. You might have observed that the force of the wind is strong enough to blow sand grains into the air. Have you ever been caught in a strong wind? You might have needed a support to withstand the force exerted by the wind. Winds blowing at more than 175 km/hour rip roofs off the buildings, blow trucks and make it virtually difficult to walk on the streets.

In this unit we will also identify the landscapes sculptured by the action of underground water. The dissolving action of soluble rocks like limestone by groundwater gives rise to **Karst topography.** We have read in Unit 5 Rock Weathering that the weak acids attacking rocks dissolve them easily and develop very distinctive and imposing landforms at the ground surface and underground.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ discuss about wind as a agent of transportation;
- ❖ describe erosional landforms resulting due to wind action;
- ❖ elaborate depositional landforms formed due to action of wind;
- ❖ define water table;
- ❖ explain the movement of groundwater;
- ❖ list erosional landforms developed by action of underground water;
- ❖ identify the depositional landforms formed by groundwater action; and
- ❖ recognise the features of karst topography.

7.2 GEOLOGICAL WORK BY WIND

We have read that the wind is an important geological agent of erosion and deposition in the arid and semi arid regions. Before discussing the erosional and depositional landforms resulting due to wind action, let us distinguish between air and wind.

7.2.1 Wind as a Transport Agent

You know that sun heats the Earth's surface, and as a result the air in contact is also heated and being lighter it moves upwards and cold air comes to occupy the emptied place; as a result, motion in the system is set in. The moving air is termed as **wind**. It blows from the areas of higher pressure to areas of lower pressure. Wind is controlled by the uneven distribution of solar heat over the Earth's surface, due to seasonal variations. We have discussed about sediment transportation by river action in the previous unit, i.e. geological work by river. Wind is a turbulent fluid, in the same way as running water transports sediment. However wind typically flows at a greater velocity than water though it has a lower density and thus can carry only **clay** and **silt** particles as **suspended load**. Sand and larger particles are moved along the ground as **bed load**. The wind exerts the same kind of force on particles on the land surface that a river exerts on its bed.

Wind acts as an agent of erosion and deposition like water. Wind is effective in transporting and depositing unconsolidated sand, silt and dust sized particles. Even the lightest breeze carries dust. Wind can carry dust to great heights and many kilometres. It transports huge quantities of windblown material. Moisture dampens the action of the wind. Hence, water table is regarded as an ultimate **base level** for erosion of wind. **Base level** is the theoretical lowest level to which the land will erode, ultimately equal to the sea level. Vegetation also checks its activities.

The stages of transportation are the function of wind velocity and sediment load, viz.

- Rolling;
- Traction; and
- Saltation or suspension.

Heavier particles and massive rock fragments are transported by **rolling** or **dragging** along the ground called **traction**.

Sediments that are too large or heavy to be carried in suspension by water or wind are moved as bed load either as **saltation** or by **rolling** and **sliding**. Saltation occurs closer to the ground, with sand size grains (2.0mm-0.02mm diameter) moving up and down in jumping motion closer to surface in the direction of the blowing wind. Saltating sand particles usually moves near the surface, and even when winds are strong, grains are rarely lifted higher than about a meter.

The silt (0.002mm-0.063mm in diameter) and clay (<0.063mm in diameter) sized particles are carried in **suspension**, above the ground in the lower part of the blowing wind. The suspended grains can reach great altitudes and travel thousands of kilometres. Even though these particles are much smaller and lighter than sand-sized particles, wind usually first starts moving the latter.

7.2.2 Erosional Landforms

We have read about wind as a transport agent let us now read about the erosional processes and landforms developed by wind action. The term aeolian is used for all processes powered by wind. It is derived from greek word '*Aeolus*' which means God of wind. Wind erosion is also termed as **Eolian or aeolian erosion**. It is performed by processes, viz. deflation, wind abrasion and wind attrition.

- **Deflation**: The word deflation is derived from latin word meaning 'to blow away'. It involves the picking up, removal and blowing away of loose rock particles from one place to the other by wind.
- **Abrasion**: This involves rubbing, grinding, polishing and abrading over the rock surfaces. In the process, individual grains may shed off some of their weight and shape thus, attaining more roundness on grinding off their angularity. Abrasion involves the impact of saltating sand grains on an object and is analogous to sand blasting. The effects of abrasion are usually minor because sand, the most common agent of abrasion, is rarely carried more than a meter above the surface
- **Attrition**: The term refers to the wear and tear of load sediments due to mutual impacts during the process of transportation. This brings about further reduction in size.

Now we will discuss about some of the important landforms developed by aeolian processes.

1. **Deflation basins**: Deflation by strong winds scoop out sand sized particles producing shallow depressions of varying shapes. These evacuated blowouts or depressions are up to 1.5 Km long and a few meters deep. Some depressions reach down to water table and a swamp or **oases** develops (Fig. 7.1). Oases form where the groundwater table comes close to the surface so that roots of trees can reach it.

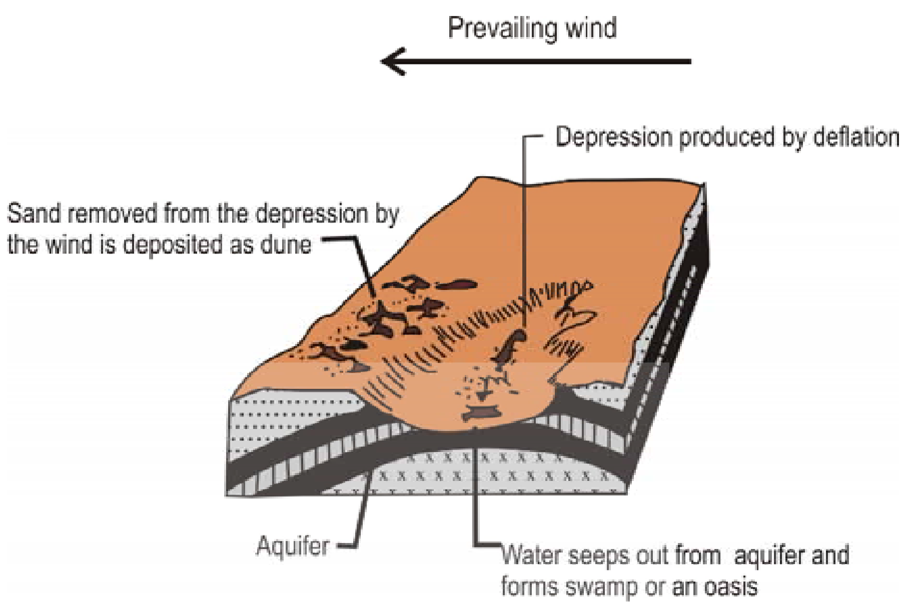


Fig. 7.1: Deflation basins are produced by the evacuation of wind.

2. **Desert pavement**: On deflation of the fine-grained particles, the bigger fragments like **pebbles** (diameter between 4 and 64 mm) or **boulders** (diameter greater than 256 mm) that are too large for the wind to transport remain over thousands of years. As deflation removes the finer grained particles, the accumulated coarser remains of fairly smooth shinning surface of pebbles and boulders are left behind as **lag deposits** or **desert pavement** (Fig. 7.2). It marks the maximum limit of aeolian activity by deflation. Desert pavement forms a coarse gravelly ground surface that protects the soil or sediments below from further erosion.

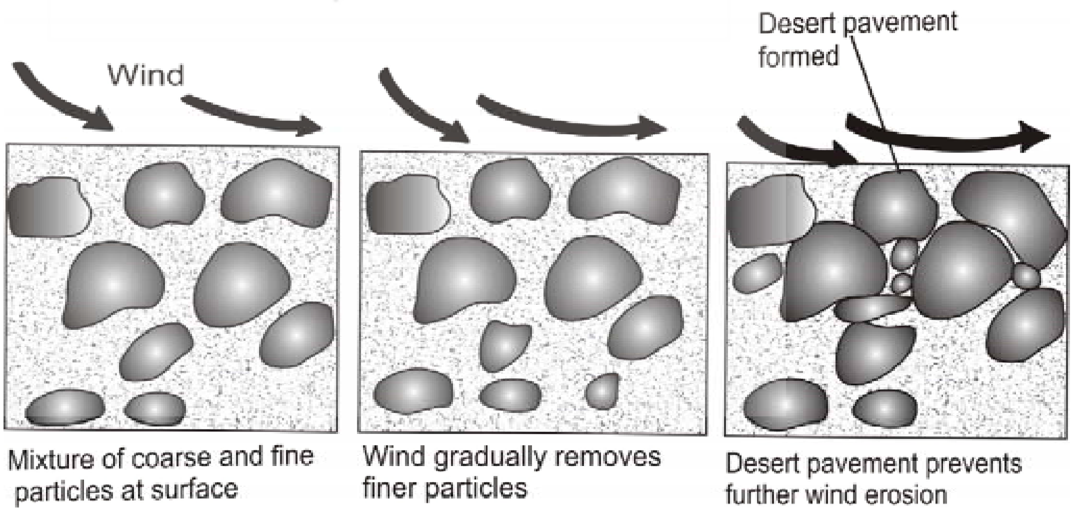


Fig. 7.2: Wind blows away fine-grained materials from heterogeneous sediment resulting in the desert pavement.

3. **Mushroom table or zeugens**: The wind abrasion develops ridge and furrow structure by cutting down the underlying soft rocks more rapidly than hard rocks resulting in the formation of **mushroom table**. Nearly horizontal ridges with top of hard rocks, having low dips and joints are parallel to the prevailing winds (Fig. 7.3). They are very often elongated in direction of the prevailing wind and are also known **zeugens**.

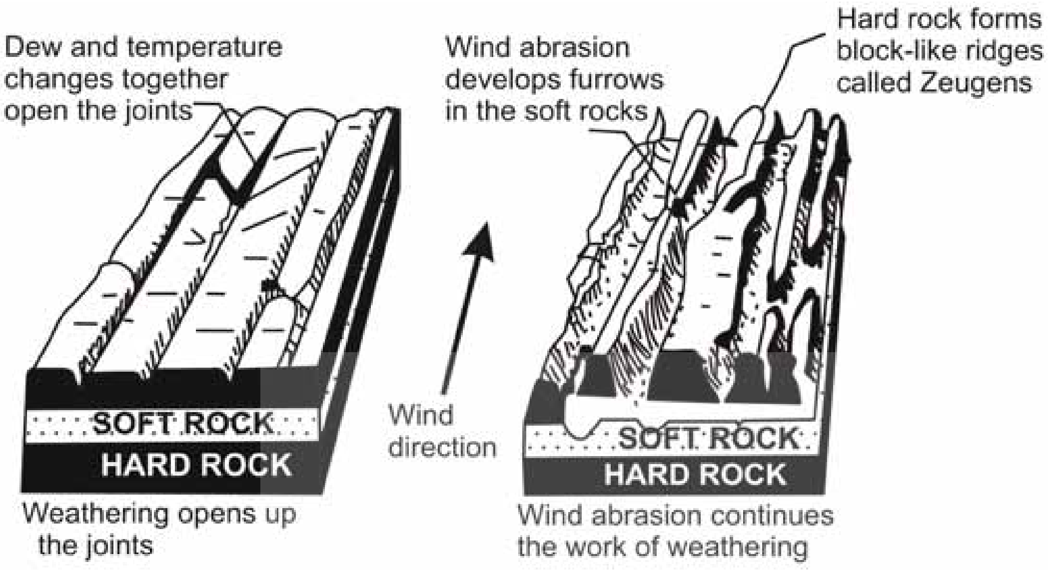


Fig. 7.3: Block diagram showing mushroom table.

4. **Yardang**: It is a stream-lined hill, carved from bedrock or any consolidated or semi consolidated material by the dual action of wind abrasion, dust and sand, and deflation. Yardangs become elongated features typically three or more times longer than wide (3:1 ratio) and when viewed from above, resemble the hull of a boat. Harder rocks may stand up higher more than 20 meters in height (Fig. 7.4), a feature common in Central Asian deserts. They are commonly (i) asymmetrical in shape perhaps because of slight inconsistency in wind direction, and (ii) show elongated leeward tails.

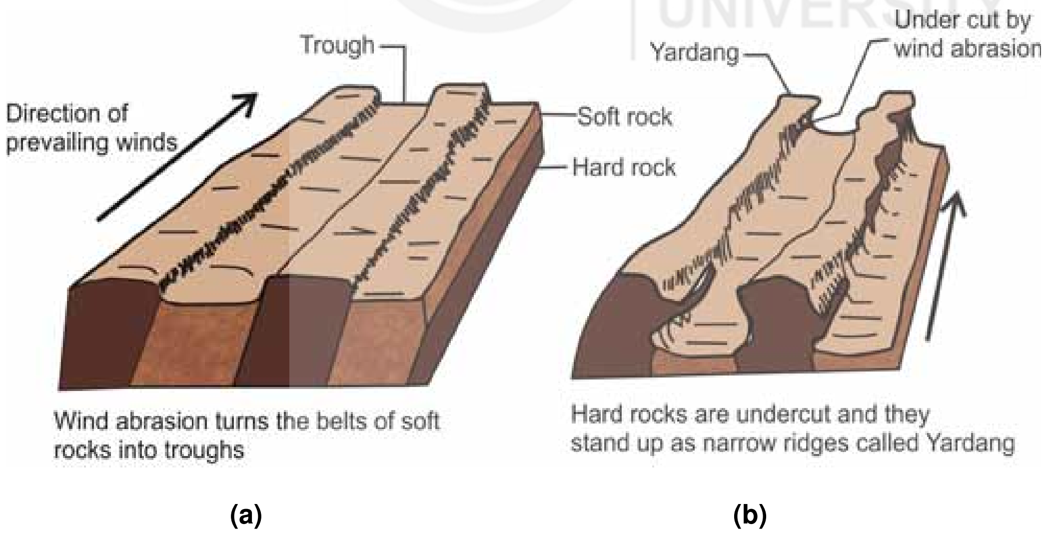
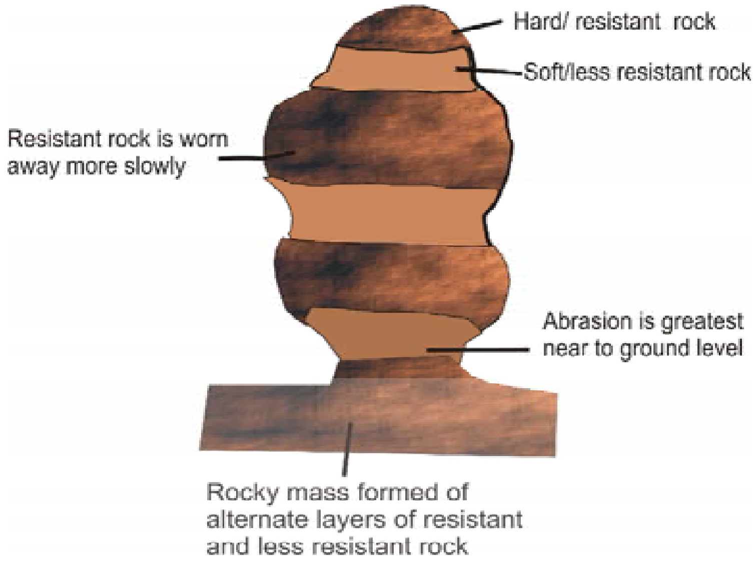


Fig. 7.4: Stages of development of yardang.

5. **Pedestal rocks**: They are produced as the heavier and larger particles remain near the ground and only smaller lighter particles move above at higher level with the wind. When they strike the homogeneous rocks in their path, they differently abrade or undercut the upstanding rock mass in such a way that rock head or cap balances over a very slender neck which could be attacked by the moving particles resulting into a pedestal fan like shape landform. They are called as pedestal rocks (Figs. 7.5a, b and c).



