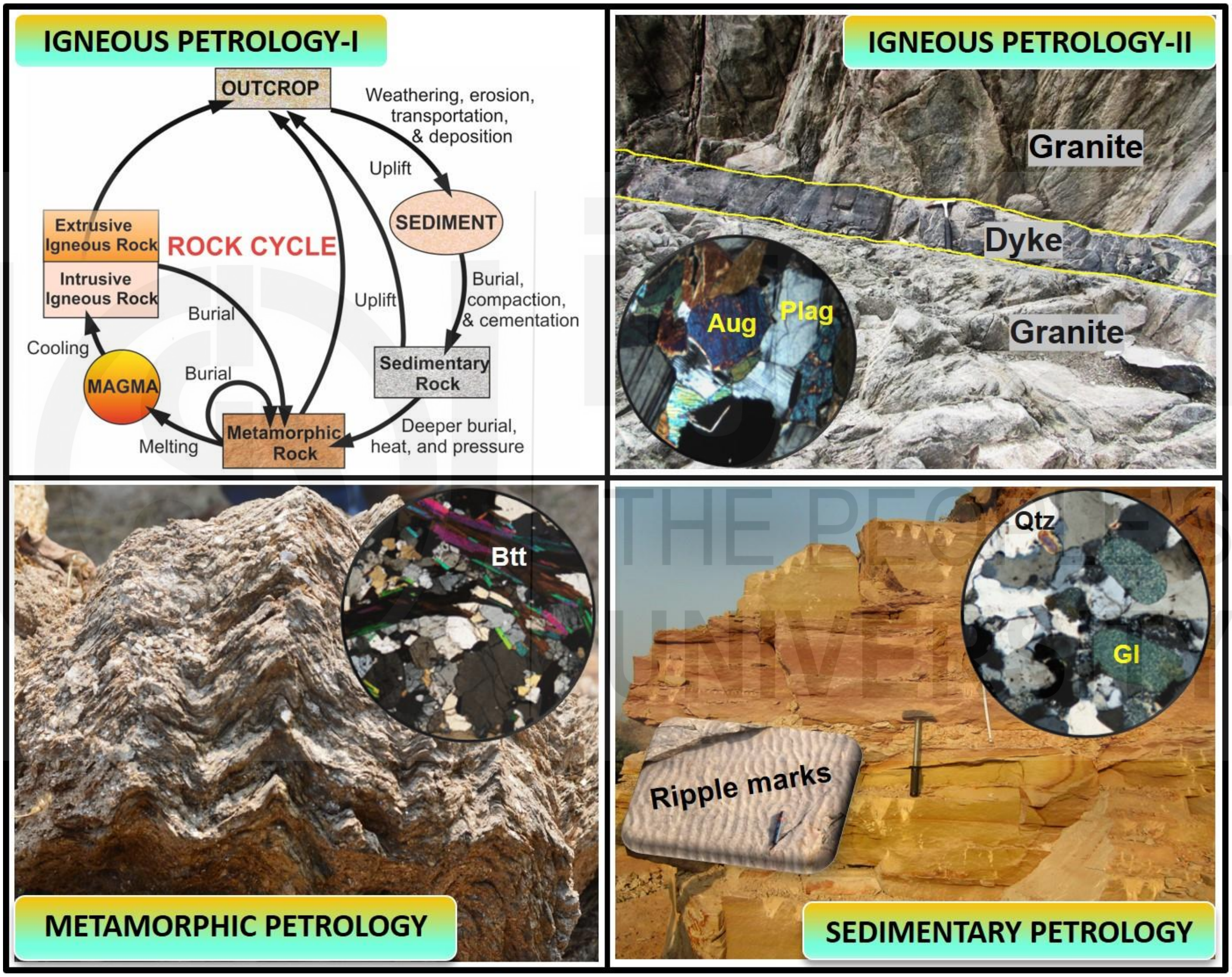
Indira Gandhi National Open University
School of Sciences

BGYCT – 135
PETROLOGY



Sedimentary Petrology and Metamorphic Petrology

Vol. 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

Indira Gandhi National Open University
School of Sciences

BGYCT – 135
PETROLOGY

Volume

2

SEDIMENTARY PETROLOGY AND METAMORPHIC PETROLOGY

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BGYCT-135: PETROLOGY

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Unit 12	Metamorphism
Unit 13	Types of Metamorphism
Unit 14	Textures and Structures of Metamorphic Rocks
Unit 15	Classification of Metamorphic Rocks

List of audio / video materials related to this course

1. **Igneous Textures, Processes and Pathways: An Overview**

   Link: https://www.youtube.com/watch?v=9NU3SL7HWF4

2. **Igneous Textures, Processes and Pathways: Aphanitic Textures**

   Link: https://www.youtube.com/watch?v=pboabkaFzWY&t=5s

3. **Igneous Textures, Processes and Pathways: Phaneritic Textures**

   Link: https://www.youtube.com/watch?v=tw7vVvp6R_U

4. **Igneous Textures, Processes and Pathways: Homogenous Textures**

   Link: https://www.youtube.com/watch?v=Zx6wQG0qiG4

5. **Igneous Textures, Processes and Pathways: Inhomogeneous Textures**

   Link: https://www.youtube.com/watch?v=XYb_tzRlSKc

6. **Igneous Textures, Processes and Pathways: Volcaniclastics**

   Link:

7. **Geology around us-Part I**

   Link: http://egyankosh.ac.in//handle/123456789/63948

8. **Geology around us-Part II**

   Links: https://youtu.be/BtmJ8lOfxek

   http://egyankosh.ac.in//handle/123456789/65950

9. **Deccan Volcanism- An inside story**

   Link: https://www.youtube.com/watch?v=1a3glcg0oGs&t=109s

10. **Physical Features of Volcanic Terrain**

    Link: https://www.youtube.com/watch?v=Wrbw0MQzSQU&t=141s

11. **Microscopic view of basaltic rocks**

    Link: https://www.youtube.com/watch?v=2RGL3XB2x3E&t=103s

12. **Exsolution Intergrowth**

    Link: https://youtu.be/7SnfV0nJMvk

13. **Rapakivi Texture**

    Link: https://youtu.be/voXGUT4HSxY

14. **Textures Related Zoning in Igneous Rocks**

    Link: https://www.youtube.com/watch?v=Wrbw0MQzSQU&t=141s

15. **Sedimentary structure of clastic rocks**

    Link: https://www.youtube.com/watch?v=llg5aAbaL0s&t=44s

16. **Sedimentary Structure of non-clastic rocks**

    Link: https://www.youtube.com/watch?v=3iL__lYkFRM

17. **Soil: Product of Weathering**

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

18. **Weathering its types and significance**

    Link: https://www.youtube.com/watch?v=gBYijIPPVgc

19. **Contact Metamorphic and Contact Metasomatic Deposits**

    Link: https://youtu.be/8uoDoJwNHCc

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 at http://egyankosh.ac.in/handle/123456789/36575

VOLUME 2: SEDIMENTARY PETROLOGY AND METAMORPHIC PETROLOGY

The course **BGYCT-135 Petrology** consists of four blocks, which have been packaged in two volumes.

In **Volume 1** of this course you have already read the first two blocks i.e. Block 1 and Block 2 which deal with igneous petrology. In **Block 1** you have learnt the fundamental concepts about petrology. You also learnt how to classify major rock types, concept of rock cycle, textural elements present in igneous rocks like crystallinity, granularity and fabric. Mineralogical classification of igneous rocks has also been discussed. In **Block 2** you were introduced to the concept, physical properties, composition and crystallisation of magma. We also discussed the megascopic and petrographic description of the common felsic, intermediate, mafic and ultramafic rocks.

Volume 2 contains last two blocks i.e. Block 3 and Block 4 which pertain to sedimentary and metamorphic petrology. **Block 3 Sedimentary Petrology** comprises four units. Now in this block we will discuss about the source of sediments, mode of origin, process of formation of sedimentary rocks and their textures and structures. We will also discuss the megascopic and petrographic details of some important siliciclastic and carbonate rocks and classification of sedimentary rocks. **Block 4 Metamorphic Petrology** comprises four units. The block will acquaint you with process and products of metamorphism. We will discuss the types, factors, zones and grade of metamorphism and the megascopic and petrographic details of some common metamorphic rocks. We will also discuss textures, structures and classification of metamorphic rocks.

Expected Learning Outcomes

After studying this volume, you should be able to:

- describe the processes that form sedimentary rock;
- discuss the mineral composition of sedimentary rocks;
- explain the types, factors, zones and grade of metamorphism;
- explain the textures and structures of sedimentary and metamorphic rocks;
- classify the sedimentary and metamorphic rocks;
- describe megascopic characters of common sedimentary and metamorphic rocks; and
- discuss microscopic characters of the common sedimentary and metamorphic rocks.

Hope you will enjoy reading this volume!

Wishing you success in this endeavour!!

Indira Gandhi National Open University
School of Sciences

BGYCT – 135
PETROLOGY

Block

3

SEDIMENTARY PETROLOGY

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BLOCK 3: SEDIMENTARY PETROLOGY

About 75% of the Earth's surface including its seafloor is covered with sediments and sedimentary rocks such as sand/sandstone, silt/siltstone and the limestone etc. These rocks originated either from the weathering of the continental crust or as chemical precipitates or as organic material. The process of transformation of sediment to sedimentary rocks involves a number of geological processes such as weathering, erosion, transportation, deposition, lithification and diagenesis.

Block 3 Sedimentary petrology will introduce you to the source of sediments, mode of origin, process of formation of sedimentary rocks and their textures and structures. You will also read about the classification of sedimentary rocks. This block consists of 4 units.

In **Unit 8 Formation of sedimentary rocks** you will get acquainted with the sedimentary particles that form the sedimentary rocks. You will learn about clastic and non-clastic sedimentary rocks, weathering processes and products, process of lithification and depositional environment of sedimentary rocks.

In **Unit 9 Textures of sedimentary rocks** you will get familiarised with sedimentary textures. In this unit you will study the grain size of particles, their distribution, morphology, packing and genetic significance of sedimentary rock.

In **Unit 10 Sedimentary structures** you will learn about sedimentary structures. You will discuss the mechanical, chemical and organic structures.

Unit 11 Classification of sedimentary rocks deals with the classification of sedimentary rocks on the basis of their mineralogical composition, environment of deposition, mode of formation and textural and structural features. Megascopic and petrographic details of common siliciclastic and carbonate rocks have also been discussed.

Expected Learning Outcomes

After studying this block, you should be able to:

- identify kinds of sedimentary particles, clastic and non-clastic sedimentary rocks;
- describe the processes that transform sediment to sedimentary rock;
- list the depositional environments;
- familiarise with the basic sedimentary textures and structures;
- know the mineral composition of sedimentary rocks;
- classify the sedimentary rocks; and
- describe some of the common sedimentary rocks.

After studying this block you will be able to get familiarised with the processes responsible for formation of sedimentary rock and classify and discuss some of the common sedimentary rocks.

In order to evaluate your learning while reading the self-learning material of this block, we have provided self-assessment exercises under the caption "**Self Assessment Questions (SAQ)**" at a few places and at the end "**Terminal Questions**" in all units of the block, which invariably end with answers to the questions, set in these exercises. You should attempt the exercises yourself and not be tempted to look up the answers given under the caption "Answers" beforehand. It should be noted that the check your progress is provided as study tools to help you keep on the right track as you read the units. You have been provided with the links of **audio/video materials** related to this course. They are blended with the self-learning material. You are instructed to watch/listen these audio video programmes and **answer the questions** given after "terminal question".

We advise that as you read the units, jot down important points in the space provided in the margins of each page. In fact, broad margins in the booklet are provided for you to write your notes on. Make your notes as you work through the materials. This will help you prepare for the term end examination (TEE) and also in assimilating the content.

Your feedback pertaining to this block will help us undertake maintenance and timely revision of the block. Send your feedback to us to the address given below or e-mail to kakoligogoi@ignou.ac.in or meenalmishra@ignou.ac.in:

The Course Coordinator BGYCT-135

Discipline of Geology

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We hope that you would enjoy reading the self-learning material.

Wishing you success and all the best in this endeavour!!

UNIT 8

FORMATION OF SEDIMENTARY ROCKS

Structure

8.1 INTRODUCTION

In Block 1 and Block 2 of BGYCT-133 you have been introduced to magma, rocks types, textures, structures, forms of igneous rocks. Now let us study about sediments and processes of formation of sedimentary rocks. We know that the most common rocks exposed on the Earth's surface are sedimentary rocks. They occupy about 75% of the total surface area of the globe. Sedimentary rocks are also known as 'secondary rocks' since they are formed by the consolidation of loose sediments or chemical precipitation from solution or organic matter consisting of secretions or remains of plants and animals. Sedimentary rocks record the conditions that existed on the Earth at the time of their deposition and subsequent changes. Shale, sandstone, conglomerate, limestone

and dolomite are examples of sedimentary rocks. These constitute about 95% of the total sedimentary rocks, rest being less than 5%. Sedimentary rocks are important as they may contain oil and natural gas, coal, salt deposits, phosphates, groundwater, and many other natural resources. Study of the source of sediments, mode of origin and process(es) of formation of sedimentary rocks immensely helps in reconstructing depositional environment. You have been introduced to the basic concepts of rock weathering in Unit 5 of course BGYCT-131. In this unit we will discuss about sedimentary rocks, clastics and non-clastics, their formational processes and depositional environments. We will also discuss the formation of various sedimentary rocks.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ discuss sedimentary particles, clastic and non-clastic sedimentary rocks;
- ❖ describe the processes that form sedimentary rock;
- ❖ explain formation of various sedimentary rocks; and
- ❖ recognize the depositional environments.