(a)

(b)

(c)

Fig. 7.5: Formation of pedestal rock: a) Sketch showing differential erosion resulting in formation of pedestal rock; b) Field photographs of pedestal rock from Thar Desert (Photo credit: Prof. K.L. Shrivastava)**; and c) Madan Mahal granite, Jabalpur commonly known as balancing boulder. They are characterised by huge ball like head, resting on the parent rock body intervened by slender neck.** *(*Photo credit: Prof. Vaibhava Srivastava)

6. **Blow outs**: These are broad-shallow caves in hills resulting due to wind erosion (Fig. 7.6).

Fig. 7.6: Field photograph of blow out, Thar Desert
(Photo credit: Prof. K.L. Shrivastava)

7. **Ventifacts**: Such structures are produced by wind abrasion on boulders and rock surfaces. Ventifacts are rocks that have been abraded, pitted, etched, grooved or polished by wind-driven sand (Fig. 7.7).

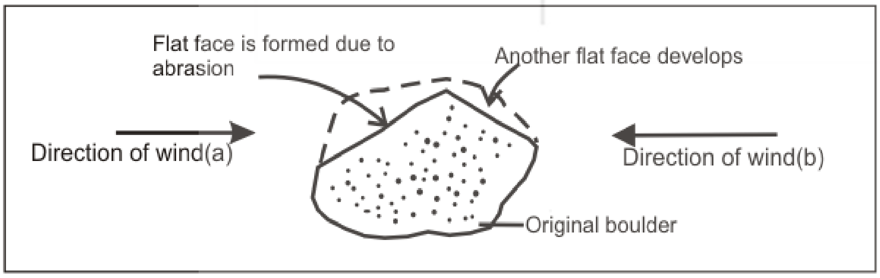


Fig. 7.7: Sketch showing formation of ventifacts. Note that the wind is blowing from two directions.

7.2.3 Depositional Landforms

We have read about erosional landforms now let us identify the depositional landforms resulting from wind action. The deposition by wind action is known as **eolian** or **aeolian deposits**. Wind is an excellent agent for sorting of materials according to their size and weight or shape. Decrease in velocity of the wind causes deposition of wind blown sediments, which are highly sorted in nature.

Let us first read about the reasons of aeolian deposition before discussing the depositional landforms. Wind deposition can take place by:

- obstruction in the movement of wind like cliff, trees, bushes, buildings etc;
- reduction in the wind velocity; and
- moisture enhancement.

They form following depositional landforms:

i) **Loess**: The clayey and silty fractions are deposited as **loess**, (pronounced '*lus*', like lucks). Loess is clastic, predominantly clayey and silt-sized sediment, which is formed by the accumulation of wind-blown dust, exposed by repeated advances and retreats of continental glaciers. Loess is homogeneous, porous, friable, pale yellow or buff, slightly coherent, typically non-stratified and often calcareous (Fig. 7.8). Loess grains are angular with little polishing or rounding and composed of quartz, feldspar, mica and other minerals. Loess deposits create rich soil, e.g. loessic deposit in Northern China is about 300 meters thick.

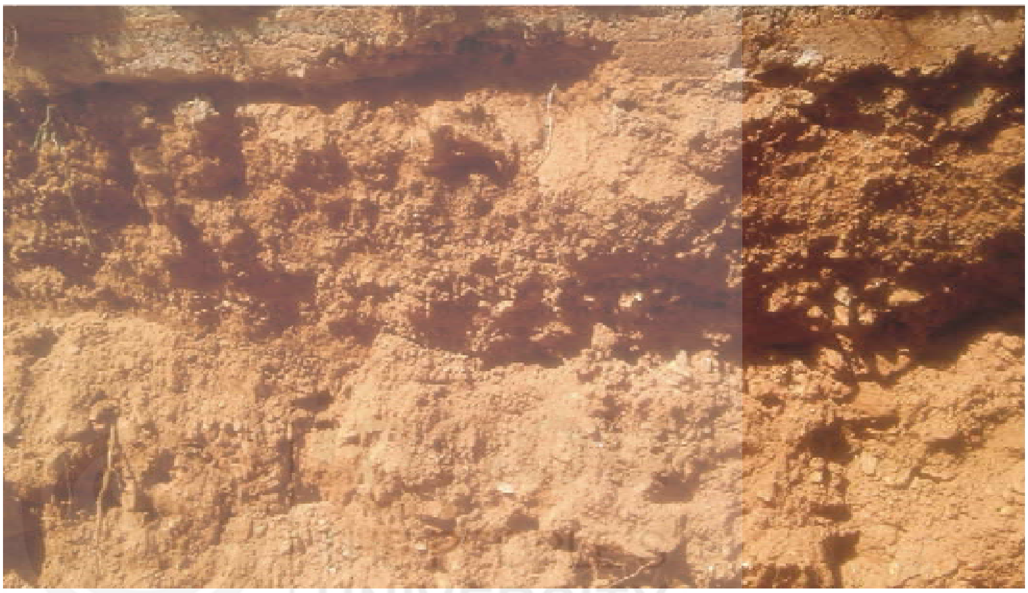


Fig. 7.8: Loessic sediments deposited over Delhi ridge, IGNOU campus, Maidan Garhi.

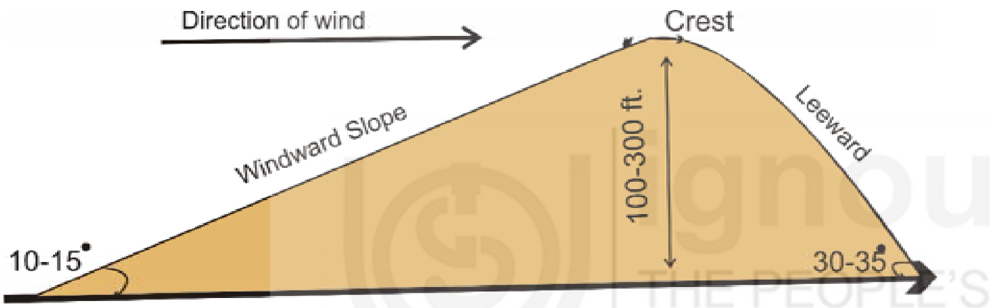
ii) **Sand Dunes**: There are following three types of desert: (i) **Rocky desert** consists largely of barren, hard and rocky plateaus and plains that have very little amounts of sand e.g. Sahara, (ii) **Stony desert** constitutes rocky waste e.g. near Shrikolayatji, Bikaner, (iii) **Sandy desert** is essentially composed of sands and poor vegetation e.g. Pokharan, Rajasthan. When you think of deserts, what come to our mind first are sand dunes and dune fields (Fig 7.9a). Many dunes grow up to the height of 300m. The conditions required for formation of dunes are:

- abundant supply of loose sediment i.e. sand;
- sufficient energy to move sediment i.e. wind velocity;
- obstacle around which sand accumulates i.e. cliff, amount of vegetative cover; and
- dry or arid climate.

Sand dune is a mound or ridge of sand deposited with a crest (Fig. 7.9).

An **ideal dune** has a gentle windward slope of about 10 to 15°. On the other side it has much steeper leeward slope of 30 to 35°. They are variable in height which is 100 to 300 feet or more depending on transporting power and available material.

(a)



(b)

Fig. 7.9: a) Photograph of dune field from Thar desert (Photo credit: Prof. K.L. Shrivastava); **and b) Dune morphology.**

Migration of Dunes: A sand dune often moves or migrates forward windward from one place to the other in the desert region. The wind lifts sand grains from windward side and drops them on leeward side also known as slip side. Consequently the migration takes place. A dune advances by the movements of individual grains of sand e.g. Jaiselmer desert. The structures of static and migrated dunes are shown in Fig. 7.10.

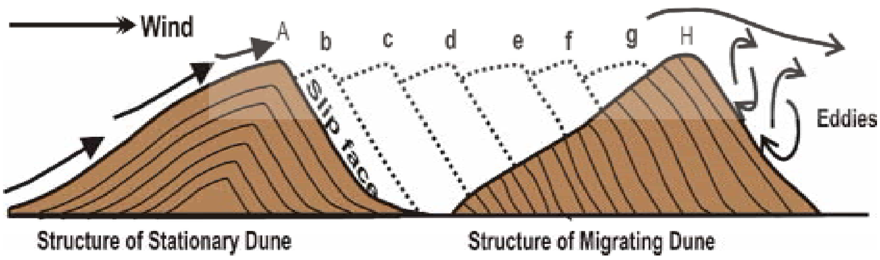
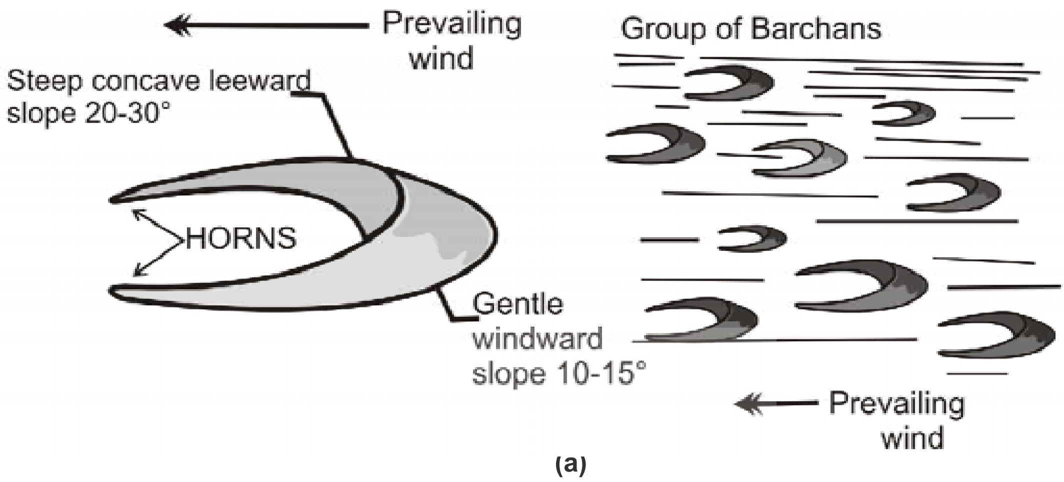


Fig. 7.10: Migration of Dunes.

Types of Dunes: Dunes are classified on the basis of shape. Characteristics of different types of sand dunes are summarised in Table 7.1. There are four principal types of dunes. The first three dune types are asymmetrical with a gently sloping windward side and steeply sloping leeward face. The fourth type, the **star dune**, is complex with arms and ridges formed by wind blowing from different directions (Fig. 7.12e). You will read about them in Table 7.1.

You can observe a group of crescent shaped dunes-barchan (Fig. 7.11).



(a)

(b)

Fig. 7.11: a) Morphology of a barchan dune and crescent shaped sand dunes with tapering horns known as barchan in a dune field; and b) Field photograph of barchan from the Thar desert. (Photo credit: Dr. L.K. Sinha)

ii) **Seif dune** is similar to the barchan except one wing is missing which is caused by an occasional shift in wind direction or converging winds.

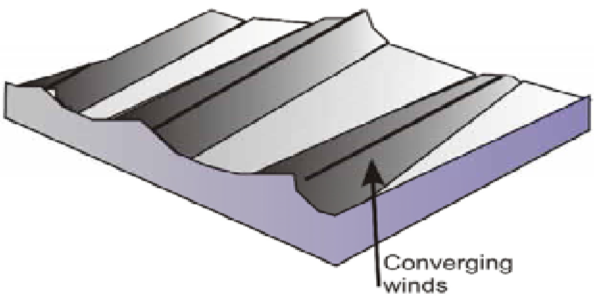
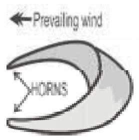
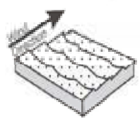
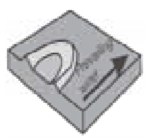


Fig. 7.12: Seif dune.

iii) **Playa**: The flat area at the bottom of desert basin becomes a playa when water collects in it that may result in the formation of an oasis. If playa deposits have more saline matter and salts then it is known as **salina**. As already mentioned oasis may be produced when the bottom of a basin intersects the groundwater.

Table 7.1: Types of sand dunes characterised on the basis of shape, grain size characteristics, wind characteristics and environment of deposition (Source: Fletcher, 2011)

Sl. No.	Dune Types	Crescentic		Parabolic	Longitudinal	Star
		Barchan	Transverse			
1.	Shape	Crescent moon, 2 tapering horns point downwind, steep slip face on concave side	Long, wavy, linear ridge oriented transverse to wind direction	Crescent moon, Horns point upwind	Large, linear or slightly sinuous sand ridges, generally much longer than wide	Pyramid shaped, 3 or more arms radiate from a peaked centre
2.	Wind characteristics	Constant wind from one direction	Constant/ moderate unidirectional wind speed	Variable strength, unidirec-tional wind	Strong, steady winds that blow from 2 directions	Wind blows from several different directions
3.	Environment of Deposition	Limited vegetation and sediment, often on flat bare rock	Limited vegetation, more sediment than barchan	Abundant supply of sand and vegetation common	Long axis of sand ridges is parallel to the direction of net sand movement	Grow taller rather than migrating
4.	Grain Size characteristics	Well sorted. Very fine to medium sand	Well sorted. Very fine to medium sand	Well-sorted. Very fine to medium sand	Well sorted.Very fine to medium grained sand	Well-sorted. Very fine to medium sand
5.	Figures	 **Fig. 7.12a: Barchan dune**	 **Fig. 7.12b: Transverse dune**	 **Fig. 7.12c: Parabolic dune**	 **Fig. 7.12d: Longitudinal dune**	 **Fig. 7.12e: Star dune**

You have read about wind geological agents and erosional and depositional landforms resulting from wind action. Let us spend 5 minutes to check your progress before discussing about the geological work of groundwater.

SAQ 1

a) Define wind. What causes air to move?

b) What is the difference between wind abrasion and attrition?

c) What is the base level of erosion for wind?

d) Describe morphology of a dune with the help of a diagram.

7.3 WATER TABLE AND MOVEMENT OF GROUNDWATER

Manifestation of water, as we know, on the Earth's surface, is in all the three known states of matter, solid (in form of glaciers), liquid (as water) and gas (as vapours). They combine together to constitute **hydrologic cycle**, which appears more or less stable. The ultimate source of all its forms is the gigantic reservoir i.e. oceans. Water evaporates from the ocean surface in the form of vapours which collect in the atmosphere and precipitate down on the Earth's surface termed as rainfall or snowfall. The rain water flows either as run off that generates streams which combine together to form a river or percolates down to form **underground water, groundwater** or **subsurface water**. Groundwater is one reservoir of the hydrologic cycle and accounts for approximately 22% of the world's supply of fresh water. You may note here that several factors like ground slope, attitude of rocks forming the ground also affect the surface runoff and percolation. Both the surface water and subsurface water move down ultimately to the ocean completing the hydrologic cycle.

The source of groundwater is rainfall and snow melt. At shallow depths, the material is unsaturated: pores contain some air and are not completely filled with water. This level is called the **unsaturated zone** (also called **vadose zone**). Below it is the **saturated zone** (often termed as **phreatic zone**), in which pores are completely filled with water. At the boundary between two zones is the **groundwater table**, usually called **water table** (Fig. 7.13). The water table is a surface that marks the upper limit of the zone of saturation. Let us realise that the water table does not remain at a fixed depth below the land surface, but in any given area it fluctuates with the quantity of recent precipitation, loss by outflow to the surface, and the amount of removal by pumping. The water table rises and can be easily observed after an unusually wet period.

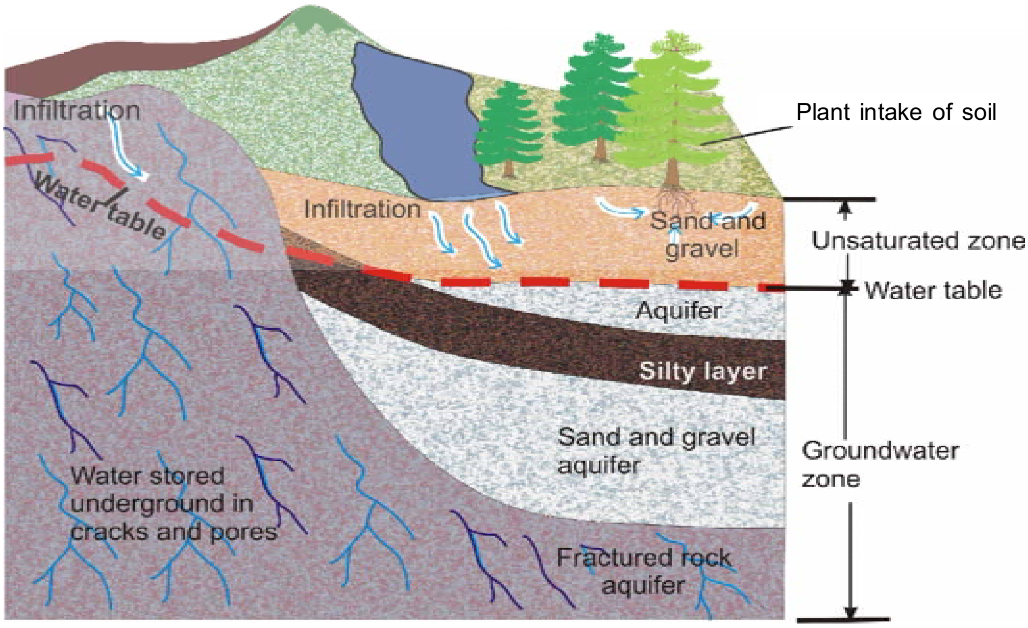


Fig. 7.13: Water in the ground is found in the saturated zone beneath the water table.

Groundwater is an important agent of both erosion and deposition and is responsible for development of karst topography and a variety of cave features. Let us learn about the movement of groundwater. Water enters the system when surface water infiltrates the ground (recharge) and moves through the system by percolating through pore spaces of rock and ultimately leaves the system by seeping into streams, springs or lakes (discharge). Along this flow path, groundwater does geological work which is mostly as a result of solution or precipitation of rock. Groundwater moves downward because of the force of gravity. It usually follows the surface topography and therefore may be a regular plane or irregular uneven surface.

The factors controlling underground water are:

- climate;
- topography; and
- rock characteristics i.e. permeability and porosity.

Porosity and permeability are important physical properties of Earth materials (soil, sediment and sedimentary rocks) and are largely responsible for the amount, availability and movement of groundwater. Water soaks into the ground because soil, sediment and rock have open spaces or pores. **Porosity** is the percentage of total volume or the amount of space available between the particles, i.e. pore spaces present between particles in soil, sediment and sedimentary rocks. **Permeability** is the property and capacity of Earth materials to transmit fluids. Permeability is dependent not only on porosity, but also on the size of the pores and their interconnections. Let us read an example that will help us to relate to the connectivity between porosity and permeability. The clay sediments are very fine grained particles. Despite the high porosity of the pore spaces present are poorly interconnected, giving them a low permeability.

7.4 SURFACE MANIFESTATIONS OF UNDERGROUND WATER

We have read about unsaturated and unsaturated zones and water table in the previous section. Now let us acquaint ourselves with the different surface manifestations and sources of underground water. They are:

- **Springs**: They are natural openings through which water comes and flows on the surface (Fig. 7.14a).
- **Hot springs** or **Thermal springs**: At many places hot water comes out in form of springs (Fig 7.14b) when encounters a hot source below.
- **Ordinary wells**: In these wells we get water at the water table. They indicate depth of water table of the area.
- **Tube wells**: These are like ordinary wells but are drilled to withdraw water mechanically.
- **Artesian wells**: These are special types of wells in which water escapes to the surface, driven by of the water table in an **aquifer**. Aquifers are rock

(a)

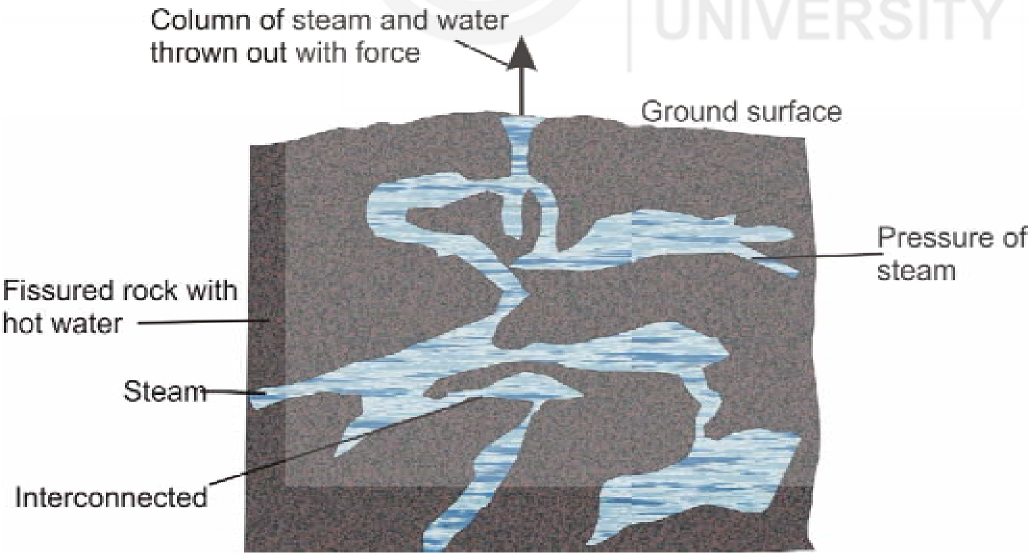
(b)

Fig 7.14: a) Natural spring which is source of the Kaveri river at Tal Cauvery, Western Ghats; and b) Hot springs at Manikaran, Kulu (Himachal Pradesh). Temperature of water is quite high that food may be cooked by putting metal vessels in the water.

formations through which groundwater flows in sufficient quantity to supply wells. **Hydraulic gradient** is the difference in elevation between two points in an aquifer divided by their distance. **Impervious** refers to the impermeability of the rock.

- **Geysers**: These are hot springs from which a column of hot water and steam is discharged at intervals. The water rises up to hundreds of feet like a fountain. Temperature varies from 70^{o} to 90^{o}C (Fig. 7.15a). As they are thermal springs the water temperature in cavities beneath rises producing steam which increases pressure, forcing the hot water and steam out of the vent and forming geyser (Fig. 7.15b).

(a)



(b)

Fig 7.15: a) Geyser in action at Roturva, New Zealand; and b) Working of geyser.

7.5 GEOLOGICAL WORK OF UNDERGROUND WATER

We have learnt about water table, related terminology and surface manifestations of underground water. Now let us read about the geological action of ground water and karst topography.

Let us understand the erosional and depositional landforms developed by the action of underground water. The solution effect of the underground water is conspicuous in limestone (consist of mineral calcite – $CaCO_3$) regions or in some other easily soluble rock material like rock salt. Limestone [(including dolomite, $[CaMg(CO_3)O_2]$ is ordinarily soluble in water but if the water contains CO_2 in solution, it becomes a good solvent for limestone. The atmosphere contains about 0.03% of carbon dioxide. Apart from this carbon dioxide is also produced in soil by the decay of organic matter, most groundwater is slightly acidic. When groundwater percolates through the various openings in limestone, the slightly acidic water readily reacts with the calcite to dissolve the rock by forming soluble calcium bicarbonate, which is carried away in solution. Topography developed due to the action of groundwater is known as **karst topography**.

In section 7.6 we will discuss about karst topography.

7.5.1 Erosional Landforms

Erosion by underground water mainly involves the processes of chemical action, dealt earlier in Unit 5 Rock Weathering viz. solution, oxidation, hydration, carbonation, etc. You cannot ignore the mechanical erosion done by ground water flowing in the underground channels. Now let us learn and list erosional landforms developed due to the action of underground water.

i) **Landslides**: Underground water enters the fissures, cracks present in the rocks, which acts as lubricant and facilitates movement. The huge unstable rockmass may slip downwards under the influence of gravity causing landslides.

ii) **Caves**: They are formed as a result of solution activity in the soluble rocks like limestone (composed of calcium carbonate) (Fig. 7.16).

Fig. 7.16: Limestone cave from Krem Mawmluh, Khasi hills, Meghalaya. (Photo credit: Prof. R. Baskar)

iii) **Underground channels**: These are subsurface tunnels formed on dissolution of rocks, mainly carbonates like limestones over which the groundwater flows. These channels may connect the caves with one another (Fig. 7.17).

Fig. 7.17: Subsurface water channels are visible at the left bringing water in the main channel at Sahastradhara, Dehradun, Uttarakhand.

Shallow groundwater dissolves carbon dioxide and forms a weak acid. The slightly acidic water then flows and percolates through along the joints, fractures and bedding planes, slowly dissolving the limestone and enlarging the openings (Figs. 7.17, 7.18 and 7.19). This creates a system of connected passageways within the soluble bedrock called as caves, e.g. Amarnath caves in Himalayan region.

iv) **Caverns**: These are interconnected underground cavities in limestone, formed by solution action of ground water. In these underground caverns and channels streams sometimes flow (Fig. 7.17). The caverns may be connected by the horizontal **gallery** and vertical linking passage the **shaft**.

v) **Sinks, sinkholes, dolines, uvala and swallow hole**: These are basin-shaped or funnel-shaped hollows of varying sizes, which are developed in limestone regions by the underground solution. Surface water contains a good amount of CO_2 in solution. When this water percolates downward through limestone rock, a good amount of rock is taken into solution. The result is the formation of a basin with consequent collapsing of the roof into it and hence these sinks take the form of funnels. Such concentrated solution can cause the development of roughly circular surface depressions, called **sinkholes** or **dolines**, which are prominent features of many karst landscapes. Dolines are also called as **swallow hole**. As sinkholes coalesce, the larger depressions that develop, called **uvalas**, or **valley sinks**. They are often linearly arranged along former underground water courses (Fig. 7.18). The terms doline and uvala are derived from Slavic languages used in the former Yugoslavia.

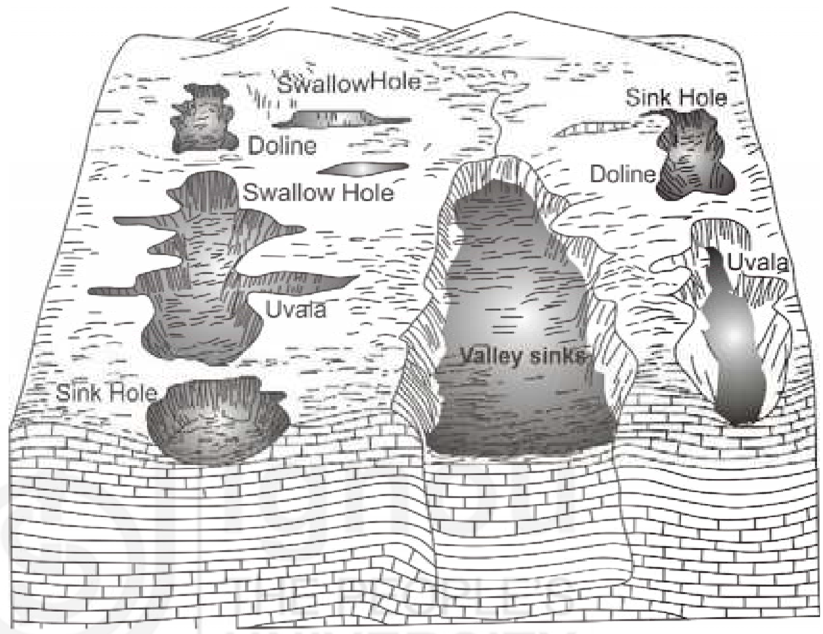


Fig. 7.18: Block diagram showing sink holes, valley sinks, doline, swallow hole and uvala.

vi) **Solutional valley**: When several of solutional features are engulfed together in a valley in the limestone region then the valley is called as solutional valley.

7.5.2 Depositional Landforms

We have read about the landforms developed due to the erosional action of groundwater.

Now let us read about some of the depositional landforms resulting due to activity of groundwater.

i) **Geyserite**: Hot water in geyser contains lots of material dissolved in it. When it comes on the surface, it gets cooled and the material is deposited around the mouth of such springs as geyserites or sinter deposits (Fig. 7.19).

ii) **Replacement**: The percolating water takes into solution certain substances and deposits an equal volume of material which the water was carrying in solution. Such substituion commonly occurs molecule by molecule so that the original stucture of dissolved substances is kept intact. Soluble material is replaced by less soluble one e.g. petrification.

Fig. 7.19: Geyserite forming terraces around geyser in action at Roturva, New Zealand.

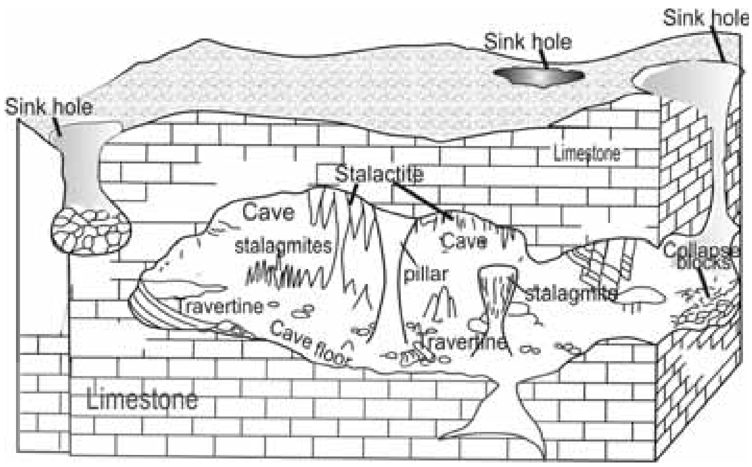
iii) **Petrification** involves the replacement of cellulose by silica. As the substitution takes place volume for volume, the woody structure is exactly preserved.

iv) **Geode**: Cavities of basic volcanic rocks are generally filled up by solutions of silica, calcite, zeolites, etc. which were carried in solution by underground water.

v) **Concretions**: As a result of percolating underground water, concretions of irregular shape and size are formed. These are nodular shaped and often occur in sedimentary beds or upon the surface. They are harder than surrounding rock and so stand out prominently e.g. **Kankar**. They are formed by deposition of calcium carbonate.

vi) **Stalactites and stalagmites**: These are depositional features formed in limestone caves. They are composed of $CaCO_3$. Stalactites are masses hanging from the roof of the cave. Whereas stalagmites are deposits formed at the base of the cave (Fig. 7.20). Stalactites are long slender masses whereas stalagmites are thicker. Please note '**C'** in stalactite indicates ceiling and '**G'** in stalagmite indicates ground. Sometimes, stalactites of the roof and stalagmites of the floor join together to form **pillar** or **column** which results in columnar deposit. These cave deposits are collectively called **dripstones**. For example we can observe these features at Sahastradhara, Dehradun, Uttarakhand. **Speleothem** is the generic term for any chemical precipitate feature deposited in caves. They develop in a great variety of textures and shapes.

vii) **Calcareous tuffa**: $CaCO_3$ is deposited at the floor of the caves in form of layers. You can see in Fig. 7.20.