8.2 SEDIMENT AND SEDIMENTARY ROCKS

Let us study about sediments and sedimentary rocks.

Sediments are the precursors of sedimentary rocks. Most of the Earth's surface is covered with sediments, layers of loose material, such as sand, silt and clay that had originated from the weathering of the continental crust, either as solid debris from rocks or as dissolved substances. The word sediment is derived from Latin word *sedimentum*, which means "to settle," a reference to solid material settling out of a fluid (water or air). **Sediments** are loose solid particles (also known as detrital or terrigenous or clastic material) originating from the breaking apart of older pre-existing rocks by the process of weathering and erosion.They form a surface veneer or 'cover' on bedrock ranging in thickness from practically non-existent (in places where bedrock crops out at the Earth's surface) to few kms. Sediment transforms into soil which we know is essential for life. You have read about soil and its formation in Unit 5 Rock Weathering.

Watch the following video to know more about formation of soil.

- **Soil: Product of Weathering**

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

You have read in the earlier section that sedimentary rocks can be clastic and non-clastic. Non-clastic sedimentary rocks form from chemical reaction, precipitation of dissolved component(s) or from organic materials. Examples of sediments include sand, gravel, mud, pieces of shells etc. Sedimentary rocks are made by the accumulation of particles (i.e. sediments) of older rocks, either as clasts (large piece of rocks) or as mineral grains, chemically or biogenically precipitated. Sedimentary rocks are known to cover as much as 75 percent surface area of land. The study of sediments can reveal the provenance, transportation and depositional environment of the source area and also reflects the history of formation of rocks at the source. Source areas generally are upland, mountainous regions undergoing uplift, but detritus also may be supplied from erosion in lowland and coastal areas.

According to F.J. Pettijohn, 'A **sedimentary deposit** is the body of solid material accumulated at or near the surface of the Earth under prevalent normal temperatures and pressures, which normally characterise its environment of deposition'. Sedimentary rocks of the geological record were deposited in the whole range of natural environments that exist today. The study of these modern environments and their sediments and processes contributes much to the understanding of their ancient equivalents.

8.2.1 Importance of Studying Sedimentary Rocks

You must be wondering as why we study sedimentary rocks?

The study of sedimentary rocks is enormously important and interesting and has great practical value. The study and analysis of the structure, texture and composition of the sediments and sedimentary rocks enables sedimentologists to comprehend about the origin of the sedimentary rocks in order to deduce the environment of deposition like ancient shorelines, mountains, riverine flood plains, deserts, and swamps in other regions. Let us consider an example of the top of Mount Everest which consists of fossiliferous limestone. We know that such limestones are formed in sea/ocean, it can be inferred that Mount Everest was part of an ocean floor in the geological past.

We get most valuable sources of energy like oil, gas and coal from these rocks. The fossil fuels oil and gas are derived from the maturation of organic matter present in sediments and these then migrate to the suitable reservoir which is mostly porous sedimentary rocks. Sedimentary rocks supply much of the world's iron, aluminum, potash, salt, building materials and many other essential raw materials. There are many reasons for studying sedimentary rocks apart from the wealth of economic minerals and materials contained within them. Geologists are interested in sedimentary processes because they provide vital clues to understanding the palaeoclimate. Much of our knowledge of the evolution of life on Earth is derived from fossils preserved in sedimentary rocks. The study of sedimentary rocks is important deducing environment and processes of deposition and palaeogeography and palaeoclimatology which would contribute towards knowledge and understanding of the earth's geological history.

Watch the following videos to know more about importance of sedimentary rocks.

- **Geology around us-Part I**

  Link: http://egyankosh.ac.in//handle/123456789/63948

- **Geology around us-Part II**

  Link: https://youtu.be/BtmJ8lOfxek

  http://egyankosh.ac.in//handle/123456789/65950

You have read about sediment and sedimentary rocks in this section now let us learn about kinds of sedimentary particles.

8.2.2 Kinds of Sedimentary Particles

Now let us read about sedimentary particles.

The particles that form a sedimentary rock are called sediment, and may be composed of detritus/minerals or biological detritus/organic matter. Thus, sedimentary particles or sediments are building blocks of sedimentary rocks. We can classify sedimentary particles into three groups:

1. **Terrigenous particles**: They are the fragments of the pre-existing rocks that have been worn down into small pieces such as gravel, sand, silt, or clay by weathering, mass-wasting events by geological agencies like wind, water or ice and volcanoes. They form basic components of clastic rocks such as sandstone and shale.

   Terrigenous sedimentary particles can also comprise volcanic-derived clasts such as ash, lapilli and bombs or blocks. **Volcaniclastics** sediments are those composed mainly of grains and clasts derived from contemporaneous volcanic activity.

2. **Chemical precipitates**: These materials are transported in solution as dissolved load, but later they grow as solids in the depositional basin as a result of chemical precipitation. Carbonate rocks and evaporites are examples of chemical precipitates.

3. **Organic materials**: They are plant and skeletal remains or imprints of organisms**;** Examples are coal deposit and coquina or biological secretions like fossiliferous limestone.

8.3 TYPES OF SEDIMENTARY ROCKS

In the previous section we have read about different kinds of sedimentary particles. Now, in this section let us study about types of sedimentary rocks. Sedimentary rocks have been variously classified on the basis of their mineralogical composition, mode of formation, environment of deposition and textural features. Depending on the origin and nature of the sedimentary particles, sedimentary rocks can be classified as:

1. Clastic Rocks
2. Non-clastic Rocks

Now, let us discuss more about them.

8.3.1 Clastic Rocks

Sediments of clastic rocks are derived from disintegration of pre-existing rocks. Their grain size is quite variable ranging from clay, silt and sand up to pebble, cobble and boulder size materials. These sediments or clasts are transported by gravity, running water, wind and glaciers and are laid down in various depositional basins, marine, fluvial, aeolian, lacustrine, etc. under prevalent conditions of temperature and pressure. This type of sedimentary deposition is referred to as **clastic sedimentation**. Example of rocks formed by deposition of clastic materials are conglomerate, sandstone, and shale.

Let us now discuss the composition and texture of clastic rocks.

- **Composition**: Clastic rocks contain grains of quartz, feldspar, mica, clay minerals, iron oxides, and fragments of rocks. Lithic fragments may include pieces of limestone, mudrock, plutonic/volcanic rock, chert, etc. Plant debris, shell and skeletal materials may also be present. Calcite and amorphous silica may occur as secondary cementing minerals. A very small amount of heavy minerals like zircon, tourmaline, rutile, etc. may as well be present.

  Amongst all the mineral constituents, quartz is the most abundant mineral due to its resistance to weathering both physical and chemical. Feldspars are common minerals present in clastic rocks. They are chemically reactive and alter to clay minerals during chemical weathering. Other minerals derived from the source rock, such as olivine, amphiboles, pyroxenes, micas, and carbonates are chemically reactive and tend to be absent in mature clastic sediments.

- **Texture**: Clastic sedimentary rocks exhibit clastic texture, i.e. a framework consisting of variable size mineral grains cemented by chemical precipitates or matrix. Texture refers to grain size, grain shape and sorting of sediments which has been discussed in detail in the Unit 9 of this course. Texture of clastic rock is very significant in the interpretation of geological history of the rock.

Watch the following video to know more about clastic rocks.

- **Sedimentary structure of clastic rocks**

  Link: https://www.youtube.com/watch?v=llg5aAbaL0s&t=44s

8.3.2 Non-Clastic Rocks

Non-clastic sedimentary rocks are made up of fragments of interlocking minerals formed by chemical processes such as evaporation, precipitation, crystallisation or biochemical processes, i.e. accumulation of remains of hard parts of organisms. Thus, non-clastic sedimentary rocks are further subdivided into:

- Chemical Sedimentary Rocks
- Biochemical / Organic Sedimentary Rocks

Now, let us discuss them one by one.

- **Chemical Sedimentary Rocks**

The dissolved mineral products that are removed from the site of weathering are transported in solution and deposited in a basin by chemical precipitation. Chemically precipitated such rocks are known as chemical sedimentary rocks, e.g. limestone and dolomite. Other chemical precipitates may include ironstone and phosphates. Some rocks are produced by chemical precipitation and evaporation of substances dissolved in sea water in enclosed basins. Common examples are evaporites like gypsum ($CaSO_4.2H_2O$) and rock salt (NaCl). This type of sedimentation is referred to as chemical sedimentation.

- **Biochemical /Organic Sedimentary Rocks**

Carbonaceous materials like plant and skeletal remains of organisms form the major components of organic and biogenic sedimentary rocks. Examples of rocks formed by the accumulation of plant debris in swamp or bogs are coal deposits. Another example of rocks deposited by the accumulation of macro- and microorganisms is coquina and chalk deposit.

Watch the following video to know more about non-clastic rocks.

- **Sedimentary structure of non-clastic rocks.**

  Link: https://www.youtube.com/watch?v=3iL__lYkFRM

8.4 SEDIMENTARY PROCESSES

You have already read about rock weathering, geological work of rivers, wind, underground water, glaciers and oceans in Block 2 Earth Surface Processes of course BGYCT-131. Rocks existing on the Earth at any given point of time are exposed to the action of atmospheric agencies like wind, water, ice, etc. resulting in breakdown of these rocks into small particles. These particles are transported to varying distances and finally deposited in suitable basins. Thus, the formation of sedimentary rocks involves the following processes. Let us discuss them in detail:

- Weathering
- Erosion
- Transportation
- Deposition

8.4.1 Weathering

You have read about weathering in Unit 5 of BGYCT-131 course. Rocks exposed to the atmosphere and hydrosphere are constantly changed by various processes of physical disintegration and chemical decomposition. The process is known as weathering. It is caused by precipitation, change in temperature, frost action, plant growth, animal and human activities and dissolution of minerals by chemical action. Physical and chemical characters of rocks are changed during the process of weathering. Physical and chemical weathering processes are different but they work together in breaking and disintegrating rocks and minerals. Weathering of rocks can take place by physical, chemical and biological actions. Let us read about them.

Watch this video to know about weathering its types and significance.

- **Weathering its types and significance**

  Link: https://www.youtube.com/watch?v=gBYijIPPVgc

1. **Physical Weathering**

Let us recall what we have learnt about physical weathering in Unit 5 of BGYCT-131 course. Physical weathering (also called mechanical weathering) involves disintegration of rocks and minerals into smaller pieces through direct contact with atmospheric conditions, such as heat, water, ice and pressure without changing their chemical composition. It causes physical disintegration only and is more effective in cold or dry regions. Physical weathering takes place by variety of processes such as abrasion, frost action, unloading, thermal cycling, plant and animal activities, as mentioned below:

- **Abrasion**: In this weathering, the sediments and other clasts are reduced in size. Water and wind loaded with sediments have tremendous power of cutting the rocks through which they pass (Fig. 8.1). Huge moving glaciers grind rocks in their way and carry large amount of materials.

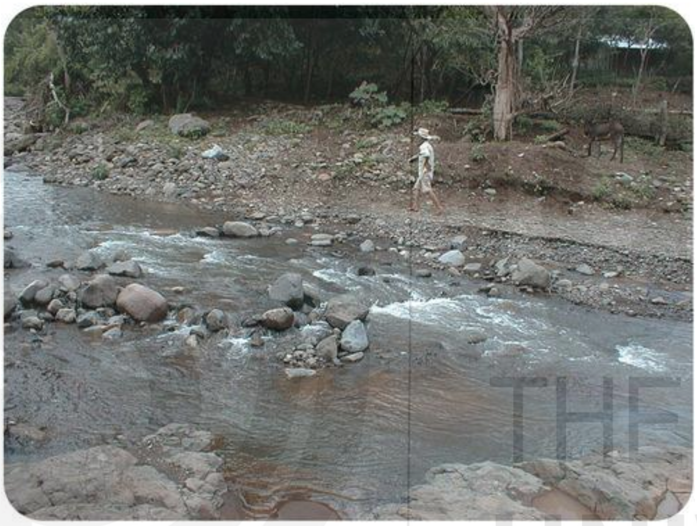

Fig. 8.1: Sediments produced by weathering and their transportation by stream.