(a)

(b)

Fig. 7.20: a) Sketch showing sink hole, cave, stalactites, stalagmites and cave pillars; and b) Stalactites, stalagmites and pillars from Krem Mawmluh, Khasi hills, Meghalaya. The white material is the calcareous tuffa deposits. (Photo credit: Dr. Sushmitha Baskar)

SAQ 2

a) List the factors controlling the movement of underground water.

b) What are sources of underground water?

c) How are caves formed?

d) What are geyserite?

e) What are stalactites and stalagmites?

7.6 KARST TOPOGRAPHY

The irregular topography of limestone country showing various erosional features is known as karst topography. **Karst** is the German form of the Indo-European word *kar*, which means rock. The Italian term is *carso*, and the Slovenian *kras*. In Slovenia, *kras* or *krš* means 'bare stony ground' and also a rugged region. The type area for karst topography is in Yugoslavia and North West Italy. Different erosional and deposional features about which we have read in previous two sections along with many others are found together in Karst topography (Fig. 7.21). The formation of karst topography is the result of underground solution in limestone rocks. It is irregular surface feature formed by differential erosion of the country rock i.e. limestone. The close formation of sinks, caverns, underground channels and solution valleys produces a peculiar surface feature with a rugged surface, mostly waterless e.g. at Tapkeshwar, Dehradun, Uttarakhand.

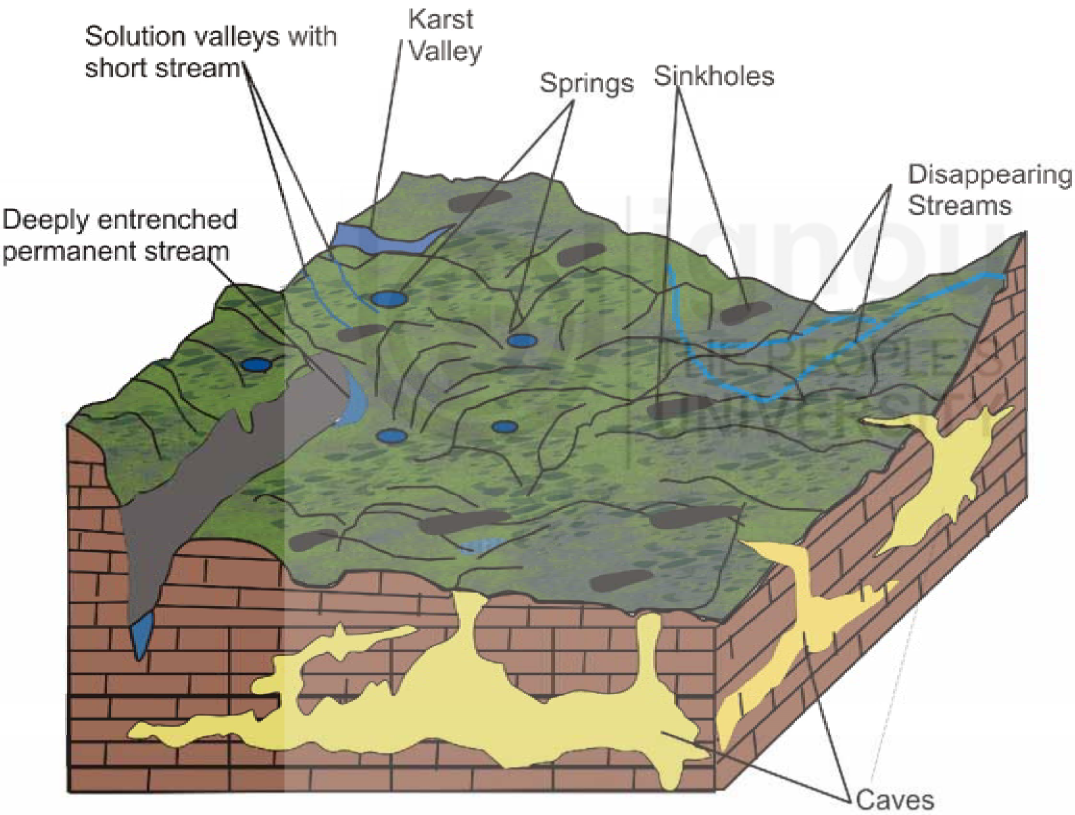


Fig. 7.21: Karst topography with caves, channels, sinks and solutional valleys.

7.7 SUMMARY

The landscape of the Earth is sculptured by various geological agents namely, wind and groundwater. Let us summarise what we have learnt in this unit:

- Wind erosion results in erosional landforms such as deflation basins and desert pavement, mushroom table, yardangs, pedestal rocks and ventifacts, by processes of deflation, wind abrasion and wind attrition. Transportation of wind borne sediments takes place by rolling, traction, saltation or suspension resulting in depositional landforms like loess deposits and sand dunes.

- Underground water is the water which percolates downwards. The boundary between unsaturated and saturated zones is the groundwater table also called water table. Sources of underground water are rainwater and glacial melt. The springs, ordinary wells, tube wells, artesian wells, hot or thermal springs and geysers are manifestations of groundwater. Topography developed due to action of groundwater is known as karst topography.
- Erosion by underground water involves the processes of chemical action. The resulting erosional landforms are landslides, caves, underground channels, caverns and sink. Precipitation from underground water due to loss of CO_2 leads to depositional landforms like geyserite, calcareous tuffa, replacement, geode, concretions, stalactites and stalagmites and dripstone.
- Summary of the geological work of the external agents about which we have read in the previous and this unit, viz. river, wind and underground water are tabulated in Table 7.2.

Table 7.2: Summary of Geological Work done by geological agents

Geological Activity		WIND	RIVER	GROUND WATER
EROSION	Erosional Processes	Deflation, abrasion, attrition,	Corrosion/ solution activity,hydraulic action, corrasion/ abrasion, attrition,	Chemical action, mechanical action
	Erosional landforms	Deflation basin, desert pavement, mushroom table, zeugen, yardangs, gour, pedestal rocks, ventifacts	V-shaped valley, pot holes, gorge,canyon waterfall	Landslides, caves, underground, channel, caverns, widening of joints, sinks, solutional alleys, karst topography
TRANSPOR-TATION	Transpor-tational Processes	Traction, saltation, suspension,	Solution, suspension, traction, rolling, saltation	In solution
DEPOSITION	Causes of Deposition	Obstruction, reduced velocity, rainfall	Reduction of gradient & volume, river bed widening, obstruction, meandering, sinking into gravels	Loss of CO_2, evaporation, decrease in temperature, fall in pressure, chemical reaction
	Depositional Landforms	Loess, dunes: cresentic, parabolic, longitudinal, transverse, star; playa, salina, deserts	Alluvial fans & cones, braided and meander river deposits,ox-bow lake, flood plains, alluvial deposits, levees, delta, bar, spit, hook	Geyserite, replacement geode, concretions, stalactites, stalagmites

7.8 ACTIVITY

In whatever region you are residing, visiting or working, there is always an opportunity to observe, interact and enjoy the *nature around you.*

1. Download Bhuvan Google Earth or similar software in your computer at home or internet cafe. Now visualise rivers, mountains, desert and the Himalayan regoins in the Google Earth and try to identify different kinds of erosional and depositional landforms about which you have studied in this unit.

2. Try to identify landforms present in your region on the google earth images.

3. Now try to observe the landforms on ground which you have identified in the google earth images.

4. Think or watch all around you–a dust storm or an evening during summer. You may find it very dusty all around. After a little rain the atmosphere around becomes so clear. Why is it so? Where has sand and dust gone?

7.9 TERMINAL QUESTIONS

1. Elaborate on 'wind as a transport agent'.
2. Describe the aeolian erosional landforms. Draw well labelled diagrams wherever required.
3. Write a short note on sand dune and its migration. Also draw well labelled diagrams wherever required.
4. Discuss the depositional landforms produced due to geological action of underground water.
5. List the erosional and depositional landforms produced by wind, river and underground water.

7.10 REFERENCES

- Fletcher, C. (2011) Physical Geology, The Science of Earth. John Wiley & Sons, 679p.

- Google Earth Images. (Accessed on 15 December 2014)

7.11 FURTHER/SUGGESTED READINGS

- Dutta, A. K. (2010) (Reprinted), Introduction to Physical Geology, Kalyani Publishers, Ludhiana, 250p.

- Mahapatra, G. B. (2013) (Reprinted), A Textbook of Geology, CBS Publishers, New Delhi, 366p.

- Verma, V. K. (2002) Lectures on Geomorphology, Pilgrims Book Pvt. Ltd. Delhi, 485p.

7.12 ANSWERS

Self-Assessment Questions

1. a) Wind may be defined as air in motion. It is produced by differences in barometric pressure. Air flows from higher pressure to lower pressure. The greater the pressure, the more will be the difference in the velocity of the wind.

   b) Both abrasion and attrition are the methods of wind erosion. In abrasion, particles moving with the wind strike the rocks on their path and erode them forming varied shapes. On the other hand, in attrition, the particles moving with the wind strike against one another, become rounded and smaller.

   c) Base level is the level below or beyond which effect of the erosional processes is ineffective. Wind becomes ineffective in presence of water. Hence, water table is the base level of wind erosion.

   d) An ideal dune has a gentle windward slope of about 10 to 15°. On the other side it has much steeper leeward slope of 30 to 35°. They are variable in height which is 100 to 300 feet or more depending on transporting power and available material.

2. a) Climate, topography and rock characteristics like permeability and porosity.

   b) Springs, hot springs or thermal springs, ordinary wells, tube wells, artesian wells, aquifer and geysers.

   c) Caves are formed as a result of solution activity in the soluble rocks like limestone. The slightly acidic water then flows and percolates through along the joints, fractures and bedding planes, slowly dissolving the limestone and enlarging the openings which develops a system of connected passage ways within the soluble bedrock.

   d) When hot water in geyser comes on the surface, it gets cooled and the material deposited around the mouth of such springs known as geyserites.

   e) They are depositional features formed in limestone caves. They are composed of $CaCO_3$. Stalactites are masses hanging from the roof of the cave. Whereas stalagmites are deposits formed at the base of the cave. Stalactites are long slender masses whereas stalagmites are thicker.

Terminal Questions

1. Refer subsection 7..2.1. Discuss about three types of load transported by wind and stages of transportation.

2. Refer subsection 7.2.2. Firstly discuss three processes for wind action viz. deflation, wind abrasion and wind attrition. Discuss erosional landforms like deflation basins and desert pavement, mushroom table or zeugens, yardangs, pedestal rocks and ventifacts

3. Refer subsection 7.2.3 for the answer, draw Figs. 7.9 and 7.10 to show the morphology of dunes and their migration.

4. Refer subsection 7.2.4. you can discuss geyserite, replacement, geode, concretions, stalactites and stalagmites,

5. Refer table mentioned in the summary Table 7.2.

UNIT 8

GEOLOGICAL WORK OF GLACIERS AND OCEANS

Structure

8.1 INTRODUCTION

In the previous units we have learnt about geological work done by agents namely wind, river and underground water. We discussed the erosional processes involved in the action of these agents in shaping the Earth's surface. We also have learnt the erosional and depositional landforms created by these agents. Now in this unit we will be introduced to the geological agents such as glacier, ocean and sea and the landscape sculptured by them. It is exciting to see the ocean or sea water washing the shore and bringing sediments back and forth. In this unit we will study the landforms developed by marine action. Similarly with the movement of the glacier down the valley erosion and deposition initiates due to the glacial action.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ define glacier and discuss its types and morphology;
- ❖ explain erosional processes of the geological work done by glaciers;
- ❖ discuss the transportation of glaciers;
- ❖ list the erosional and depositional landforms developed due to geological action of glaciers;
- ❖ identify the processes of marine erosion; and
- ❖ elaborate the landforms developed due to marine erosion and deposition.

8.2 GEOLOGICAL WORK OF GLACIERS

You might have seen glaciers.

Let us define them.

Glaciers are rivers of ice which flow out under the influence of gravity. Geologists define a glacier as a moving body of ice on land that flows downslope or outward from an area of accumulation. The glaciers move from fraction of a centimeter to several meters in a day.

Snow line is the lowest line of permanent ice or snow. It is the line up to which snow melts in the summers whereas above the snow line ice is present in all seasons.

Now let us distinguish between **ice** and **snow**.

Snow is newly fallen dry snow which is feathery, light and porous (Fig. 8.1). The snow flakes change into granular ice mass, known as '*nèvè*' in French and '*firn*' in German. When the body of granular snow become is so compact that it is impermeable to air then it is said to be **ice.** Formation of glaciers takes place under the influence of temperature, pressure and moisture. As snow continues to fall and gather, thickness of snow field increases and this causes more pressure upon the lower layer of snow. The ice becomes thick and moves outward or downhill. The movement is greater in the central part than at the sides.

Fig. 8.1: Porous and soft also known as snow flakes.

8.2.1 Types of Glaciers

Three types glaciers have been identified:

a) **Mountain / Valley glacier**: They are also known as Alpine glaciers, they occupy pre-existing valleys and are present above the snow line. **Hanging glaciers** are snow tributaries which do not meet the main glacier at the same level (Fig. 8.2) and remain overhanging. Valley glaciers are long, narrow tongues of ice that confine to the shape of the valley they occupy, and the existing topographical slope determines their direction of flow.

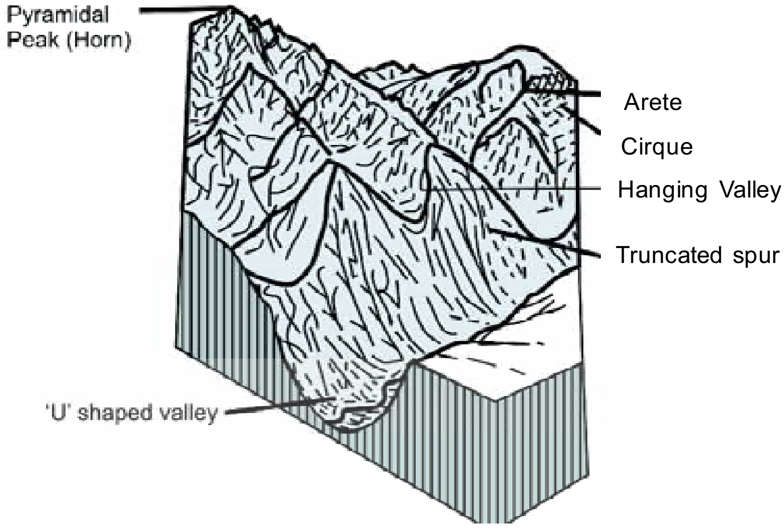


Fig. 8.2: Mountain glacial features.

b) **Piedmont glaciers**: These are those which are formed near or at foot of the mountains. They are formed when two or more valley glaciers meet together.

c) **Ice sheets and ice caps**: They are huge covers of ice and are also known as '**continental glacier'** or **ice sheets**. They are vast, covering at least 50,000 km^2 area, and are unconfined by topography; that is, their shape and movement are not controlled by the underlying landscape. Sometimes ridges and rocks project through ice, referred as **nunataks** (Fig. 8.3). Valley glaciers are small compared with the much more extensive continental glaciers, but even so, they may be as large as several kilometers across and hundreds of meters thick.