- **Frost action**: It occurs mainly in the areas where there is a lot of moisture and frequent fluctuation of temperatures above and below freezing point. In the areas of high altitudes, water percolated in the cracks and joints of the rock freezes during night. We know that there is about 9% increase in volume of water upon freezing. Repeated freeze - thaw cycle exerts pressure on its surrounding causing fracture in the rock. As process repeats over time, cracks become larger and break up along the joints of the rocks into angular pieces (Fig. 8.2). Talus or scree deposits along the foothills are example of frost action.

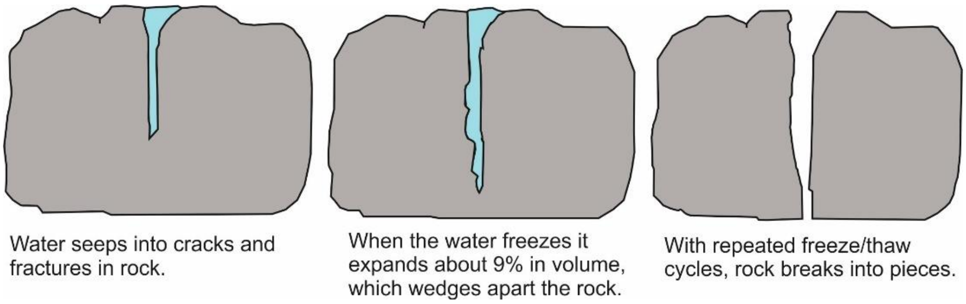

Fig. 8.2: Frost action in a rock.

- **Pressure release or unloading**: Intrusive igneous rock, for example; granite is formed at great depth. They bear tremendous pressure. As the material is removed from above due to erosion or any other reason, pressure on the rock is released and the outer rock surface expands. The expansion of the rock sets up stresses causing outer surface to break into sheets parallel to the rock surface (Fig. 8.3). This type of weathering is known as 'exfoliation' or 'sheeting'. You have read about exfoliation in Unit 5 of BGYCT-131 course.

Fig. 8.3: Exfoliation in granite. (Source: Prof. Meenal Mishra)

- **Thermal cycling**: In the area of arid regions, there are large temperature variations between day and night. Days are hot whereas nights are cold causing differential expansion and contraction of some minerals in the rocks. This sharp temperature changes set up differential stresses causing fracture and enlargement of joints in the rocks and thus, breaking of blocks takes place.
- **Plant and animal activities**: Growing roots of plants present in the rocks can exert pressure causing widening of the cracks. Burrowing activity of animals also break down rock producing disintegrated particles.

2. **Chemical Weathering**

Chemical weathering involves direct effect of atmospheric chemicals or biologically produced chemicals in the breakdown of rocks and minerals by alteration or decomposition. Chemical reactions take place between minerals and water/air interface. It changes chemical composition of the rock. Chemical weathering alters unstable minerals to more stable mineral substances. As a result, new or secondary minerals are formed from the original minerals. Main agents responsible for chemical weathering are water and weak acids like carbonic acid. Carbonic acid is produced by reaction of carbon dioxide gas with water in atmosphere.

Chemical weathering is a gradual and continuous process. It is common in areas of hot humid climate. Chemical reactions include carbonation, oxidation and hydrolysis. Let us discuss them in detail.

- **Carbonation and dissolution**: Carbonation is very common solution weathering process. In this process, carbonic acid reacts mostly with the mineral calcite present in the limestone and chalk. The formation of caves in limestone country takes place by etching of carbonic acid. Carbonate minerals are completely dissolved by acidic water giving rise to formation of caves. Gupt Godavari caves in limestone near Chitrakoot, Madhya Pradesh are good example.

The reactions are as follows:

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

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

$$\underset{\text{Calcite}}{CaCO_3}+\underset{\text{carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{Calcium ion}}{Ca^{2+}} + \underset{\text{bicarbonate ion}}{2(HCO_3)^-}$$

- **Oxidation**: The reaction of a substance with oxygen is known as oxidation. When chemically active oxygen from atmosphere reacts with iron, it forms iron oxide and gives a reddish-brown coloration (‘rust’) on the surface of the affected rocks. Oxidised rock becomes weak and crumbles easily. The reaction is as below:

$$\underset{\text{Iron}}{4Fe} + \underset{\text{Oxygen}}{3O_2} \longrightarrow \underset{\text{Hematite}}{2Fe_2O_3}$$

- **Hydrolysis**: Chemical break down of a substance when combined with water is known as hydrolysis. It is a chemical weathering process affecting silicate and carbonate minerals. Common example of hydrolysis is the alteration of feldspar minerals into clays in granite rock.

Alteration of Feldspar: Feldspars are the most common mineral occurring in the Earth’s crust. In the presence of acidic rain water, feldspars easily break down and form clay minerals. K, Na and Ca ions are released into water along with SiO_2 in solution and carried away as below:

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

$$\underset{\text{Orthoclase}}{4KAlSi_3O_8}+\underset{\text{carbonic acid}}{4H_2CO_3}+18H_2O \longrightarrow \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_8}+\underset{\text{potassium ion}}{4K^+}+4HCO_3^-+\underset{\text{Silicic acid}}{8H_4SiO_4}$$

Similarly, the chemical alteration of hornblende, augite and biotite leads to the formation of clay and chloritic minerals. Table 8.1 shows weathering of rocks and their products:

Table 8.1: Weathering of common rocks and their products.

Rock	Primary Minerals	Weathering Products	Leached Ions
Granite	Feldspars	Clay Minerals	Na^+, K^+
	Micas	Clay Minerals	K^+
	Quartz	Quartz	----
	Fe-Mg Minerals	Clay Minerals+	
Hematite+Goethite		Mg^{+2}	

Basalt	Feldspars	Clay Minerals	Na^+, Ca^{+2}
	Fe-Mg Minerals	Clay Minerals Magnetite, Hematite, Goethite	Mg^{+2}
Limestone	Calcite	None	Ca^{+2}, CO_3^-

We can see from Table 8.1 that clay minerals, quartz and oxide minerals are the most common residual products of chemical weathering. Therefore, quartz and clay minerals are the most abundant contributors to clastic sedimentary rocks.

3. **Biological Weathering**

Weathering takes place by various activities of living organisms. It includes digging activities by animals causing movement (pedoturbation) and mixing of materials and the action of moss and lichens on various minerals and rocks. There are several rodents, insects, and other animals that can burrow into a crack in a rock. Constant burrowing widens cracks and breaks rocks apart. Apart from burrowing rocks can also be fractured by pressure from growing roots, known as root wedging. Organisms influence the moisture content of soils and enhance weathering. In humid regions, the growth of algae, bacteria, lichens, and mosses on rock surface produce weak acids, which weaken rocks and can alter some minerals to clay.

Mineral Stability during Weathering

Some minerals are more stable than others on the Earth's surface. Thus, rates of chemical weathering vary from one mineral to other. Olivine, pyroxene, amphibole, plagioclase and biotite are more sensitive to weathering and alter faster than orthoclase and muscovite. Quartz shows negligible effect. The hardness and lack of cleavage in quartz make it resistant to breaking down physically or by chemical reactions. Thus, quartz becomes abundant mineral in sedimentary rocks. The ranking of relative chemical stabilities of various minerals is referred to as Goldich stability series, about which you have already read in Unit 5 of BGYCT-131 course.

Factors Controlling Processes of Weathering

You have learnt in detail about the factors controlling processes of weathering in Unit 5 of BGYCT-131 course. A number of factors are responsible for the rate of weathering and actual amount of sediment yield. They are; type of rocks exposed, climate, surface conditions and vegetation cover.

i) **Type of rocks**: Igneous rocks such as basalt and granite formed at higher temperature and/or pressure are hard but due to the presence of unstable minerals in the composition, they alter faster when exposed to the agents of weathering. Soft sedimentary rocks break down under prevalent environmental conditions quickly. Metamorphic rocks such as quartzite and marble tend to weather slowly.

ii) **Climate and vegetation**: Heat and humidity accelerate chemical weathering. As such hot and moist regions of the Earth surface are prone to more chemical weathering. Weathering is slower in dry climate. Exposed rocks are more sensitive to heat, wind and water, and therefore weather very fast whereas land covered with vegetation does not weather quickly.

Watch this video to know about weathering its types and significance.

- **Weathering its types and significance**

Link: https://www.youtube.com/watch?v=gBYijIPPVgc

8.4.2 Erosion

Erosion is the process by which the rocks are disintegrated and removed simultaneously by any natural agency like flowing water, wind and glacier. Hydraulic action of streams quarry and pluck fragments, pieces of rock and sediment particles from beds of solid rock. Wind erodes and carries away loose sand, silt and clay size particles to short or long distances depending upon its velocity. Similarly, glaciers remove rock fragments and sediment particles to lower slopes.

8.4.3 Transportation

Sediment transport occurs in natural system where the particles are clastic rocks, i.e. sand, gravel, boulders, mud or clay. Transportation refers to the movement of solid particles or dissolved ions away from its source or site of erosion to a site of deposition. Transporting agents can be running water, wind and glacial ice. Majority of sediments are usually transported by water. Streams, rivers and wind, carry the lighter and the smaller sized materials more easily than the heavier and the bigger sized ones. The force of gravity acts to move the particles along the sloping surface on which they are resting.

- **Types of Sediment Load**

Streams transport materials in four different ways: i.e. as dissolved load, suspended load, saltation load and bed load.

i) **Dissolved Load**: Material carried into solution as dissolved load is part of the moving water. The amount of material in solution depends on the supply of a solute, water temperature and the saturation point of the solvent. Tropical rivers carry larger amount of dissolved loads than those in temperate regions.

ii) **Suspended Load**: Terrigenous material that moves through the channel of river as suspension in the water column is suspended sediment load. Mainly silt and fine sand remain in suspension by the upward flux of turbulent water generated at the river bed (Fig. 8.4). For suspended load of the sediment to be sustained, the upward currents must equal or exceed the sediment fall-velocity.

iii) **Saltation Load**: Generally sand size particles that bounce along the stream bed or move directly or indirectly by the impact of bouncing particles come under saltation load. The velocity of a particle during saltation is less than that of water in motion.

iv) **Bed Load or Traction Load**: It includes larger clastic particles that are rolled, bounced and slide along bottom of stream bed. Its movement through the stream is fully supported by the channel bed. Gravel and coarse sand are kept in rolling and sliding motion by the shear stress.

- **Distance of Sediment Transport**

Sediments can be transported few meters or even less to several hundred kilometers from the source of their origin. It depends upon the energy condition of the transporting medium, size of the sediment and slope of the ground. The size of particles decreases with increased distance of transport. As the coarser sediments are left behind by the transportation process, they are usually found closer to the source area and fine-grained sediments being lighter transported to longer distances and hence found farther away from the source. Presence of angular clasts indicate short distance of transport from the source whereas rounded clasts show long transport distance. Mature sediments are deposited farther from their source rocks than immature sediments.

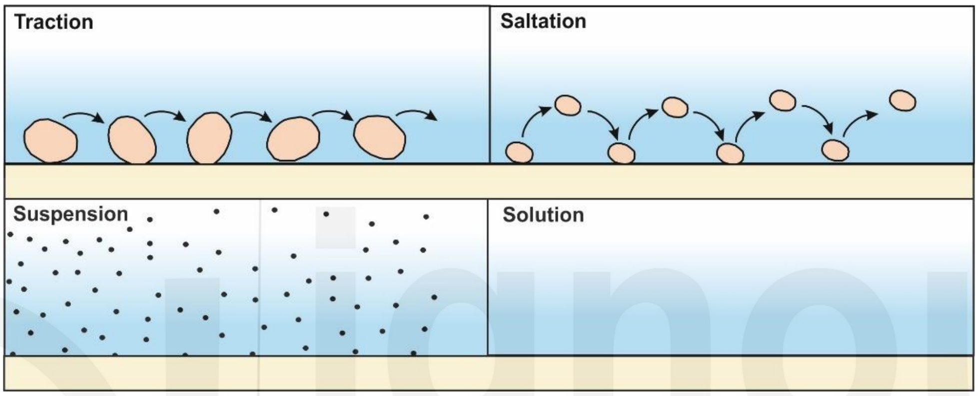

Fig. 8.4: Mode of Sediment Transport.

Watch this video to know more about factors affecting weathering and types of bedload.

- **Sedimentary structure of clastic rocks**

Link: https://www.youtube.com/watch?v=llg5aAbaL0s&t=44s

8.4.4 Deposition

Deposition of sediments takes place when energy necessary to transport particles is no longer available. If the velocity of the transporting medium becomes too low, the deposition will take place. The sediments fall down due to the gentle settling of mineral grains and deposited in a basin as layers with the oldest layers at the bottom and the younger layers lying on over the older layers. Some layers or beds may be plane horizontal; others may be cross bedded or graded bedded. The resulting deposit thus reflects the energy condition of the depositional environment. Deposition can also be result of chemical precipitation and evaporation due to changing conditions in the basin of deposition. Therefore, the type of a sedimentary rock depends not only on the sediment supply, but also on the depositional environment of the basin in which it formed. Fig. 8.5 shows the major sedimentary processes.