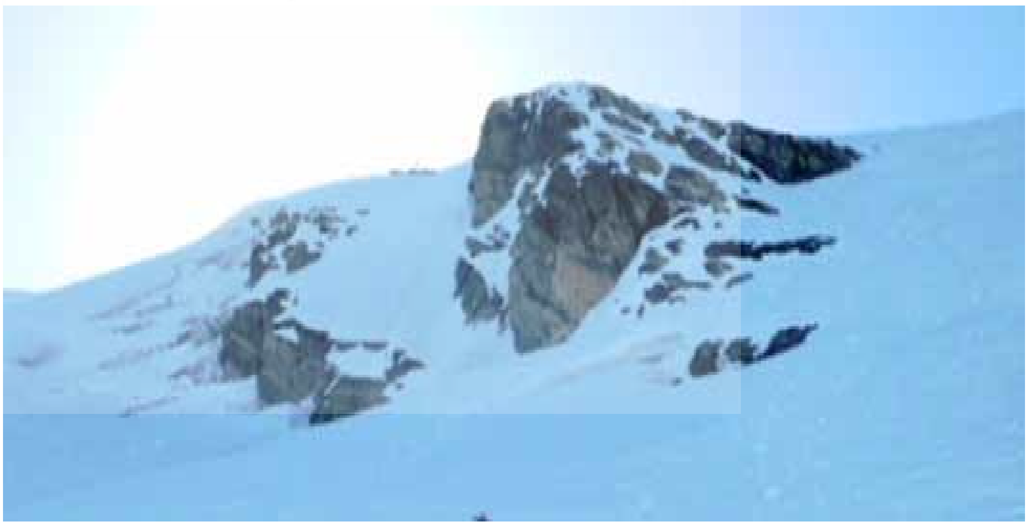


Fig. 8.3: Rocky masses- nunataks projecting through ice cover.

8.2.2 Morphology of Glaciers

The most important and common surface feature of the glacier is a crevasse. **Crevasses** are the cracks present on the surface of the glacial ice. They are most likely to occur in places where glacial deformation is strong. You will read about types of crevasses based on their origin and location (Fig. 8.4a and b).

i) **Bergschrund**: It is very wide and deep crevasse present near the head of the glacier. It is formed due to pulling of the thick ice downwards (Fig. 8.4a).

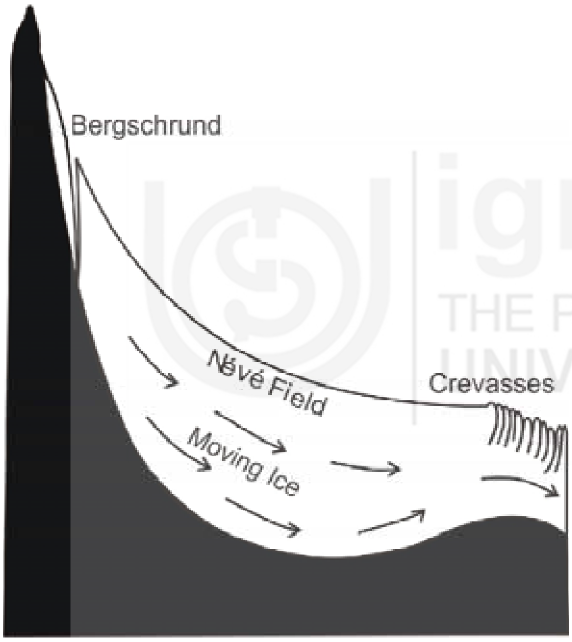
ii) **Longitudinal or Lateral crevasses**: These are present on the lateral sides of the glaciers. They are formed when glacier enters in a wider valley from a narrow valley (Fig. 8.4b).

iii) **Transverse crevasses**: They are formed perpendicular to the length of the glacier because of increase in gradient of glacial valley flow (Fig. 8.4b).

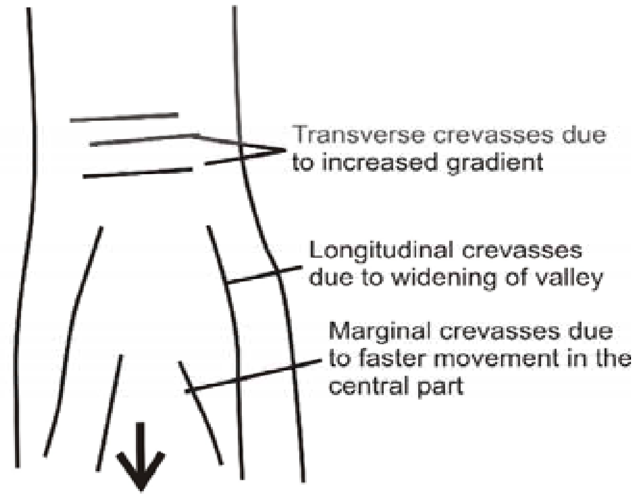
iv) **Marginal crevasses**: These are produced near the end of the glacier due to faster movement in the central part of the glacier. They are directed in the uphill direction (Fig. 8.4b).

Geological work of glaciers is known as **Glaciation**. Glaciation is the alteration of a land surface by massive movement of glacier ice over it that includes erosion, transportation and deposition.

Let us now read about the glacial erosional processes in the next subsection.



(a)



(b)

Fig. 8.4: Sketch of: a) Bergschrund; and b) Crevasses.

8.2.3 Erosional Processes

As the glacier moves, it erodes the underlying bedrock. By rubbing and grinding, the rocks are scratched, striated and grooved. Glacial erosion is influenced by the following factors:

- thickness of ice;
- amount of rock material carried or transported by it;
- velocity of glacier; and
- nature of bedrock.

Before reading about erosional landforms developed by the glaciers let us list the two main processes of glacial erosion-

i) **Plucking** occurs when melt water beneath the glacier penetrates fractures and crevices and holds the associated rocks firmly, while glacier in motion exerts pressure and tears/plucks off the grippped rock mass. The process is termed as plucking and is unique to temperate region.

ii) **Abrasion** is breaking away of rocks by rubbing action. As they grind and pulverise the bedrock beneath a glacier, carving scars termed as **glacial striations** are developed. Pulverised rock is known as **rock flour**.

8.2.4 Erosional Landforms

Now let us discuss some of the important erosional landforms produced by glaciers:

i) **Cirque**: It is a bowl-shaped amphitheater like depression formed by glacial plucking and abrasion at the glacier head. Cirques mark the birth place of valley glaciers where conditions are favourable for perrenial snow accumulates (Fig. 8.5a and b 8.6). They form by erosion of a preexisting depression on a mountain side. As snow and ice accumulates in the depression, frost wedging and plucking, combined with glacial erosion, enlarge and transform the head of a steep mountain valley into a typical amphitheater-shaped cirque. Cirques become wider and are cut deeper into mountain sides by headward erosion as a result of abrasion, plucking and several mass wasting processes. For example, part of a steep cirque headwall may collapse while frost wedging continues to force open loose rocks that tumble downslope, so a combination of processes erode a small mountain side depression into a large cirque. After ice melts cirques may become or turn into a small lake, called **tarn** or **cirque lakes**.

ii) **Arête**: Two adjacent cirques filled with glacial ice carves a sharp ridge line as shown in Fig. 8.5 and 8.6. Arête are narrow, serrated ridges and forms in two ways. In many cases, cirques form on opposite sides of a ridge and headward erosion reduces the ridge until only a thin partition of rock remains. The same effect occurs when erosion in two parallel glacial troughs reduces the intervening ridge to a thin spine of rock.

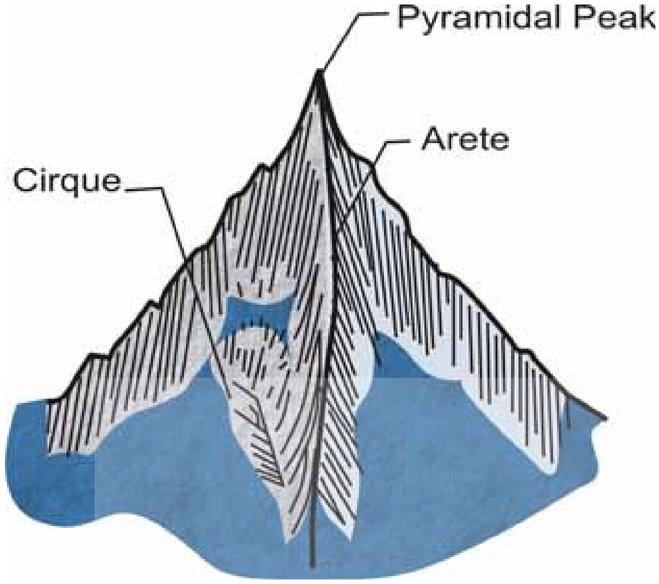


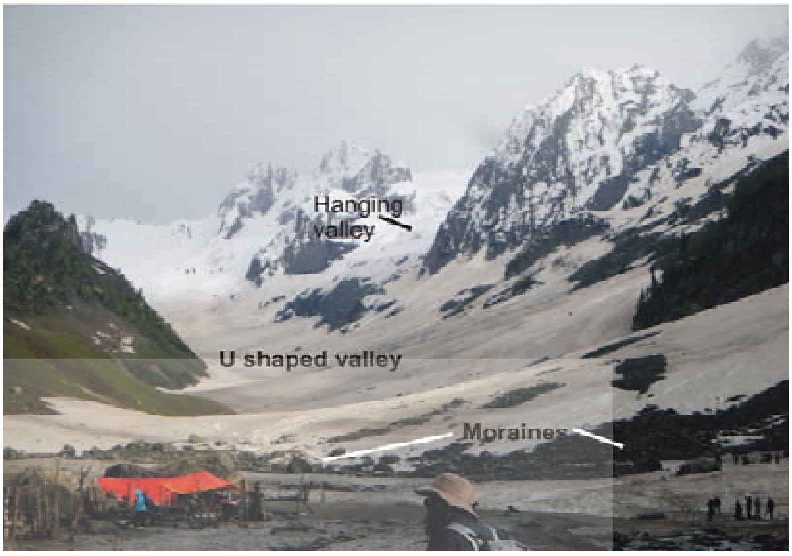
Fig. 8.5: Sketch showing pyramidal peak, arête and cirque.

Fig. 8.6: Field photograph of glacial features-cirques and arête related, Nubra Valley, Ladakh, J & K. (Photo credit: Dr. Rakesh Chandra)

iii) **Horn** or **pyramidal peak**: It is a pyramid like sharp peak formed when three or more cirques meet (Fig. 8.5 and 8.6). The most majestic of all mountain peaks are horns, steep-walled, pyramidal peaks formed by headward erosion of cirques. For a horn to form, a mountain peak must have at least three cirques on its flanks, all of which erode headward.

iv) **'U' shape valleys or glacial trough**: As glacier flows down from its cirque, it excavates a new valley or deepens an existing stream valley, shaping into characteristic 'U' shape valley (Fig 8.7). U-shaped glacial trough is one of the most distinctive features of the valley glaciation.

v) **Hanging valleys:** When the ice melts, the tributary valley is left as a hanging valley-positioned above the main valley floor (Fig. 8.7). After ice melts streams occupy valley and junction is marked by the water fall.



(a)

(b)

Fig. 8.7: a) Hanging valley and U-shaped glacial valley at Sonamarg, Kashmir valley; (Photo credit: Dr. Rakesh Chandra); **and b) Aerial photograph of Kashmir Himalaya taken from aircraft showing cirque, arête, horn, U-shaped valley.** (Photo credit: Ms Sainandini Mishra)

vi) **Striations**: As a glacier drags rocks along its base, which when harder scratch and groove the bedrock beneath, abrasions produced are called as striations.

vii) **Glacial stairways**: These are large step like features produced by glacial erosion.

viii) **Fjords (pronounced as fiords)**: Submerged glacial valleys are known as fjords. These are geomorphic features developed at or near the coast where marine waters enter inland through oversteeped glacial valley with high walled rocks. The conditions necessary for fjord formation are

- highlands-mountains or plateau
- intense glaciations
- deep –stream like valleys

Fiords are restricted to high latitudes where glaciers exist at low elevations, such as Alaska, western Canada, Scandinavia, Greenland, southern New Zealand, and southern Chile.

ix) **Roche Moutonnees**: They consist of asymmetrical mounds of rock of varying size, with a gradual smooth abraded slope (called as **stoss side**) on one side and steeper rougher slope on the other side (known as **lee side**) (Fig. 8.8).

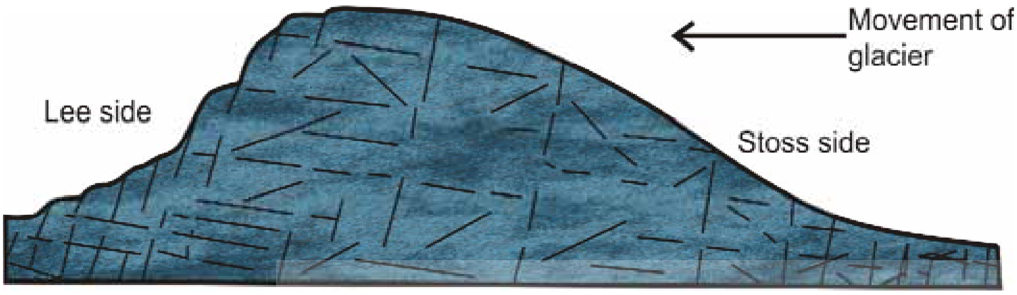


Fig. 8.8: Roche moutonnees resembles sheep's back

x) **Crag and Tail:** These are formed when hard vertical rock such as dyke obstructs the moving glacier passage. Crag faces boldly in the direction from which glacial ice advances. Tail is formed as gentle slope on the opposite side where the sediments are protected because of crag's obstruction (Fig. 8.9)

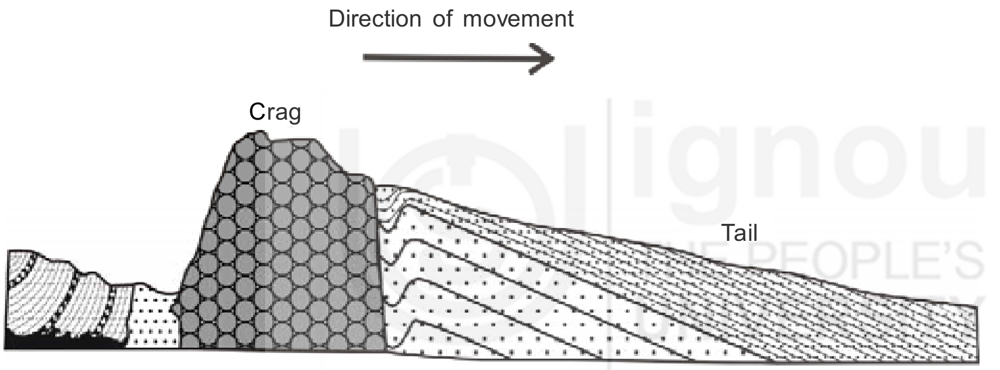


Fig. 8.9: Crag and tail.

xi) **Glacial table:** If sand or rock pebbles fall on some part of glacier, they protect glacial ice from melting. So sometimes huge blocks of ice are seen standing in the glacial fields. They stand over a pedestal of snow and are known as glacial tables.

xii) **Kettle:** Ice of glaciers is sometimes burried under glacial drift. After sometime ice melts and collapse of the roof takes place giving rise to basin like depressions which are called kettles.

xiii) **Glaciomarine drift:** It is glacial deposit which forms when glaciers reach to a ocean or lake. **Stratified drift** are deposits left by streams or pools of glacial melt water that are sorted and layered according to size. **Till** are unsorted and unlayered drift deposited directly by glacial ice. It ranges in size from clay-sized to huge boulders, even to the size of truck.