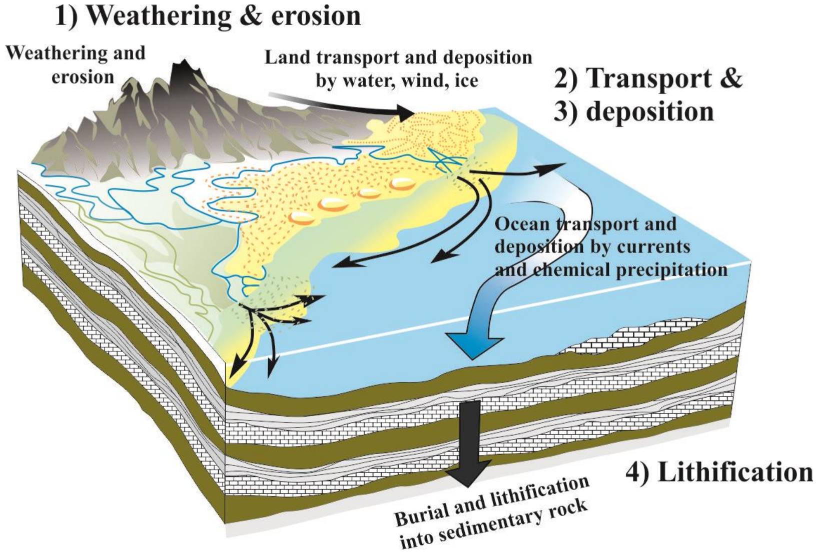

Fig. 8.5: Block Diagram Showing Sedimentary Processes.

In the previous sections you have studied about processes of formation of sediments. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

a) Define sediment.

b) Chemical weathering is common in areas of ----------------- climate.

c) Why quartz is the most abundant mineral in sedimentary rocks?

d) What are terrigenous particles?

8.5 SEDIMENT TO SEDIMENTARY ROCKS

We have learnt about sediments and sedimentary rocks in Section 8.1. Let us now discuss the processes of transformation of sediment into sedimentary rock, i.e. lithification and diagenesis are by which loose sedimentary particles deposited in a basin are transformed into rock.

Do you know that a single quartz grain in the sand or sandstone has a story to tell? Originally this quartz grain might have been a crystal in the igneous rock like granite or granodiorite or metamorphic rock like quartzite or gneiss or sedimentary rock like sandstone. This quartz crystal along with other grains/minerals got detached, released and liberated from of the parent rock by the processes of weathering. This became a loose quartz grain which may be deposited *in situ* or may participate in the dynamic surface process(es). Eventually grain got deposited in the ocean basin along with other grains to form a layer of sediment. These loose grains are further compacted, bound or cemented to form the sedimentary rock such as sandstone.

Isn't it amazing!!!

The process of changing sediments into sedimentary rocks is called **lithification** and the various processes that lead to lithification is known as **diagenesis**. Let us discuss them in detail.

8.5.1 Lithification

The word lithification consists of two words: *lithos* means 'stone' and *fication* means 'making'. Lithification refers to the processes by which unconsolidated sediments are transformed into sedimentary rocks. Lithification takes place after the sediment has been deposited and buried. During the process of lithification, sandstones are cemented, limestones are recrystallised and shales are compacted. The original porosity of the rock is reduced. Lithification usually involves various processes like burial, compaction, and cementation.

- **Burial**: The burial occurs when more sediments are piled onto existing layers of sediments deposited earlier. The deposition of sediments for a long period causes heavy pressure at the bottom of the basin floor and thus subsidence of the basin takes place. This permits hundreds and thousands meter of burial to occur depending on the tectonic setting and structure of the basin.

- **Compaction**: As sediments are buried, the weight of overlying material exerts lithostatic pressure, causing compaction of sediments. Compaction squeezes the sediment layers from all sides resulting reduction of the sediments into a smaller volume. The pore spaces between grains are reduced by expelling the original connate water from the squeezed sediment layer. This leads to a tighter packing of the layers. Compaction may cause recrystallisation of the minerals. Fluids flowing through the rock may precipitate new minerals in the pore spaces as cement that holds the sediment together and makes the rock harder (Fig. 8.6). For example, when clays are buried beneath several thousand meters of material, the volume of clay may be reduced by as much as 40 percent. As pore space decreases, much of the water that was trapped in the sediments is driven out. Some chemically precipitated sedimentary rocks, such as evaporites form without having undergone to burial and compaction.

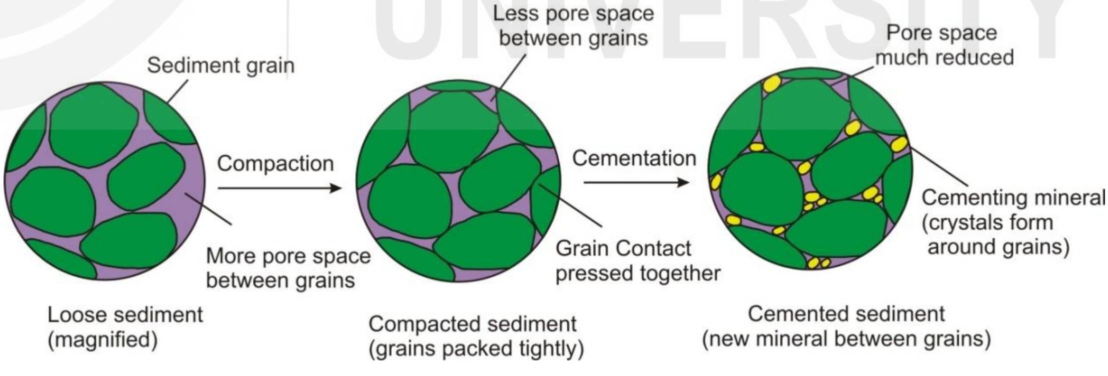

Fig. 8.6: Compaction and Cementation of Sediments.

- **Cementation**: Sediments are often saturated with seawater or groundwater during lithification. Some of this water may carry mineral components in solution, from which new minerals can precipitate between the sediment grains. These new minerals bind the sediment grains together and act as cement in open pore spaces. In this way, cementation makes loose sediments in a sedimentary rock more compact and competent. The cementing material in clastic rocks is usually secondary silica, calcium carbonate and iron oxide. Silica cement commonly occurs as growth of quartz rims on the surface of pre-existing quartz grains. Calcite precipitates from calcium carbonate ions dissolved in the water in the pore spaces. Red coloured iron oxide mineral hematite precipitates in the pore space and onto the sediment grains from a combination of dissolved iron and oxygen from water.

- **Matrix**: Accumulated sediments harden into rock by lithification. Fluids and materials fill in the spaces between the loose particles of sediment and crystallize and form the groundmass. The matrix or groundmass of sedimentary rocks is finer-grained sedimentary material, such as clay or silt, in which larger grains or clasts are embedded. The packing of the grains relates only to poorly sorted sediments in which the finer clasts form a matrix around the coarser clasts. If the large grains are in contact with each other, the packing is said to be **clast-supported**. If the coarse grains are separate and are not in contact with each other, with the finer-grained sediment between them, the packing is said to be **matrix-supported.**

8.5.2 Diagenesis

The term diagenesis (*dia* means 'change' and *genesis* means 'origin') is a collective term which refers to the sum of all the physical, chemical and biological changes that act on the sediment subsequent to deposition and during and after lithification but before its final conversion to rock. The process occurs at relatively low temperature and pressure, below about 250^0 C, 1 to 2K bars and at depths of up to about 5000 m. As sediments get buried deeper, there is increase of pressure and temperature. Increase of temperature, beyond the realm of diagenesis, leads to metamorphism. There is no sharp boundary between diagenesis and metamorphism but the latter occurs at relatively higher temperature and pressure. An example of diagenesis is the alteration of feldspar to form clay mineral in its place. Diagenesis includes all post depositional alterations for conversion of sediment or sedimentary rocks such as changes in mineral composition and the amount of space between the grains, but does not include erosion or metamorphism. Diagenesis refers to changes that occur in sedimentary rocks. Diagenetic processes occur at temperatures below 250ºC and pressures below 2 Kilobar. It may be distinguished from metamorphism which starts above the temperature and pressure range. Metamorphism does not include weathering, diagenesis, and melting.

Study of diagenesis is helpful in tracing geological history of the rock formation. It also helps in likelihood of finding various mineral and hydrocarbon deposits.

Kinds of diagenesis: There are three phases of diagenesis.

- Syndiagenesis
- Anadiagenesis
- Epidiagenesis

Syndiagenesis is the early diagenetic process that includes those processes associated with deposition and shallow burial. Late diagenesis or anadiagenesis are those associated with deeper burial. At any stage, accumulating sediments below may well be raised, by tectonic forces, from one regime to another and can cause a reversal of some of the diagenetic processes. Such reactions are termed epidiagenesis as they are superimposed on previous diagenetic features.

Effect of Diagenesis: The diagenetic processes can bring the following changes in the rocks:

- Changes to mineral composition and texture.
- Formation of new minerals.
- Complete or partial dissolution of minerals.
- Mobilisation and migration of elements.
- Replacement of one mineral by another mineral.
- Influence of bioturbation (reworking of soils and sediments by animals or plants).

In the previous sections we have studied about the processes of changing sediments into sedimentary rocks. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 2

a) What is the difference between lithification and diagenesis?

b) Compaction causes reduction in porosity of sediments -----True/False

c) Give example of sediments deposited as bed load.

d) Differentiate between cement and matrix.

8.6 COMMON SEDIMENTARY ROCKS

We have already studied that clastic rocks are buildup of fragments of pre-existing rocks which are produced by the processes of weathering and erosion, and in general get transported to a point of deposition. Clastic sedimentary rocks are composed of other rock fragments that were cemented by silicate minerals. Conglomerate, sandstone, breccia and shale are the most common clastic sedimentary rocks. Conglomerates and breccia are made mostly of gravel; sandstones are made mostly of sand; and mud rocks are made mostly of the finest material.

The soluble substances like calcium carbonate, siliceous material, ferruginous compound, aluminum compound, phosphatic material, magnesium potassium and sodium chloride, carried in solution to the ocean and they ultimately form non-clastic sedimentary rocks. Limestone and dolomite form the most common non-clastic sedimentary rocks. Others include ironstone, phosphates, chert and evaporites.

The components of biogenic sedimentary rocks are derived from living organisms and plant debris. When the organism dies, the remains can accumulate and form sedimentary rock. Examples of biogenic sedimentary rocks: Limestone containing remains of mollusks, foraminifera and corals. Another example of rocks deposited by the accumulation of macro- and micro-organisms is coquina and chalk deposits. Stromatolitic limestones are formed from the deposition of microorganism of blue green algae.

Watch the following video to know more about stromatolitic limestone.

- **Sedimentary Structures of Non-Clastic Rocks**

  Link: https://www.youtube.com/watch?v=3iL__lYkFRM

Organic sedimentary rock is formed from the remains of plants that lived in moist environment rich in trees, shrubs, water and mud. Accumulation of dead plant debris takes place in swampy setting where they are quickly buried. Plant debris converts into coal in absence of oxygen under suitable temperature and pressure conditions. The carbonaceous materials are mainly carbon compounds derived from the air and from the decay of organic compounds. Sedimentary rocks formed from the carbonaceous materials are coal, peat, lignite, etc. Volcaniclastic sediments are composed of volcanic or pyroclastic materials.

You will study about common sedimentary rocks in detail in Unit 11 Classification of Sedimentary Rocks.

8.7 DEPOSITIONAL ENVIRONMENT

The layers of sedimentary rock are like the pages of a book which record tales of ancient events and ancient environments of ever-changing face of the dynamic Earth. Sedimentary rocks occur only in the upper part of the crust and form a “cover” that buries the underlying “basement” of igneous and /or metamorphic rock. Sedimentary environment is the space generated or developed on interaction of lithosphere, hydrosphere and atmosphere. A depositional environment (also known as sedimentary environment) is a specific type of environment where sediments ultimately accumulate after transportation. Sediments deposited in different depositional environment have distinctive characteristics and provide useful information for reconstructing Earth’s history and understanding Earth processes.

You might be wondering that how do the sedimentologists study depositional/sedimentary environments?

Sedimentologists compare the sedimentary textures and structures found in ancient rocks with those formed in the recent modern sedimentary environments. This provides insight in an understanding of what processes may have been operating in the past, even if the deposition occurred millions of years ago. We have read ‘Present is the key to past’ in Unit 1 of course BGYCT-131.

Deposition of sediments can occur in one of the following basins as given in Table 8.2 and shown in Fig. 8.7.

Table 8.2: Sedimentary Environments.

Environment	**Agent of transportation/ depositional basin**
Continental Environments	
Fluviatile	River
Aeolian	Wind

Lacustrine	Lake currents, waves
Glacial	Ice
Marine Environments	
Shallow and marginal marine (coastal/transitional)	Continental shelf, beach, delta, tidal flat, barrier reef and estuaries
Deep marine (open ocean)	Continental slope (offshore) and deep ocean

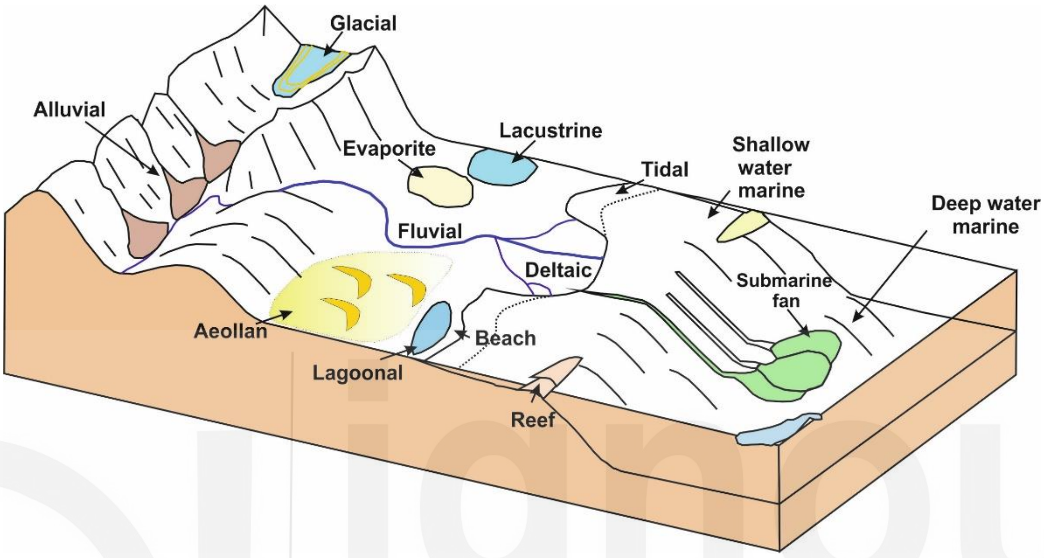

Fig. 8.7: Schematic diagram showing different types of depositional basins.

These environments are built around rivers, deserts, lakes, glaciers and sea/oceans:

- Fluviatile environment occurs in a river channel and the flood plains (Fig. 8.8). We know that the rivers provide widespread alluvial deposits on the continents, e.g. Indo-Gangetic alluvial deposits.

Fig. 8.8: Flood plain sediments deposited in fluviatile environment by Son River.

- Aeolian environment represents an arid type of climate. Since the aridity inhibits organic growth therefore the organic impact is little on the sediment. Desert sand dunes, e.g. Thar deposits provide a special sandy environment.

- Lacustrine environment encompasses inland bodies of fresh or saline water which are controlled by the relatively small waves and moderate currents. Saline lakes in deserts evaporate and precipitate a variety of minerals, such as halite, e.g. Sambhar Lake deposits.
- Glacial environment is controlled by the dynamics of moving masses of ice and is characteristic of a cold climate, e.g. Gangotri glacier.
- Marine environments include a wide variety of sub environments, ranging from shallow water to deep water, e.g. Bengal Fan in Bay of Bengal, beaches at Puri and Goa.

8.8 SUMMARY

Let us summarise what we have learned in this unit.

- Weathering can take place by physical, chemical and biological actions.
- Sediments are transported to the basin of deposition by water, wind, ice, mass movement or glaciers.
- Process of formation of sedimentary rocks is ever prevailing phenomenon which involves: weathering - erosion - transportation - deposition - burial - compaction - cementation - diagenesis.
- The compaction and cementation (lithification) reduce the porosity of the rocks and intensify the cohesion between the grains.
- In diagenesis sediments undergo physical, chemical and biochemical changes during or subsequent to lithification.
- Clastic sedimentary rocks such as conglomerate, sandstone and shale are made of fragments of rock or mineral grains that have been broken from pre-existing rock.
- The sediments are deposited in a basin as layers with the oldest layer at the bottom and the younger layers lying on over the older layers.
- Non-clastic sedimentary rocks like limestone and dolomite form from the precipitation of minerals from ocean water or from the breakdown of the shells and bones of sea animals.
- Sedimentary environments can be fluviatile, aeolian, lacustrine, glacial and marine.

8.9 ACTIVITY

- Make a list of sedimentary deposits present in your state.
- Pick up handful of sand and try to identify various minerals. Also try to find out the grain size.

8.10 TERMINAL QUESTIONS

1. Discuss the processes of lithification and diagenesis?
2. Discuss about clastic and non-clastic sedimentary rocks.

3. Explain the processes that are involved in the formation of sedimentary rocks.

Audio/Video Material Based Questions:

- Explain the processes of sediment transport.
- List the sedimentary rocks which are used as building stone.
- Discuss how soil is indispensable for human life.
- Name the economic deposits formed due to weathering processes.
- Why are clastic particles known as terrigenous particles?
- What are plant acids? Explain the role of plant acids in biological weathering.

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8.12 FURTHER/SUGGESTED READINGS

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- Verma, V.K. and Prasad, C. (2001) Sedimentation. Harman Publishing House, New Delhi, 57-67p.

8.13 ANSWERS

Self Assessment Questions

1 a) Sediment is loose solid particle originating from the breaking apart of older rocks by the process of weathering and erosion.

b) Hot and humid.

c) Due to its resistant to weathering under surface conditions.

d) Terrigenous particles are the fragments of the pre-existing rocks that have been worn down into small pieces such as gravel, sand, silt, or clay by weathering, mass-wasting events by geological agencies like wind, water or ice and volcanoes.

2 a) Lithification is the compaction and cementation of sediment into rock while diagenesis is all the chemical, physical, and biological changes sediment goes through during and after lithification.

b) True.

c) Gravel and coarse sand.

d) Cement refers to new minerals that bind the sediment grains together and act as cement in open pore spaces. The matrix is finer-grained clastic material, such as clay or silt, in which larger grains or clasts are embedded and binded.

Terminal Questions

1. Refer to section 8.5
2. Refer to sub-section 8.3.2
3. Refer to section 8.4

UNIT 9

TEXURES OF SEDIMENTARY ROCKS

Structure

9.1 INTRODUCTION

You have read in Unit 8 that the sedimentary rocks have been classified on the basis of their origin into two major groups; Clastic and Non-clastic. They have different composition and texture, and

are products of the kinds of source materials, mode and distance of transportation and depositional environments. **Texture** is an important aspect of identifying and describing sedimentary rocks and very helpful tool for environmental analysis. In this unit we will learn the characteristic textural properties of sedimentary rocks. Let us discuss the grain size of particles, their distribution, morphology, packing and their genetic significance.

Expected Learning Outcomes

After studying this unit, we should be able to:

- know the meaning of texture;
- determine grain size and their distribution in the sediments;
- present grain size data in graphical form;
- describe shape, roundness and sphericity;
- explain grains packing and its significance;
- identify matrix and cement.; and
- learn about textures present in non-clastic rocks.

9.2 TYPES OF TEXTURE

Texture refers to the size, shape and three-dimensional arrangement of the grains that make up sediments or sedimentary rock. Texture is a small-scale character of a rock, but assumes importance in many of its significant properties, such as bulk density, porosity and permeability. We can use texture of sedimentary rocks to infer the mode and distance of transport, energy condition and depositional processes.

Textures can be clastic, where they are composed of grains derived from pre-existing rocks or non-clastic, where sediments precipitate from a fluid.

i. **Clastic texture**: Clastic textures are commonly described in terms of grain size of sediments, their sorting behaviour, degree of roundness, packing of grains, textural maturity and grains binding materials like matrix and cement. Texture of clastic sedimentary rocks is produced primarily by physical processes of sedimentation. It is characteristic feature of rocks such as conglomerates, sandstones and shales fragments which are derived from pre-existing rocks – igneous, metamorphic or even pre-existing sedimentary rocks. Some biochemical sedimentary rocks such as fossiliferous limestones (coquina) are composed of shell fragments also exhibit clastic texture.

ii. **Non clastic (crystalline) texture**: It is formed by chemical or biochemical precipitates from fluids. It may also be produced by recrystallisation or alteration of pre-existing rocks. Grains show an interlocking mosaic of crystals. Chemical sedimentary rocks such as limestone, dolomite, rock salt and gypsum show such texture.

Textures are said to be **primary**, where the detrital grains possess their arrangement that existed after they came to rest in the basin of deposition or after precipitation (in the case of crystallines). **Secondary textures** are produced due to the alteration in the original arrangements of grains. Grains are rearranged due to the weight of overlying sediments causing compaction during lithification.

➢ **Textures are controlled by the following factors**:

- The nature and type of the source rocks or provenance. It can be igneous, sedimentary, and metamorphic;
- Texture and composition of pre-existing or source rock;
- Mode of weathering which can be physical, chemical and biological;
- Mode, energy and nature of medium and distance of transportation;
- Depositional processes;
- Diagenesis of sediments; and
- Tectonics of depositional sites.

9.3 GRAIN SIZE

In the above section you have read about texture of sedimentary rocks. Grain size is an important textural character of clastic sedimentary rocks. It gives information about nature of source rocks, mode and strength of transportational medium, sorting, depositional history of sediments and tectonics of depositional basin. We will examine the character of grains present in the sediments, their size, distribution, and interpretations.

- **Particle (Grain) Size Distribution**

Particle size in terrigenous sedimentary rock is highly variable ranging from a few microns to a few meters. Particle size distribution is the quantitative expression by weight of the constituents size-grades present in a sample referred to as size frequency distribution in sediments. Grain size can be expressed as a diameter or a volume, and is always an average value. Broadly, the grain size is described as coarse, medium or fine (Fig. 9.1).

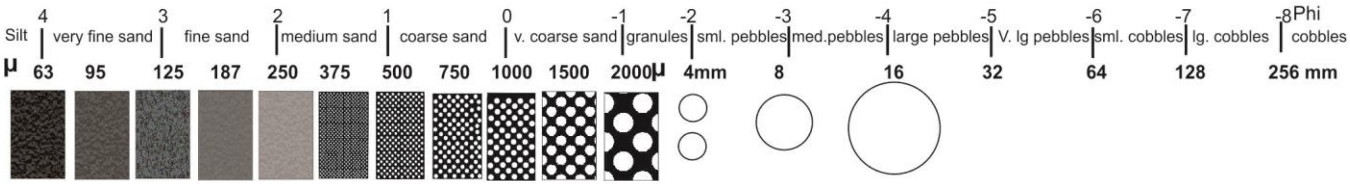

Fig. 9.1: Udden-Wentworth grain size scale.

- **Grain Size Scale**

Several grain-size scales have been proposed, but the universally adopted size scale in use is the Udden-Wentworth scale (Fig. 9.1). It is well suited for description of sediments, because it gives equal significance to size ratios, whether they relate to gravel, sand, silt, or clay. In this scale, each successive size class is half as large as the previous size i.e. ¼, ½, 1, 2, 4, 8…..mm. Krumbein used phi scale which is an arithmetic scale (i.e. 1, 2, 3, 4,..) of phi units (Φ).The Phi scale is logarithmic based modification of the Udden-Wentworth scale and very useful. Grain-size diameters in millimeters are converted to phi units using the conversion formula:

$$\Phi \text{ (phi)} = -\log_2 d$$

where Φ is size expressed in phi units and d is the grain size in mm. Phi values are dimensionless, but the scale is a geometric one.

➢ **Advantages of using the phi scale are:**

- Grain size distributions can be plotted easily on arithmetic paper instead of log paper.
- Statistical parameters can be conveniently interpolated.
- Boundaries between different size units are in whole numbers.

Particle size scale for clastic sediments and sedimentary rocks based on the basis of predominant grain size of clasts in the rock is given below (Table 9.1) wherein we may note that increase in phi values decreases with particle size. Accordingly, phi values for grains coarser than one millimeter are negative, while those for grains finer than one millimeter are positive.

Table 9.1: Particle size scale for clastic sediments and sedimentary rocks.