8.2.5 Glacial Transport

The valley glaciers move more rapidly than continental glaciers, but the rates for both vary from centimeters to tens of meters per day. The main glacier in a valley glacier system contains a greater volume of ice and thus has a greater discharge and flow velocity than its tributaries. Temperature exerts a seasonal control on valley glaciers because plastic flow remains rather constant year-round. However basal slip is more important during warmer months when melt water is abundant. Flow rates also vary within the ice itself. Valley glaciers are similar to streams, in that the valley walls and floor cause frictional resistance to flow. Therefore the ice in contact with the walls and floor moves more slowly than the ice some distance away. As the mass of ice accumulates over a period of time, the ice begins to deform and shift its position moving downhill by flowing, slipping and sliding. Velocity of the ice is greater at the middle of the channel than it is on the sides (because there is less friction). The velocity is measured by marking a straight line across the glacier and then observing the change in the line over time. There is also a difference between flow at the top and the bottom of the ice sheet: higher velocity occurs at the top of the sheet. Deformation is also linked to the velocity: the areas with higher velocity have less deformation then the sections of the ice sheet with lower velocities. The stress exerted on the ice flow depends on both gravitational and frictional forces. The glaciers transport most of the material by **traction**. Traction means rubbing action. Regelation is important in transportation. **Regelation** means melting of ice under pressure and subsequent freezing. Some of the material may be mixed within ice and transported.

Avalanches are masses of ice flowing downhill with great rapidity. They are large to very large masses of ice which get detached and move downhill like landslides destroying everything that comes in its way. Avalanches may be regarded as a type of mass wasting. Sometimes the glaciers reach to the sea and its parts break and start floating in water. Such floating masses of ice are called as **Icebergs**.

8.2.6 Depositional Landforms

Deposition by a glacier takes place when the ice begins to melt and the glacier slows down and vanishes, losing its transporting power. Glaciers deposit material if they are overloaded with debris or glacial ice starts melting.

Let us read about depositional landforms.

i) **Till** or **boulder clay**: The sediments deposited by glaciers are extremely unsorted known as **till** or **boulder clay**, which on consolidatation forms the rock known as **tillite**.

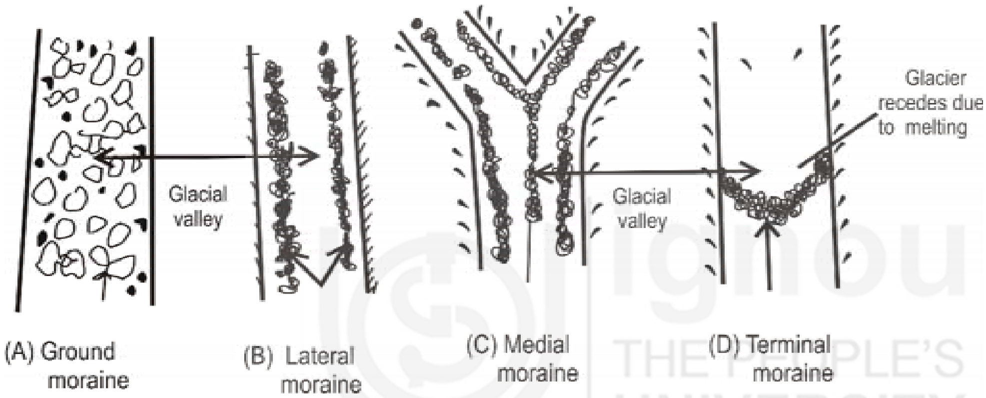
ii) **Erratics**: These are big to very big boulders with angular faceted striations left behind by the glaciers because of melting of glacial ice.

iii) **Moraines**: These are landforms composed of till left behind by a retreating glacier composed of unstratified, unsorted debris, i.e. boulders, pebbles, gravel, sand, silt and clay dropped in random fashion by glacier form deposit known as moraines.

Let us now discuss five types of **morainic deposits** (Fig. 8.10) which have been differentiated on the basis of their location in the valley.

- **Ground moraine**: It is deposited on the ground or the bed rock on which glacier moves. It has thin irregular surface of deposits.

(a)



(b)

Fig. 8.10: a) Geologists studying morainic deposits at Sonamarg, Kashmir valley (Photo credit: Dr. Rakesh Chandra); **and b) Sketch showing different types of morainic deposits.**

- **Lateral moraine**: Valley glaciers transport considerable sediment along their margins, much of it abraded and plucked from the valley walls, but a significant amount falls or slides onto the glacier's surface by mass wasting processes. In any case, this sediment is transported and deposited as long ridges of till called lateral moraines along the margins of the glacier.

- **Medial moraine**: It is present along middle part of the glacier or are formed by union of two lateral moraines of two intersecting valleys. Where two lateral moraines merge, as when a tributary glacier flows into a larger glacier, a medial moraine forms. A large glacier will often have several dark stripes of sediment on its surface, each of which is a medial moraine. One can determine how many tributaries a valley glacier has by the number of its medial moraines.

- **Terminal moraine**: These are deposited at the end of glacier when ice starts melting. They have convex side downwards because of faster movement in the central part of the glacier.

- **Recessional moraines**: When snow line goes up, the glaciers recede by melting. After a glacier has retreated for some time, its terminus may once again stabilise, and it deposits another end moraine. Because the ice front has receded, such moraines are called recessional moraines.

iv) **Drumlins**: They have also been described as '**Basket of eggs'**. They have shape of inverted tea-spoons and occur in groups. Their long axis is parallel to the direction of ice movement. Uphill sides are blunt and downhill sides are gently sloping (Fig. 8.11 and Fig. 8.13). In many areas where continental glaciers deposited till, the till has been reshaped into elongated hills known as drumlins varying in size from 50 m high to 1 km long, but most are much smaller. Drumlins are rarely found as single, isolated hills; instead, they occur in **drumlin fields** that contain hundreds or thousands of drumlins.

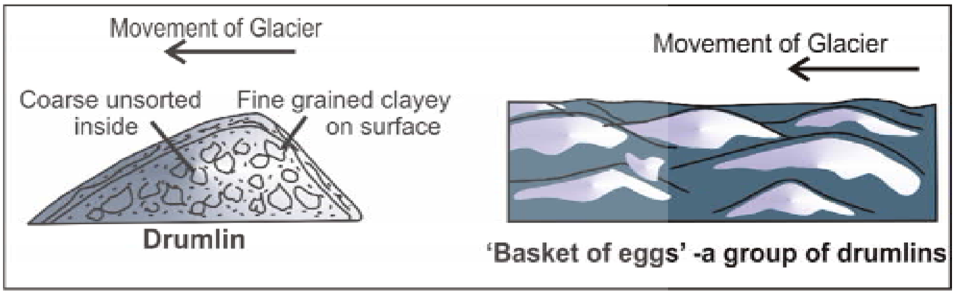


Fig. 8.11: Drumlins-'basket of eggs'.

v) **Eskers:** They are long sinuous, winding steep sided ridge like features built of stream-borne stratified drift. Eskers are fluvioglacial deposits with are produced by melting of ice and deposited in the subglacial tunnel. They are low in height but have greater length (Fig. 8.12). Most eskers have sharp crests and sides that slope at about 30 degrees. Some are as high as 100 m and can be traced for more than 500 km.

vi) **Glacial streams:** The melting of ice gives rise to glacial streams. Streams occuring at or near the bottom of glacier are called **subglacial streams**. Streams supported on the upper part of glacier are called **superglacial stream**. Streams occuring within the body of the glacier are called **englacial streams** (Fig. 8.12a).

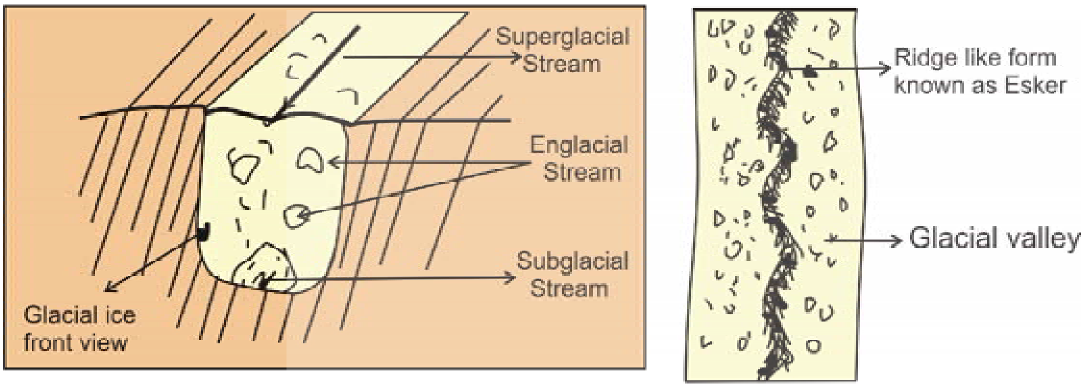
vii) **Kames or kame terraces**: Regions covered with glacial drift are often present as more or less flat-topped, steep-sided and irregular elevations called **kames or kame terraces** (Fig. 8.12b). Their origin is believed to be due to the pouring of sediments by glacial streams from high level or sedimentation between the valley walls and the tongues of glaciers. Kames are conical hills of stratified drift up to 50 m high. They form when a stream deposits sediment in a depression on a glacier's surface; as the ice melts, the deposit is lowered to the land surface. Kames also form in cavities within or beneath stagnant ice.

viii) **Crevasse filling**: These are short ridges which are usually straight. These are formed by filling up of crevasses of the glacier by glacial debris.

ix) **Glacial varves**: These are layered coarse and fine grained material deposits. Each pair is called a 'varve' which represents one year and is helpful in calculating age of the deposits.

x) **Outwash plain**: Drift that has been transported by melt water streams is called outwash, and it often forms broad sedimentary plains downstream of melting glaciers, known as outwash plains. They are better sorted amongst the glacial deposits. Strong winds can transport fine grained material from outwash plains over long distances and form deposit loess as shown in Fig. 8.12b.

xi) **Kettle lake**: They are depressions left behind after partially-buried ice blocks melt. Many are filled with water and are then called kettle lakes (Fig. 8.12b).



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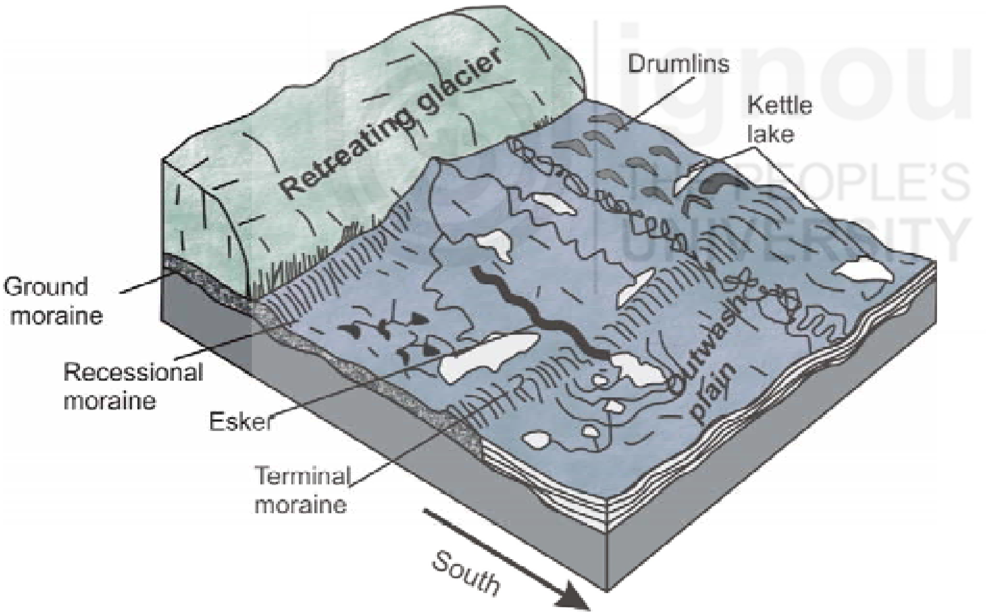


(b)

Fig. 8.12: a) Glacial streams (front view) and eskers; and b) Erosional and depositional features developed by glacier.

In the previous sections we have studied about the geological work done by glacier and the resulting landforms. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

a) What are crevasses?

b) Why does terminal moraine convex down the valley?

c) Name the erosional processes.

d) What is outwash plain?

8.3 GEOLOGICAL WORK OF OCEANS

The oceans and seas together cover a little over 71% of the Earth's surface. It has been estimated that oceans and seas cover an area of about 361 million square kilometers of the entire Earth. A large population live in the coastal areas. If you happen to live in the coastal regions, you might be aware of the impact of the waves and devastating effects of powerful storms. In this section, we will read about the geological activities carried out by the ocean and seas. There are six oceans in the world namely, Pacific, North Atlantic, South Atlantic, Indian, Arctic and Antarctic. Following types of seas may be recognised:

- **Epicontinental or marginal sea** are present on the margin of continents and have open connections with oceans e.g. Arabian sea
- **Eperic sea** are those which are nearly surrounded by land masses e.g. Red sea.
- **Relic sea** were formerly parts of oceans, now cut off by the uplift of land masses by Earth movements or by deposition e.g. Caspian Sea.

You might have observed that three primary mechanisms operate along most coasts and drive continuous processes namely, waves, tides and winds. **Waves** are the result of the transfer of wind energy to the water surface through the boundary shear along the interface. Wind direction controls the direction of wave motion. **Tides** are gravitational waves generated by the gravitational force of the Sea-Moon-Earth interaction. When waves approach a shoreline from an angle, they generate a **long shore current** that moves along the shoreline in the direction of wave current. Ocean floors are extremely irregular, rough and have relief features like those on continents.

You will read the three aspects of geological action of ocean and sea namely, erosion, transportation and deposition in the forthcoming sections.

8.3.1 Erosional Processes

Seas and oceans are continuously eroding the rock particles along their shores.

Erosion by sea is known as **marine erosion**. It occurs by four different processes:

i) **Hydraulic action:** Ocean waves, currents and tides exert considerable hydraulic action on shore rocks. There is breaking up of the rocks as waves crash against the cliffs like giant water hammers.

ii) **Corrasion or abrasion**: The waves armed with fragments of rocks strike against the cliffs and causes wear and tear.

iii) **Attrition**: During wave transgression, eroded particles mechanically collide with each other, bringing down the size of sand and silt. Rock fragments lose angularity.

iv) **Corrosion**: It is a chemical process of dislodging rock constiuents on which it acts.

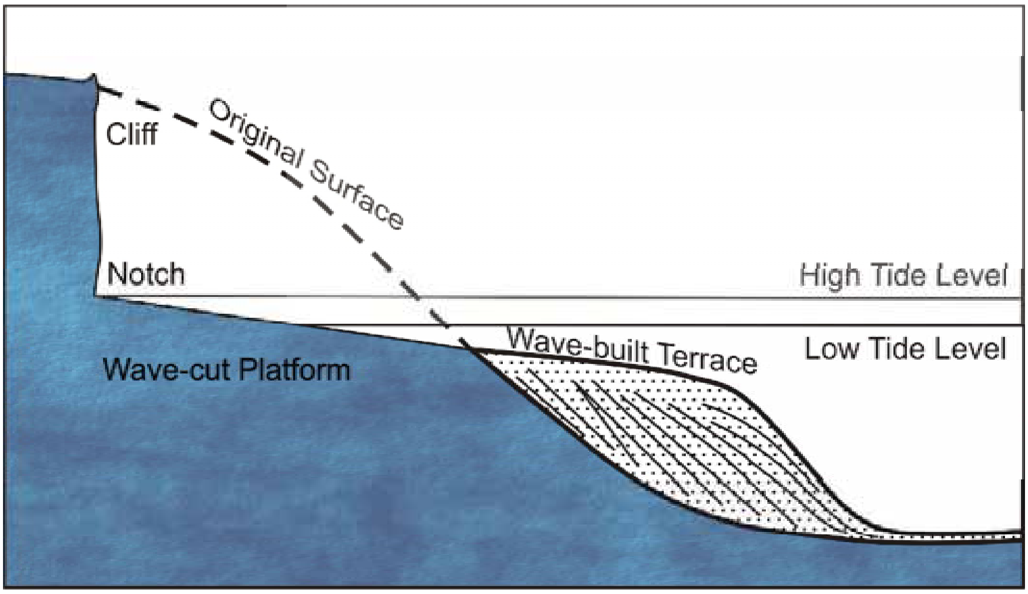
8.3.2 Erosional Landforms

Let us now learn about the erosional landforms formed due to marine erosion.

i) **Sea cliff**: Sea waves continuously cut into shores of moderately high land developing a steep front facing the sea. Sea waves attack entire length of the cliff (Fig. 8.13a and b, Fig. 8.15).

ii) **Wave cut terrace or platform**: After the breakdown of the sea cliff, the materials fall to the base to furnish more tools with which the waves may batter the cliff. Rock/sand loaded seawater abrade the basal irregularities to form a platform, which is termed wave cut platform (Fig. 8.13a and b).