Name of Particles	Size Range in mm	Phi Scale	Loose Sediment	Consolidated Rock
Boulder	>256 mm	<-8	Gravel	Conglomerate / Breccia (depending on rounding)
Cobble	64 - 256 mm	-6 to -8		
Pebble	4 - 64 mm	-2 to -6		
Granule	2 - 4 mm	-1 to -2		
Very Coarse Sand	1 - 2 mm	0 to -1	Sand	Sandstone
Coarse Sand	0.5 - 1 mm	1 to 0		
Medium Sand	0.25 - 0.5 mm	2 to 1		
Fine Sand	0.125 - 0.25 mm	3 to 2		
Very Fine Sand	0.0625 - 0.125 mm	4 to 3		
Coarse Silt	0.031 - 0.0625 mm	5 to 4	Silt	Siltstone
Medium Silt	0.016 - 0.031 mm	6 to 5		
Fine Silt	0.008 - 0.016 mm	7 to 6		
Very Fine Silt	0.004 - 0.008 mm	8 to 7		
Clay	<0.004 mm	>8	Clay	Mudstone, Shale and Claystone

9.4 MEASURING GRAIN SIZE

In the above section we have read about texture of sedimentary rocks. Grain size is an important textural character of clastic sedimentary rocks. It gives information about nature of source rocks, mode and strength of transportational medium, sorting, and depositional history of sediments and tectonics of depositional basin. We will examine the size and distribution of the grains present in the sediments. Various methods of measuring grain-size have been suggested. The choice of method depends upon the purpose of the study, range of grain sizes to be measured, and degree of consolidation of the sediment or rock.

i. **Unconsolidated Sediments**: Boulder, cobble and pebble are manually measured with a caliper or tape. Granule to silt-size particles are commonly measured by sieving through a set of nested, wire-mesh screens. Standard sieves of different mesh sizes that are kept one over, coarser at the top and finer downwards are mechanically shaken. The amount trapped in each sieve is weighed and taken as an estimate of the particle size range in the sample. Finer sediments like silt and clay are more difficult to measure. The commonest method is **elutriation**, where a sample is treated with a dispersant and placed in cylinder (settling tube). The finest fractions stay in suspension longest, whereas the larger/heavier fractions generally sink more rapidly. Size is measured by determining their settling.

ii. **Consolidated Sediments**: Consolidated granules and hard indurated sandstones are measured by thin-section method. Grains are visually counted and measured under petrological microscope with an eyepiece having a graduated scale and point counter. Size measurement of silt and clay in consolidated rock is possible by using a high magnification electron microscope. We can also use digital image processing method for grain size measurement.

9.5 GRAPHICAL PRESENTATION OF GRAIN SIZE DATA

After grain-size determination, now we will read about graphical presentation of grain size data. The data obtained can be expressed in the form of histogram, frequency curve and cumulative frequency curve to visualise the size distribution of the sediments. Grain size parameters such as mean, sorting, skewness and kurtosis can be determined from the frequency cumulative curve using grain size values in either millimeters or phi units. Size values are read off from the cumulative curve and used into standard formulae.

- **Histogram**

It is a bar diagram in which the grain size is plotted along the x-axis of the graph and weight percent of each size class (the particle frequency) is plotted as bars along the y-axis (Fig. 9.2). It is useful for depicting grain size distribution of sediments.

- **Frequency Curve**

It is essentially a histogram in which the variation in grain sizes is indicated by a smooth line diagram instead of bars. The weight percent (frequency) of each size class is plotted as a point in midway between the size class limits and these points are then connected by smooth curve (Fig. 9.2).

- **Frequency Cumulative Curve**

This curve is made by plotting grain size against cumulative weight percent i.e. the sum of all percentages of the preceding coarser size classes. The abscissa scale consists of phi units (grain size decreasing towards the right). The curve is plotted either on arithmetic ordinate scale where S-shaped curve results, or on a log probability ordinate scale and a series of straight-line segments result (Fig. 9.3). Each segment represents a normally distributed subpopulation in the sample.

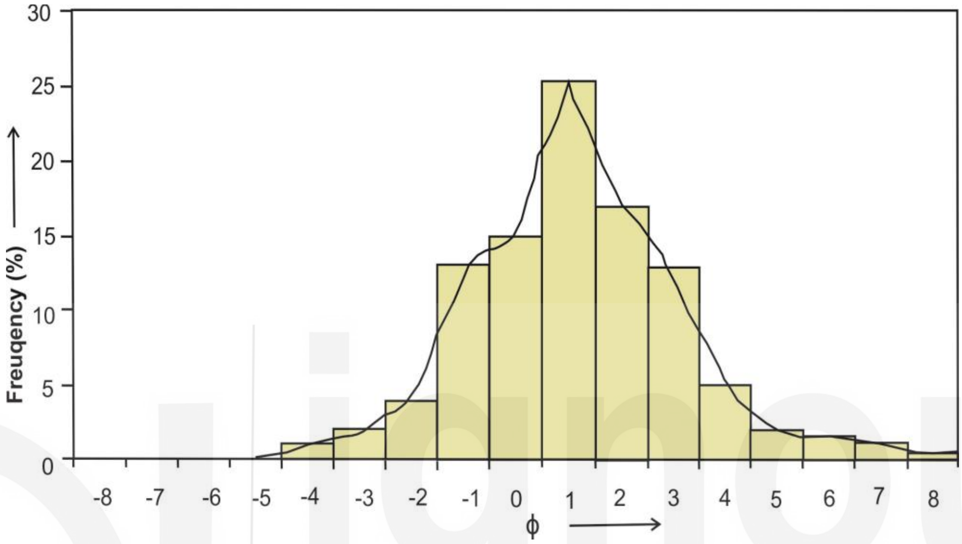

Fig. 9.2: Histogram and Frequency curve (grain size in phi unit).

➢ **Uses of Cumulative Curves:**

- Shape of cumulative curve (subpopulations) provides information about the mode of sediment transportation such as traction or rolling, saltation and suspension.
- Slope of the curve is a function of the sorting. Steeper the slope better is the sorting.
- Curve of several samples can be plotted in one graph.
- Calculation of statistical parameters is simple.

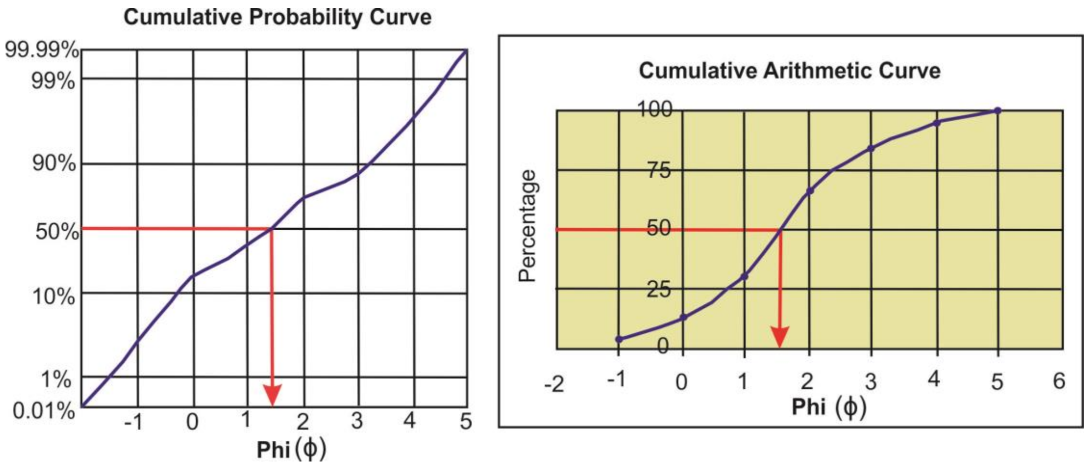

Fig. 9.3: Frequency Cumulative Curves.

SAQ 1

a) The texture of clastic deposit gives clues to infer …………………

b) Gravel includes ……………………………… size sediments.

c) How Frequency Cumulative Curve is prepared?

9.6 GRAIN SIZE PARAMETERS

In the above sections we have read about types of textures, particle size distribution, grain size scale and how grain size is measured. Now we will read about the parameters of grain size. Following standard grain size parameters are commonly described for grain-size distribution of sediments.

i. **Mode**: It is the most frequently occurring particle size or size class in the size distribution. It represents the highest point (peak) of the frequency curve. Curve showing only one dominant peak indicates **unimodal** character, two peaks **bimodal** and if more than two peaks are present, the sediment represents **polymodal** nature of the size distribution of the sediments.

ii. **Median**: Median is the size of midpoint of the grain size distribution, i.e. half the grains (by weight) are coarser and the other half finer. The median corresponds to the point where 50% line intersects the cumulative curve.

iii. **Mean**: It is the arithmetic average of all particle sizes in a sample. True arithmetic mean of most of the samples cannot be determined because the total number of grains in a sample cannot be counted or measured each small grain. However, the approximate arithmetic mean can be calculated by picking the 16^{th}, 50^{th}, and 84^{th} percentile values from the cumulative curve.

iv. **Sorting (Standard Deviation)**: Most useful aspect in the grain size distribution is sorting. It is a measure of range, or variation of grain size present in a rock. Sorting basically reflects the sedimentary process (e.g., wind, waves) and the impact of post-depositional. The rock is said to be well sorted when the grains are more or less of uniform shape and size. The rocks are regarded as poorly sorted when the grains are of different sizes. Sorting of sediments can be the following three types (Fig. 9.4):

   a. **Well sorted**: All clasts are more or less of the same size in the rock. Dune and beach sands, are often well sorted.

   b. **Moderately sorted**: There is some but significant variation in grain sizes as in river and tidal current deposits.

   c. **Poorly sorted**: Large spread in grain size distribution. Glacial till, debris flow and mudflow deposits are generally poorly sorted.

The sorting in Figure 9.4 can be represented by the frequency curves as shown in Figure 9.5. Poorly and moderately sorted sediments show a wide range of grain size whereas well sorted sediments have limited size range and exhibit sharp peak.

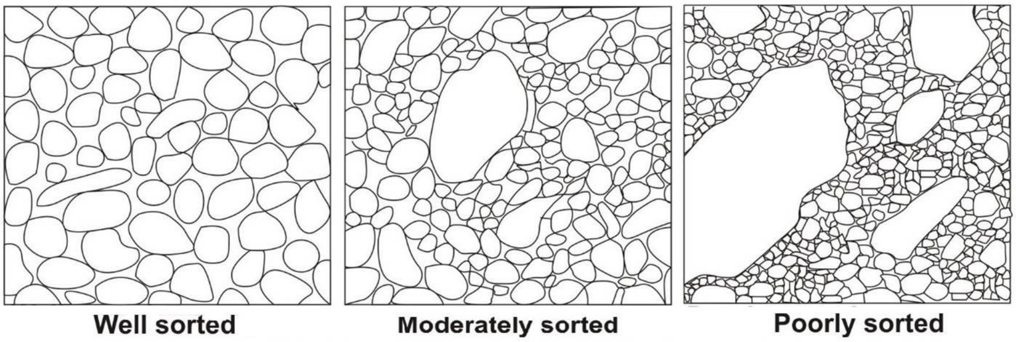

Fig. 9.4: Diagram showing sorting of grains.

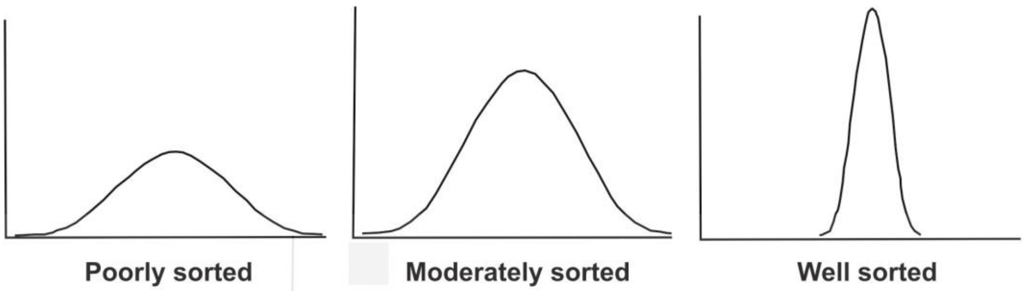

Fig. 9.5: Frequency curves showing types of sorting (X- axis shows grain size, Y axis - grain%).

➢ **Significance of Sorting**:

- Sorting gives clue to the energy conditions of the transporting medium from which the sediment was deposited. High velocity currents can carry larger fragments and can separate the fine and medium grains from the coarse grains resulting more sorted deposits.
- Sediments deposited quickly from storm or mud flow are generally poorly sorted. Sandy sediments transported and deposited by wind or water of deserts, beaches and shallow shelf seas are better sorted. Commonly coarse sediments (gravel) and fine silt - clay size sediments together are poorly sorted.

v. **Skewness**: It is a measure of the degree of symmetry of the size distribution. The mode, mean, and median in a skewed population of grains are all different in a frequency curve, however, in a normal frequency curve, they all coincide together. Depending upon the size distribution of grains in the sediment, the skewness may be negative, normal and positive.

- **Negative skewness**: If the distribution has a coarse tail i.e. excess coarse material (Fig. 9.6a).
- **No skewness**: If the distribution is symmetrical to or bell-shaped (Fig. 9.6b).
- **Positive skewness**: If there is a fine tail, i.e. excess of fine material (Fig. 9.6c).

Skewness is a reflection of the depositional process. Beach sands commonly have a negative skewness since finer sediments like silt and clay are removed by the wave action. River sands are generally positively skewed, as their finer components are not removed by the currents.

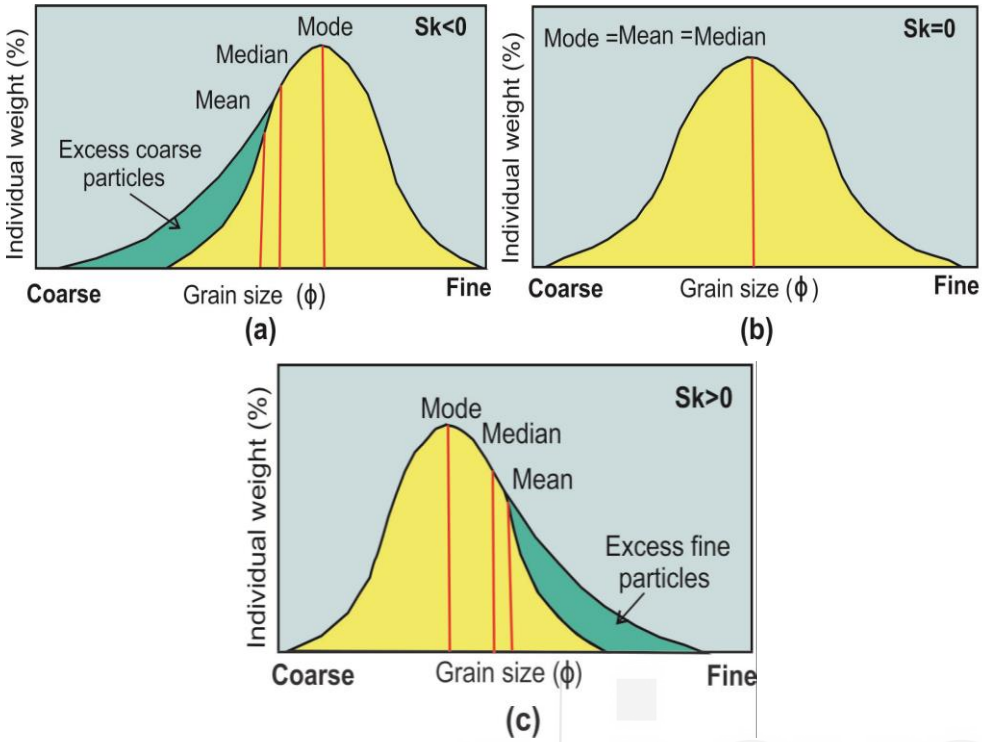

Fig. 9.6: a) Negative skew; b) No skew; and c) Positive skew.

vi. **Kurtosis**: It is the degree of peakedness or departure i.e. it is a spread of curve peakedness from the normal frequency or cumulative curve. It compares sorting in the central portion of the population with that in the tails. Kurtosis may be Leptokurtic, Platykurtic and Mesokurtic (Fig. 9.7)

a. **Leptokurtic** curves are sharp excessively peaked. The central part is better sorted than ends.

b. **Platykurtic** curves are flat-peaked. The ends are better sorted than center.

c. **Mesokurtic** curves are normally peaked (bell shaped curve).

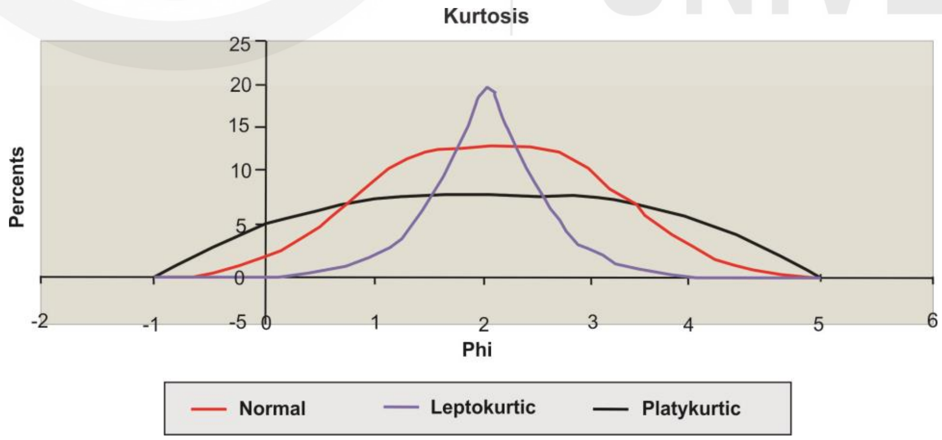

Fig. 9.7: Different types of Kurtosis curves.

9.7 CALCULATION OF GRAIN SIZE STATISTICAL PARAMETERS

Now you have known about grain size parameters. Now let us study about how statistical parameters are used for grain size calculations. Folk and Ward introduced graphic method to calculate various statistical parameters. They described grain size distribution using only percentiles taken from cumulative frequency curves. For example; ϕ50 is referred to as the 50th percentile of the sample i.e. grains size of the sample at 50% read from the cumulative curve is 1.5 ϕ (refer Fig. 9.2). Calculation of statistical parameters by the formulae suggested by Folk and Ward is easy and more accurate.

- **Formulae**

  i) Graphic Mean:

$$\textit{Graphic Mean}\ (M_Z) = \frac{\emptyset_{16} + \emptyset_{50} + \emptyset_{84}}{3}$$

  ii) Inclusive Graphic Standard Deviation:

$$\textit{Inclusive Graphic Standard Deviation}(\delta_I) = \frac{\emptyset_{84} - \emptyset_{16}}{4} + \frac{\emptyset_{95} - \emptyset_{5}}{6.6}$$

  iii) Inclusive Graphic Skewness:

$$\textit{Inclusive Graphic Skewness}(S_{KI}) = \frac{\emptyset_{16} + \emptyset_{84} - 2\emptyset_{50}}{2(\emptyset_{84} - \emptyset_{16})} + \frac{\emptyset_{5} + \emptyset_{95} - 2\emptyset_{50}}{2(\emptyset_{95} - \emptyset_{5})}$$

  iv) Graphic Kurtosis:

$$\textit{Graphic Kurtosis}\ K_G = \frac{\emptyset_{95} - \emptyset_{5}}{2.44(\emptyset_{75} - \emptyset_{25})}$$

- **Application of Grain Size Data:**

  - It is used to classify and define the terminology of clastic sediments and sedimentary rocks.
  - It is helpful to understand the source rock and the processes responsible for transportation and deposition of sediments.
  - Sorting and shape of particles are linked to porosity and permeability of sediments, and thus they help in the study of fluid accumulation and migration.
  - Grain-size data has been used to interpret coastal stratigraphy and sea-level fluctuations
  - It is useful for interpreting the depositional environments of ancient sedimentary rocks by constructing some binary diagrams, such as skewness plotted against sorting.

9.8 PARTICLE MORPHOLOGY

Now let us discuss about particle morphology. The morphology of clastic particles is physical attribute that may provide information about the sedimentation history of a deposit or the hydrodynamism of particles in a transporting medium. We shall discuss particle morphology in terms of its shape, roundness, sphericity and surface texture.

9.8.1 Shape

Grain shape is described in three dimensional forms and measured by various ratios of the long, intermediate and short axes. Particles can be spherical, prismatic, or bladelike. Zingg developed a versatile shape classification scheme based on the relative lengths of the longest, shortest, and intermediate axes. By comparing the ratios of the axes, it is possible to describe the following four basic shapes of particles (Fig. 9.8).

- Oblate (discoidal)
- Equant (spherical)
- Bladed
- Prolate (rod)

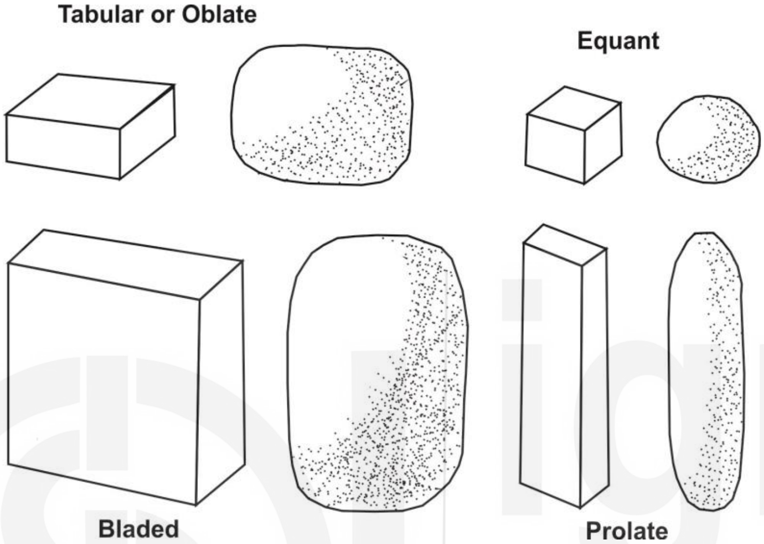

Fig. 9.8: Particles shape.

Particles shape depends on the type of source rock, weathering, distance and medium of transport and burial history. Shape in some cases reflects erosional processes as also structures and fabrics present in the parent rock. Quartzite for example, will commonly produce equant grains, whereas shale may be more flat.

Two of the most common shape indices are roundness and sphericity.

9.8.2 Roundness

In the clastic rocks the shapes of the constituent detrital fragments depend on the original material supplied by weathering, and on the amount and kind of transport it has undertaken. Roundness is related to the nature of individual grain boundary, i.e. to the absence and presence of sharp corners, edges. Abrasion of clastic particles during the process of transportation causes reduction in size and rounding of sharp edges and corners of grains. As a result, different sizes and shapes of particles are produced. Roundness (ρ) is a measure of the smoothness of particles. It refers to how smooth or sharp are the edges and corners of particles. It is often expressed as:

$$\rho = (\Sigma r_i/R)/N$$

Where, Σr_i = individual radii of the grain outline,

R= radius of a circle equal to the grain area,

N= number of curvature in the grain outline.

Power developed visual comparison chart of particles of known sphericity and roundness. It has the following six categories (Fig. 9.9):

1. Very angular
2. Angular (<0.15)
3. Sub-angular (0.15-0.25)
4. Sub-rounded (0.25-0.40)
5. Rounded (0.40-0.60)
6. Well-rounded (>0.60)

Very angular grains have sharp and jagged corners whereas well rounded grains have completely rounded smooth corners. The degree of roundness of particles gives us clues to the amount of time sediment has been in the transportation cycle.

Fig. 9.9: Diagrammatic depiction of very angular to very rounded grains.

Highly rounded substance like disc has a high roundness but lacks sphericity. A football is spherical as well as round but disc is round but not spherical. Sphericity is commonly described as high, low or moderate.

➢ **Factors controlling roundness**:

- Roundness is mainly the result of abrasion during transportation, distance travelled and the depositional environment. For example, wind blown and beach sands are well-rounded, while glacial sands and turbidity current deposits are angular.
- Roundness reflects mineralogy of the sediment and particle size. Soft minerals are abraded more readily than hard minerals. Coarse particles become rounded more rapidly than do fine ones. Gravel and sand become rounder as the distance traveled increases.
- The high degree of corrosion during diagenetic process due to intrastratal solution decreases the roundness of grains.

9.8.3 Sphericity

We can define sphericity as the degree to which the shape of a sedimentary particle approaches that of a sphere. It refers to the relation between the three axes (length, width, thickness) of a grain which define the morphology and geometric shape. Wadell defined true sphericity as the ratio of the particle surface area to the area of a sphere with the same volume. In other words, two-dimensional sphericity (ψ), can be computed as

$$\psi = di/Dc$$

Where, **di**= diameter of the largest inscribed circle

Dc= diameter of the smallest circumscribing circle.

Sphericity depends on composition, original shape, transportability and velocity of settling grains. Commonly, river gravels are relatively compact and spherical whereas beach gravels tend to be more platy or disc-shaped.

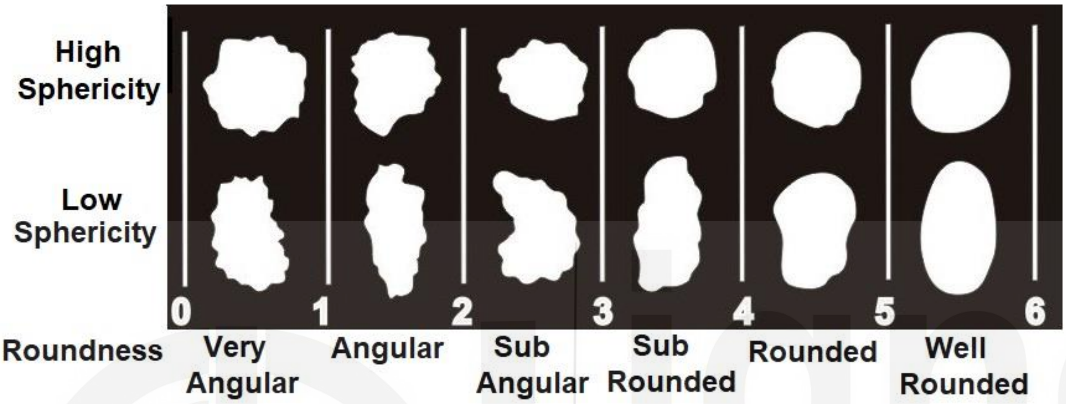

Fig. 9.10: Diagram showing roundness and sphericity of grains.

Roundness and sphericity are two different parameters of sediments. Two-dimensional objects can be round, they maybe spherical (Fig. 9.10). Three-dimensional objects can be spherical and their cross-sections can also be round. Roundness is related to corners of edges of the sediment. Sediment can be rounded but not spherical or spherical but not rounded. A slice of potato or disc is rounded but not spherical. A kankar piece may be spherical but not rounded. Mineral habit controls sphericity. Roundness is the product of travel distance.