(a)



(b)

Fig. 8.13: a) Photograph of the wave cut cliff, wave cut platform and wave built terrace (Photo credit: Dr. S. D. Shukla)**; and b) A cross sectional view.**

iii) **Sea caves**: They are hollowed-out soft portion of a wave-cut cliff. The abrasion and hydraulic action of the waves at sea level produce sea caves (Fig. 8.14a).

iv) **Sea coves and headland**: Sea waves erode softer and weaker rocks faster than resistant and harder rocks giving rise to sea cove. The harder ones that appear projecting in the sea are known as headlands (Fig. 8.14a).

v) **Sea arch**: They are formed due to partial erosion of any part of sea cave. The remaining part forms bridge like feature called sea arch or sea bridges (Fig. 8.14b).

vi) **Stacks**: It is the erosional remnant of the former headland (Fig. 8.14b).

vii) **Coast**: Coast is a strip of land of indefinite width produced by sea action. There is marked change from the sea shore to the coast (Fig. 8.15). A coast is geographic feature adjacent to shore, land immediately behind a cliff. It includes the land surfaces modelled distinctly by waves.

viii) **Shore**: It is the intersection between sea and land (Fig 8.15). A shoreline separates the land from water. The zone between high and low tides is the shore or shore zone.

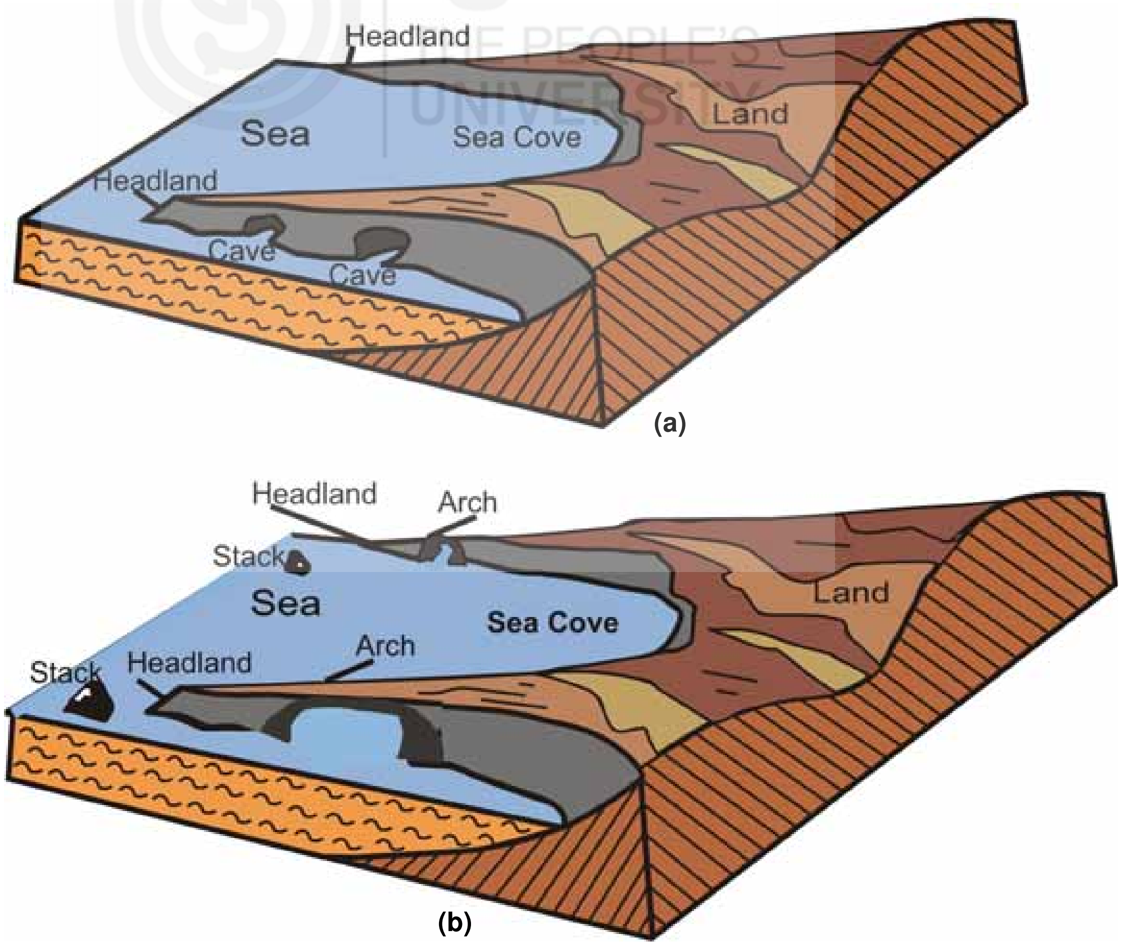


Fig. 8.14: Sea cave, sea cove, headland, sea arch and stack.

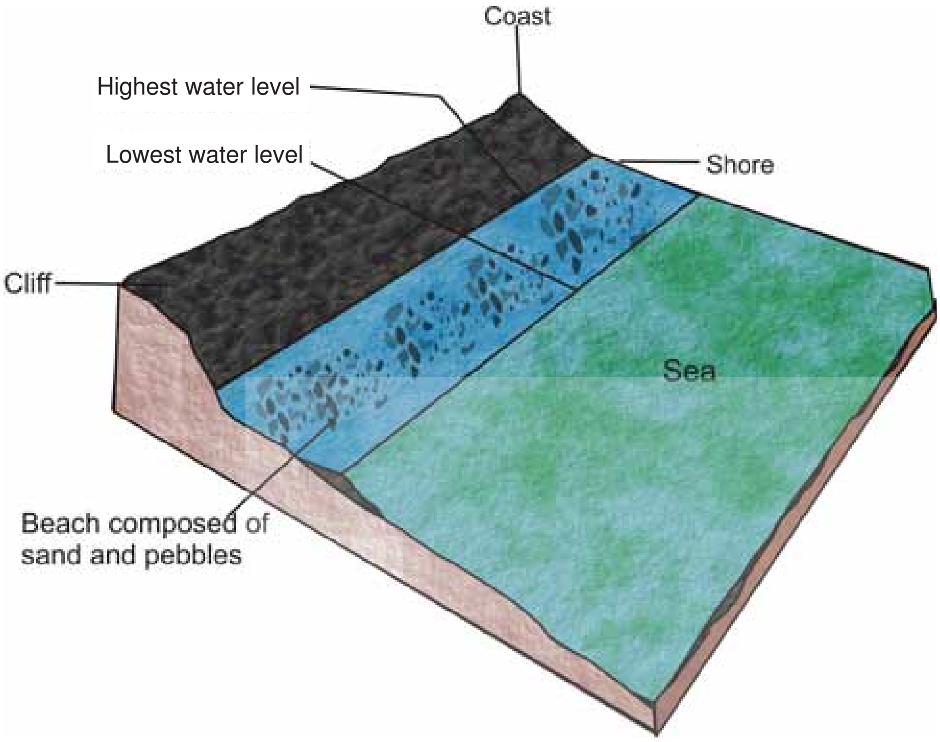


Fig. 8.15: Sea coast, cliffs, shore and beach.

In this section you have studied about the erosional processes and erosional landforms generated by seas and oceans. In the next subsection you would study about transportation by seas and oceans.

8.3.3 Transportation

Drifting of sediments in ocean takes place by different types of currents. Some of the types of currents by which drifting takes place are as follows:

- Beach drifting due to oblique waves.
- Longshore currents run almost parallel to the coast and transport the material along the coast.
- Turbidity currents are the bottom flowing density currents laden with suspended sediments, which move from the shore to deeper regions spreading horizontally on the sea/ocean floor.

8.3.4 Depositional Landforms

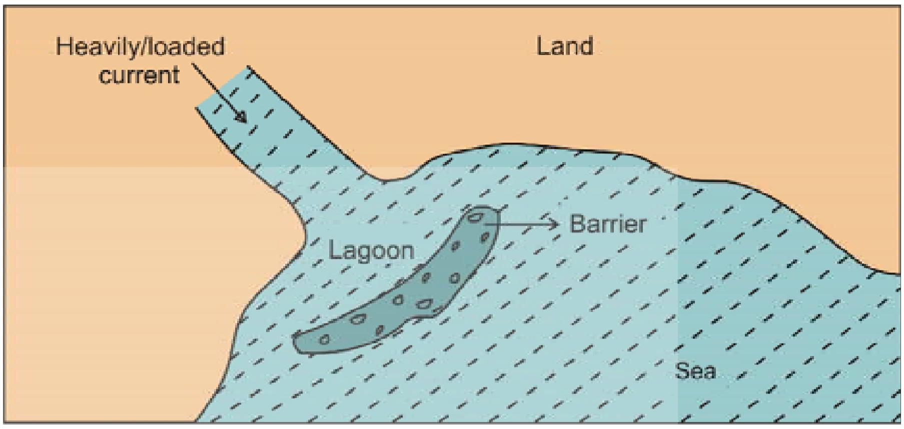
In this subsection, you would study about depositional landforms formed by the geological actions of seas and oceans. The deposition by sea is called as **marine deposition**. Marine deposits are mainly of two types:

- Shallow water deposits
- Abyssal or deep sea deposits.

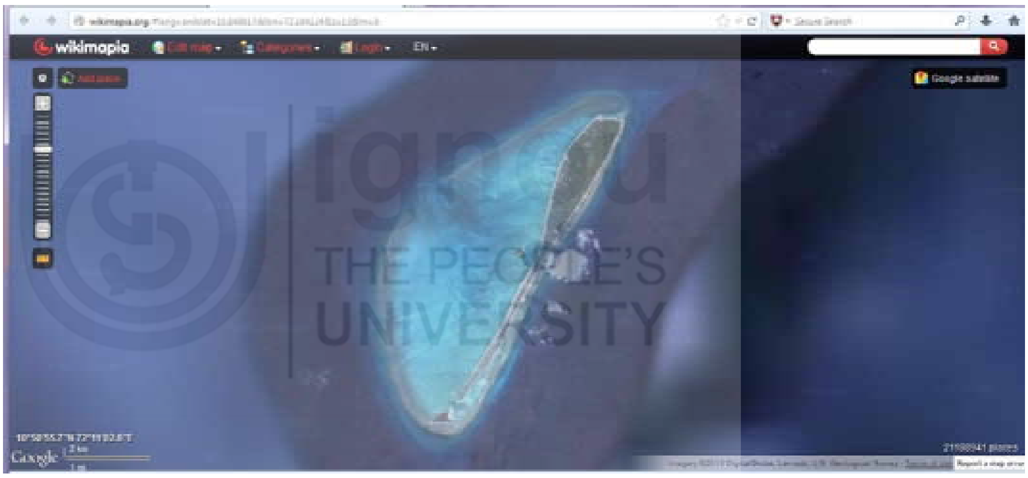
A) Shallow Water Deposits

i) **Sea beach**: It is a shoreline environment made up of sand and pebbles. It is gently sloping portion of the shore composed of sediments deposited and moved by waves, tides and longshore currents. Beaches are the most familiar coastal landforms, attracting millions of visitors each year and providing the economic base for many communities.

ii) **Barrier island**: It is a long offshore sand bar that builds up to form a barricade between open ocean waves and the main shoreline. When slope of the sea floor is less, the rivers take the material to some distance into the sea and deposit nearly parallel to the sea shore (Fig. 8.16a). The water between land and the barrier forms a **lagoon**.



(a)



(b)

Fig. 8.16: a) Sketch of barrier and lagoon; and b) Satellite imagery of lagoon and atoll, Agatti atoll in Lakshadweep with its characteristic central lagoon. (Source: www.wikimapia.org)

iii) **Wave built terrace**: The material eroded from sea cliff and wave cut terrace or platform is depositd adjacent to it in the sea producing a flat surface platform which is known as wave built terrace (Fig. 8.13). Note that **wave cut terrace** is the platform formed by destructive action of the sea waves whereas **wave built terrace** is the platform like feature which result due to constructive action of sea waves.

iv) **Spits**: It is narrow low lying tongue of sand or gravel projecting in the sea. It differs from the bar in the fact that it is attached to the land at one end. In other words, spit is a finger like projection of a beach into a body of water such as a bay. Hook is the spit curved inside forming a hook-shaped deposit.

v) **Bars**: If the spits connect themselves with coastal tract, enclosing water body they are described as bars. Bar is a ridge of sand and rock fragments formed across the mouth of a river or a bay.

vi) **Coral reefs**: These are island-like structure made up of organic deposits. Coral reefs are abundant in the Pacific and the Indian Oceans. Coral reefs are of three types:

- **Fringing reefs** are built close to main islands or volcanic cones and are laid bare only at low tides.
- **Barrier reefs** are built away from the mainland like barriers and enclose a body of water between the mainland and reef e.g. the Great Barrier Reef of Australia.
- **Atolls** are more or less circular coral reefs enclosing a characterstic lagoon (Fig. 8.16b).

B) Abyssal or Deep Sea Deposits

These sediments are formed at depths greater than 2000m in deeper part of ocean. On the floor of the seas of three to four kilometer depth mostly organic deposits are formed. Most common of those are '**oozes**' and '**red clay**'.

SAQ 2

a) List types of seas.

b) List main processes of marine erosion.

c) Name the landforms formed by marine erosion.

d) Define turbidity currents.

8.4 SUMMARY

The landscape of the Earth is sculptured by various geological agents namely, wind, water (including river, groundwater and sea/ocean) and glacier. In this unit we have read about erosional processes and landforms developed due to erosion and deposition of glacier, sea and ocean. Let us summarise what we have learnt in this unit:

- Glacial valleys are characterised by their 'U' shape. Glaciers are of three types, viz. ice sheets and ice caps or continental glacier, mountain or valley glacier and piedmont glaciers.
- Glacial erosion occurs in two ways-plucking and abrasion.
- The erosional landforms like cirque, arete, horn or pyramidal peak, hanging valleys, glacial stairways, fjords, roche moutonnees, kettles, glacial tables, crag and tail are produced by plucking and abrasion.
- Typical depositional features are moraines, erratics till or boulder clays, drumlins, eskers, crevasse filling and outwash plains.
- Marine erosion occurs in four ways hydraulic action, corrasion or abrasion, attrition and corrosion.
- Erosional landforms formed due to marine activity are sea cliff, wave cut platform or terrace, sea caves, sea coves and headland, sea arch and

stacks. Shallow marine deposits are sea beach and barriers. Abyssal or deep sea deposits are oozes and red clay.

- Marine deposits can be shallow water and abyssal or deep sea deposits.
- Summary of the geological work of some external agents are tabulated in Table 8.1.

Table 8.1: Summary of Geological Work done by geological agents

Geological Activity		WIND	RIVER	GROUND WATER	GLACIER	OCEANS
EROSION	Erosional Processes	Deflation, abrasion, attrition	Corrosion/ solution activity,hydraulic action, corrasion/ abrasion, attrition	Chemical action, mechanical action	Plucking, abrasion	Hydraulic action, corrosion/ solution, corrasion/ abrasion, attrition
EROSION	Erosional Land forms	Deflation basin, desert pavement, mushroom table, zeugen, yardangs, gour, pedestal rocks, ventifacts	V-shaped valley, pot holes, gorge,canyon waterfall, plunge pool river capture	Landslides, caves, underground, channel, caverns, widening of joints, sinks, solutional valleys, karst topography	Cirque, arete, horn, 'u' shaped valley, hanging valley, striations, glacial stairways, fjords, roche moutonnees, crag and tail, glacial tables, kettles	Sea cliff, wave cut platform/ terrace,sea caves, sea coves, sea arch, stacks, sea coast, sea shores, sea beach
TRANSPORTATION	Transportational Processes	Traction, saltation, suspension	Solution, suspension, traction, rolling, saltation	In solution	Traction, regelation-mixed with glacial ice	Beach drifting, long shore currents, turbidity currents
DEPOSITION	Causes of Deposition	Obstruction, reduced velocity, rainfall	Reduction of gradient & volume, river bed widening, obstruction, meandering, sinking into gravels	Loss of co_2, evaporation, decrease in temperature, fall in pressure, chemical reaction	Overloaded with debris, melting of ice	Shallow water deposition, deep sea deposition shallow water deposits
DEPOSITION	Depositional Landforms	Loess, dunes: cresentic, parabolic, longitudinal, transverse, star; playa, salina, deserts	Alluvial fans & cones, braided and meander river deposits,ox-bow lake, flood plains, alluvial deposits, levees, delta, bar, spit, hook	Geyserite, replacement geode, concretions, stalactites, stalagmites, calcareous tuffa	Till or boulder clay,erratics moraines, drumlins, eskers, crevasse filling, varve deposit, outwash plain	Sea beaches, barrier reefs, atoll, spits, bars, hook, delta,wave built terrace platform deep sea deposits, oozes, red clays

8.5 ACTIVITY

In whatever region you are residing, visiting or working, there is always an opportunity to observe, interact and enjoy the nature around you.

1. Download Google Earth or similar software in your computer at home or internet cafe. Now visualise glaciers in Himalayan region and coastal areas in the Google Earth and try to identify different kinds of erosional and depositional landforms about which you have studied in this unit.

2. Now try to observe the landforms on ground which you have identified in the google earth images.

8.6 TERMINAL QUESTIONS

1. Discuss the erosional landforms developed by the glacial action. Also draw well labelled diagrams whereever required.

2. Describe the depositional landforms formed by marine action. Draw well labelled diagram wherever required.

3. Distinguish between the erosional processes taking place by the geological action of glacier and ocean.

4. Differentiate between a river valley and glacial valley.

5. List the erosional and depositional landforms produced by wind, river, underground water, glacier and ocean.

8.7 REFERENCES

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8.8 FURTHER/SUGGESTED READINGS

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8.9 ANSWERS

Self-Assessment Questions

1. a) Crevasses are the cracks on the surface of glacial ice.

   b) The glaciers move faster in central part. When glacier recedes by melting, it leaves moranic deposit which is convex downwards.

   c) Hydraulic action, corrasion or abrasion, attrition and corrosion.

d) Drift that has been transported by meltwater streams is called outwash, and it often forms broad sedimentary plains downstream of melting glaciers, known as outwash plains. Strong winds can transport fine grained material from outwash plains over long distances and deposit as loess.

2. a) Relic sea, eperic sea, epicontinental or marginal sea.

   b) Corrosion, corrasion or abrasion, attrition and hydraulic action

   c) Sea cliff, wave cut platform or terrace, sea caves, shore, sea arch, stacks, coast, sea coves and headland.

   d) Turbidity currents are the bottom flowing density currents laden with suspended sediments, which move from the shore to deeper regions spreading horizontally on the sea/ocean floor.

Terminal Questions

1. Refer subsection 8.2.2 and Table 8.1
2. Refer subsection 8.3.3 and Table 8.1.
3. Main processes in glacial erosion are plucking and abrasion. Whereas in marine they are corrosion, corrasion or abrasion, attrition and hydraulic action.
4. Differences between glacial and river valley:

Glacial Valley	River Valley
U-shaped valley due to lateral erosion	V-shaped because base erosion is prominent
Hanging glacial valleys are present for the glaciers joining main glacier	Valley tributary river joining the main channel
No distinction as young, mature and old valleys	Four distinct stages present -initial, young mature and old valley
Glacial stairways are present	Rivers terraces are present
No profile of equilibrium	Profile of equilibrium is present
They can erode below sea level	Do not erode below sea level

5. Refer table 8.1 mentioned in the summary.

GLOSSARY

Abrasion : The grinding and scraping of a rock surface by the friction and impact of rock particles carried by water, wind or ice.

Abyssal plain : The area of the deep-ocean floor, usually lying at the foot of the continental rise.

Aeolian deposits : Sediments formed by wind transport.

Alluvial channel : A stream channel in which the bed and banks are composed largely of unconsolidated sediment (alluvium) that was previously deposited in the valley.

Alluvial fan : A fan-shaped deposit of sediment deposited at a point along a river where there is a decrease in gradient i.e. from mountain to plain.

Alluvium : Unconsolidated sediment deposited by a stream or river.

Angle of repose : The steepest angle at which loose material remains stationary without sliding down slope.

Aquifer : Rock or sediment through which groundwater moves easily.

Arête : A narrow, knifelike ridge separating two adjacent glaciated valleys.

Atoll : A continuous or broken ring of coral reef surrounding a central lagoon.

Back swamp : A poorly drained area on a flood plain, resulting when natural levees are present.

Barrier Island : A low, elongated ridge of sand that parallels the coast.

Base level : The level below which a stream cannot erode.

Beach : An accumulation of sediment found along the landward margin of the ocean or a lake.

Bed load : Sediment rolled along the bottom of a stream by moving water, or particles rubbed along the ground surface by wind.

Bedrock : A general term for the rock that underlies soil or other unconsolidated surface materials.

Blowout (deflation hollow) : A depression excavated by wind in easily eroded materials.

Bottomset bed : A layer of fine sediment deposited beyond the advancing edge of a delta and then buried by continuous delta growth.

Braided stream : A stream consisting of numerous intertwining channels.

Cavern : A naturally formed underground chamber or series of chambers most commonly produced by solution activity in limestone.

Chemical weathering : The processes by which the internal structure of a mineral is altered by the removal and/or addition of elements.

Cirque : An amphitheater-shaped basin at the head of a glaciated valley produced by frost wedging and plucking.

Coast : A strip of land that extends inland from the coastline as far as ocean-related features can be found.

Creep : The slow downhill movement of soil and regolith.

Crevasse : A deep crack in the brittle surface of a glacier.

Debris flow : A relatively rapid type of mass wasting that involves a flow of soil and regolith containing a large amount of water, also called mudflows.

Deflation : The lifting and removal of loose material by wind.

Delta : An accumulation of sediment formed where a stream enters a lake or ocean.

Dendritic drainage pattern : A stream system that resembles the pattern of a branching tree.

Denudation : It includes the long-term sum of processes that cause the wearing away of the Earth's surface by moving water, ice, wind and waves, leading to a reduction in elevation and relief of landforms and landscape.

Desert : It is a barren area of land where little precipitation occurs and consequently living conditions are hostile for plant and animal life. The lack of vegetation exposes the unprotected surface of the ground to the processes of denudation.

Desert pavement : A layer of coarse pebbles and gravel created when wind removes the finer material.

Dissolved load : The portion of a stream's load carried in solution.

Distributary : A section of a stream that leaves the main flow.

Drainage basin : The land area that contributes water to a stream.

Dune : A hill or ridge of wind-deposited sand.

Eluviation : The washing out of fine soil components from the A horizon by downward-percolating water.

End moraine : A ridge of till marking a former position of the front of the glacier.

Erosion	:	The incorporation and transportation of material by mobile agents, such as water, wind or ice.
Esker	:	Sinuous ridge composed largely of sand and gravel deposited by a stream flowing in a tunnel beneath a glacier near its terminus.
Estuary	:	It is a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea. Salinity here is measurably reduced by the freshwater flow of rivers.
Exfoliation dome	:	It is one of the more spectacular results of rock relaxation, which is the result of the removal of overburden by erosion. Large, dome-shaped structure, usually composed of granite, formed by sheeting.
External process	:	Process such as weathering, mass wasting, or erosion that is powered by the Sun and transforms solid rock into sediment.
Fall	:	A type of movement common to mass-wasting processes that refers to the free falling of detached individual pieces of any size.
Fiord	:	A steep-sided inlet of the sea formed when a glacial trough was partially submerged.
Floodplain	:	The flat, low-lying portion of a stream valley subject to periodic inundation.
Foreset bed	:	An inclined bed deposited along the front of a delta.
Frost wedging	:	The mechanical breakup of rock caused by the expansion of freezing water in cracks and crevices.
Geyser	:	A fountain of hot water ejected periodically from the ground.
Glacial drift	:	An all-embracing term for sediments of glacial origin, no matter how, where, or in what shape they were deposited.
Glacier	:	A thick mass of ice originating on land from the compaction and recrystallisation of snow.
Graded bed	:	A sediment layer characterised by a decrease in sediment size from bottom to top.
Gradient	:	The slope of stream or surface.
Ground moraine	:	An undulating layer of till deposited as the ice front retreats.
Hanging valley	:	A tributary valley that enters a glacial trough at a considerable height above the floor of the trough.

Headward erosion	:	The extension upslope of the head of a valley due to erosion.
Horn	:	A pyramid like peak formed by glacial action in three or more cirques surrounding a mountain summit.
Hot spring	:	A spring in which the water is 6^{O} to 9^{O}C (10^{O}C to 15^{O}F) warmer than the mean annual air temperature of its locality.
Kame:	:	A steep-sided hill composed of sand and gravel, originating when sediment collected in openings in stagnant glacial ice.
Kettle holes	:	Depressions created when blocks of ice become lodged in glacial deposits and subsequently melt.
Lateral moraine	:	A ridge of till along the sides of a valley glacier composed primarily of debris that fell to the glacier from the valley walls.
Loess	:	Deposits of windblown silt, lacking visible layer, generally buff colored, and capable of maintaining a nearly vertical cliff.
Longitudinal dunes	:	Long ridges of sand oriented parallel to the prevailing wind; these dunes form where and supplies are limited.
Longshore current	:	A nearshore current that flows parallel to the shore.
Mass wasting	:	The down slope movement of rock, regolith and soil under the direct influence of gravity.
Meander	:	A winding curve or bend of a river or road
Mechanical weathering	:	The physical disintegration of rock, resulting in smaller fragments.
Medial moraine	:	A ridge of till formed when lateral moraines from two coalescing glaciers join.
River mouth	:	The point downstream where a river empties into another stream or water body.
Mud crack	:	A feature in some sedimentary rocks that forms when wet mud dries out, shrinks and cracks.
Natural levees	:	The elevated landforms composed of alluvium that parallel some streams and act to confine their waters, except during flooding stage.
Outwash plain	:	A relatively flat, gently sloping plain consisting of materials deposited by melt water streams in front of the margin of an ice sheet.
Physical geology	:	A division of geology that examines that materials of Earth and seeks to understand the processes and forces acting upon Earth's surface from below.

Playa	:	The flat central area of an undrained desert basin.
Playa lake	:	Temporary lake in a playa.
Plucking	:	The process by which pieces of bedrock are lifted out of place by a glacier.
Point bar	:	A crescent-shaped accumulation of sand and gravel deposited on the inside of a meander.
Radial drainage pattern	:	A system of streams running in all directions away from a central elevated structure, such as a volcano or dome.
Regolith	:	The layer of rock and mineral fragments that nearly everywhere covers Earth's land surface.
River	:	A general term for a stream that carries a substantial amount of water and has numerous tributaries.
Roche moutonnee	:	An asymmetrical knob of bedrock formed when glacial abrasion smoothes the gentle slope facing the advancing ice sheet and plucking steepens the opposite side as the ice overrides the knob.
Rock flour	:	Ground-up rock produced by the grinding effect of a glacier.
Rockslide	:	The rapid slide of a mass of rock down slope along planes of weakness.
Runoff	:	Water that flows over the land rather than infiltrating into the ground.
Saltation	:	Transportation of sediment through a series of leaps or bounces.
Sea arch	:	An arch formed by wave erosion when caves on opposite sides of a headland unite.
Sea stack	:	An isolated mass of rock standing just offshore, produced by wave erosion of a headland.
Sinkhole	:	A depression produced in a region where soluble rock has been removed by groundwater.
Slide	:	A movement common to mass-wasting processes in which the material moving down slope remains fairly coherent and moves along a well-defined surface.
Slide face	:	The steep, leeward surface of a sand dune that maintains a slope of about 34°.
Slump	:	The downward slipping of a mass of rock or unconsolidated material moving as a unit along a curved surface.
Snowfield	:	An area where snow persists year round.
Snowline	:	Lower limit of perennial snow.

Soil : A combination of mineral and organic matter, water, and air, that portion of the regolith that supports plant growth.

Soil horizon : A layer of soil that has identifiable characteristics produced by chemical weathering and other soil-forming processes.

Soil profile : A vertical section through a soil showing its succession of horizons and the underlying parent material.

Soil taxonomy : A soil classification system consisting of six hierarchical categories based on observable soil characteristics. The system recognises 12 soil orders.

Spit : An elongated ridge of sand that projects from the land into the mouth of an adjacent bay.

Stalactite : The icicle like structure that hangs from the ceiling of a cavern.

Stalagmite : The column like form that grows upward from the floor of a cavern.

Stream: : A general term to denote the flow of water within any natural channel. Thus a small creek and a large river are both streams.

Striations (glacial) : Scratches or grooves in a bedrock surface caused by the grinding action of a glacier and its load of sediment.

Subsoil : A term applied to the B horizon of a soil profile.

Suspended load : The fine sediment carried within the body of flowing water or air.

Talus : An accumulation of rock debris at the base of a cliff.

Tectonics : The study of the large-scale processes that collectively deform Earth's crust.

Terminal moraine : The end moraine marking the farthest advance of a glacier.

Terrace : A flat, bench like structure produced by a stream that was left elevated as the stream cut downward.

Till : Unsorted sediment deposited directly by a glacier.

Tillite : A rock formed when glacial till is lithified.

Topset bed : An essentially horizontal sedimentary layer deposited on top of a delta during flooding stage.

Travertine : A form of limestone that is deposited by hot springs or as a cave deposit.

Trellis drainage : A system of streams in which nearly parallel tributaries occupy valley cut in folded strata.

Turbidite : Turbidity current deposit characterised by graded bedding.

Turbidity current : A down slope movement of dense, sediment-laden water created when sand and mud on the continental shelf and slope are dislodged and thrown into suspension.

Turbulent flow : The movement of water in an erratic fashion often characterised by swirling, whirlpool-like-eddies. Most stream flow is of this type.

Ultimate base level : Sea level; the lowest level to which stream erosion could lower the land.

Valley glacier : A glacier confined to a mountain valley, which in most instances had previously been a stream valley.

Ventifact : A cobble or pebble polished and shaped by the sand blasting effect of wind.

Water table : The upper level of the saturated zone of groundwater.

Wave-cut cliff : A seaward-facing cliff along a steep shoreline formed by wave erosion at its base and by mass wasting.

Wave-cut platform : A bench or shelf along a shore at sea level, cut by wave erosion.

Wave height : The vertical distance between the trough and crest of a wave.

Weathering : The disintegration and decomposition of rock at or near the surface of the Earth.

Yardang : A streamlined, wind-sculpted ridge having the appearance of an inverted ship's hull that is oriented parallel to the prevailing wind.

Zone of accumulation : The part of a glacier characterised by snow accumulation and ice formation.

Zone of saturation : Zone where all open spaces in sediment and rock are completely filled with water.

NOTE

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