9.8.4 Surface Texture

Surface texture is usually studied on sand grains and gravels. We observe the presence or absence of small scale, low relief features such as pits, polish, scratches that may occur on grain surfaces. These can be visually examined with the help of a microscope or hand lens. In some cases, a high magnification scanning electron microscope (SEM) is used for minor details. Some surface textures have been genetically linked to specific depositional environments; for example, quartz grains having v-shaped percussion marks on their surface indicate the beach and near shore zones. SEM image of a rounded sand grain showing extreme 'frosting' suggests wind transport.

SAQ 2

a) What do you understand by the term 'Mode'?

b) Define Sphericity.

9.9 PACKING OF GRAINS

In the above sections you have read about types of texture of sedimentary rocks, grain size scale, measuring grain size, graphical representation of grain size data, grain size parameters and particle morphology. Now let us discuss about packing of grain size. Packing refers to the arrangement, distribution and density pattern of grains in a sedimentary rock. It is a function of grain size, grain shape, sorting and degree of sediment compaction. Grain packing affects bulk density, porosity and permeability of a rock. **Permeability** refers to the passage through which a fluid is transmitted. **Porosity** refers to voids between the grains.

Depending upon the sedimentation and diagenetic history, packing can be classified into two types: **Primary** and **Secondary**. Primary packing is formed during sedimentation whereas secondary packing reflects the imprint of post-depositional processes such as compaction by overlying sediments.

On the basis of grains and matrix relation in the rock, packing can be:

a) **Grain or clast supported**: Grains are the main constituents of the rock. Grains touch each other and there is little matrix (Fig. 9.11a). Example: beach sand deposits and, stream flood sediments;

b) **Matrix supported**: Matrix is the major constituent in the rock and grains float in the matrix (Fig. 9.11b). Example: mudflow deposits. Generally, matrix supported rocks are poorly sorted.

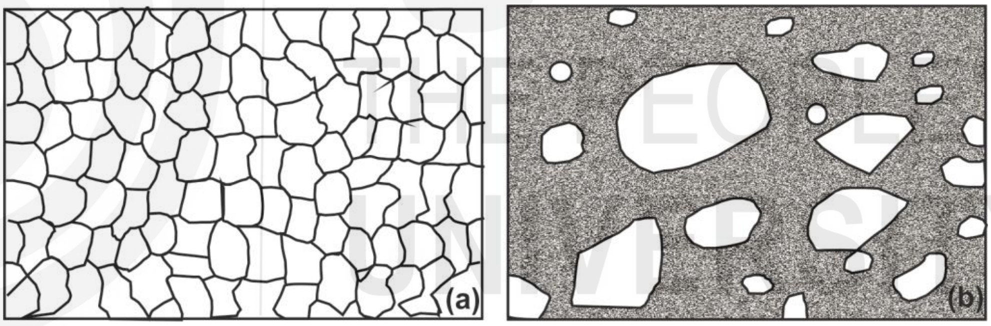

Fig. 9.11: a) Grain supported; and b) matrix supported packings.

The compaction forces during lithification bring the grains into closer contact and cause changes in grain to grain contacts. The type of grain contacts can be:

- **Tangential** - grains touching each other;
- **Concavo-convex** - grains penetrating one another;
- **Sutured** - stylolitic interpenetration of grains; and
- **Long** - straight contact.

We can observe these contacts in highly indurated sandstone under petrological microscope.

Grains packing may be ordered or random. Sediments may be **loosely** packed or **tightly** packed. In case of well sorted and less compacted sediments, packing is loose as the **cubic packing** of spheres. Compacted sediments show close and tight packing as the **rhombohedral packing** of spheres (Fig. 9.12). Increasing packing density decreases the porosity and permeability of rocks.

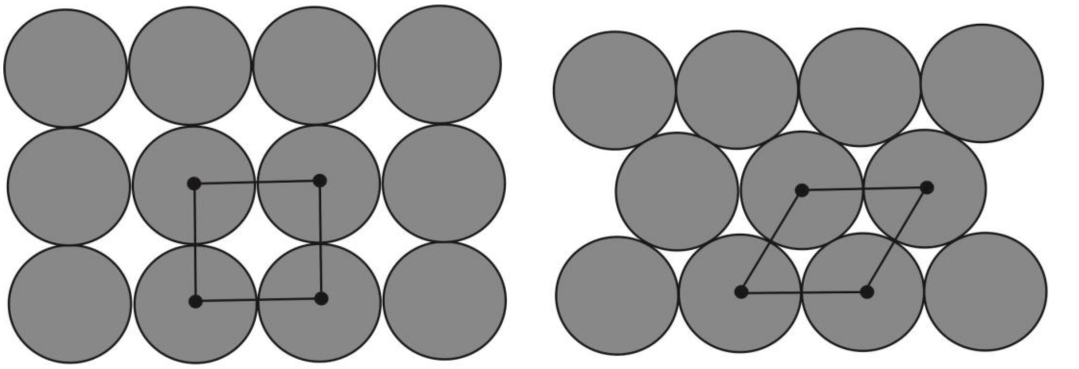

Fig. 9.12: Cubic and Rhombohedral Packing.

➢ **Importance of Packing**:

- Study of packing helps in interpreting the genesis of rocks. For example; clast-supported gravels reveal a typical stream bed or beach deposit; in contrast, matrix-supported gravels are commonly deposited by mudflow.
- In imbricated conglomerates, the long axes of the clasts commonly dip upstream, subparallel to one another (Fig. 9.13). Pebbles, sand grains, mica flakes, some of the fossils, etc. are some of the useful element determining fabric.
- This can be used to infer paleocurrent directions in ancient rocks. **Palaeocurrent** refers to the current which existed during the deposition of sediment at some period of geological history.
- Packing controls the rock's porosity and permeability and therefore vary significant in the study of reservoir rock for oil, gas and groundwater.
- It affects the strength of an aggregate under shearing or vertical load.

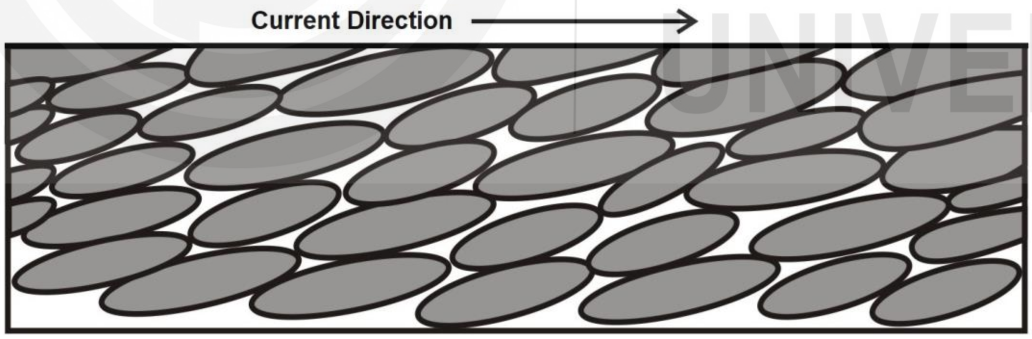

Fig. 9.13: Imbricated pebbles.

9.10 COMPONENTS OF CLASTIC TEXTURE

Clastic sedimentary rocks are composed of four main components- grains, matrix, cement and pore space (void). Grains and matrix are detrital depositional components whereas void may be depositional or diagenetic. Cement is a diagenetic material formed by chemical precipitation. Let us discuss about the components of clastic texture one by one.

9.10.1 Grains

Grains form the major framework of a clastic rock. Most common type of grain components of clastic rock are: quartz, feldspar, and rock fragments. In conglomerates and breccias the framework is formed of gravel sized materials, sand-sized materials in sandstones, and silt and clay sized materials in shale and claystone. Between the grains, the rock may contain matrix, cement and void space (Fig. 9.14).

9.10.2 Matrix

It is the fine-grained material placed between the detrital grains as groundmass (Fig. 9.14c). Matrix is generally composed of clay minerals, silt-sized grains of quartz and feldspar, and derived along with detrital framework. Matrix is composed of mud and silt in sandstone whereas in conglomerate, it is made up of sand and mud. Fine-grained carbonate material (micrite) forms the matrix in some limestones and dolomites. Based on the percentage of matrix, a rock may be **grain-supported**, where the grains are the main constituents of the rock with little matrix or **matrix supported**, where the matrix is relatively higher on which the grains float in the matrix.

9.10.3 Cement

Cement is a chemically or biochemically precipitated (authigenic) mineral formed after the deposition of sediments. They are precipitated in the void space between the grains and fractures in the rock (Fig. 9.14b). Cementation is the principal chemical process that makes a rock hard and compact. Cement is normally found in well-sorted sandstones and conglomerates. Most common cements are usually silica (SiO_2), calcite ($CaCO_3$), and hematite (Fe_2O_3).

9.10.4 Pore Space

It represents the void space in the rock (Fig. 9.14a) and aids for accumulation of oil, gas and water in the sediments. Pore space may be **primary**, having formed during sedimentation process or **secondary**, produced by dissolution of mineral or fracturing during diagenesis.

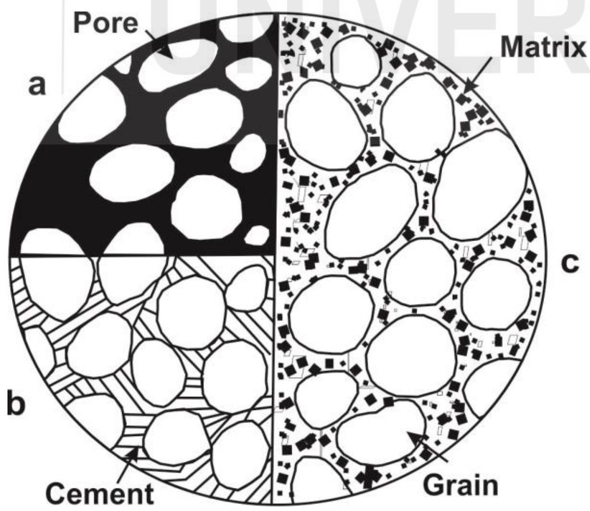

Fig. 9.14: Components of clastic texture.

9.11 TEXTURAL MATURITY

In the above section we have discussed about the components of clastic texture, now let us discuss about the maturity of texture. Textural maturity of sediment reflects the relation between the texture of the sediment and transportation process. Longer the sediment is in transportation, it has more time to become well-sorted and well rounded.

Sediments or rocks may have the following three types of textural maturity:

i. **Super-mature**: Sediments are very well sorted, well rounded having grain supported fabric without matrix (Fig. 9.9a). Example: Beach and dune sands.

ii. **Mature**: Sediments have moderate to good sorting, rounded to sub-rounded and little matrix. As in fluvial deposits.

iii. **Immature**: Sediments have angular grains, poor sorting with more matrix (refer Fig. 9.9b). Glacial and turbidite deposits are examples of it.

Textural maturity reflects the sedimentation processes involved in the deposition of sediments. Diagenetic effects during the process of lithification generally modify the original maturity of sediments.

9.12 TEXTURE OF NON-CLASTIC ROCKS

Non-clastic texture includes crystalline texture and non-crystalline texture. We have read that the term non-clastic is used for rocks formed as a result of deposition through chemical reaction. Non-clastic texture may broadly be categorised into:

i. **Crystalline texture**: They are formed due to direct precipitation from a saturated solution and the result is interlocking aggregate of crystals. Nonclastic rocks consist of crystals, and some may resemble igneous rocks, which are also crystalline.

ii. **Non-crystalline texture**: They result from the coagulation from gelatine like mass. This gelatinous mass may lose some of the water in it and eventually harden to form amorphous mass, e.g. nodular, oolitic, pisolitic textures.

The materials that make up many other non-clastic rocks may actually have originated as detrital deposits. In these instances, the particles probably consisted of shell fragments and other hard parts rich in calcium carbonate or silica. The clastic nature of the grains was subsequently obliterated or obscured because the particles recrystallised when they were consolidated into limestone or chert.

In addition, some chemical sedimentary rocks exhibit this texture. For example, coquina, the limestone composed of shells and shell fragment, is obviously as clastic as conglomerate or sandstone. The same applies for some varieties of oolitic limestone. The intergranular spaces or pores are filled by cement or matrix. The grains of non-clastic rocks are bound together by cement and grains of clastic rocks are bound together by a **matrix** and **cement** both. Cement is common in detrital or clastic sedimentary rocks. Minerals like opal (silica), carbonate minerals (calcite, dolomite), ferruginous minerals (hematite, limonite) are known to play the role of cement. Cement is less common in argillaceous rocks. Poorly sorted detrital sedimentary rocks contain matrix whereas well sorted rocks composed of well rounded or sub-rounded grains and cement.

9.13 SUMMARY

Let us summarise what we have learnt in this unit:

- Texture refers to the shape, size and three-dimensional arrangement of the grains that make up a sedimentary rock.
- Texture can be clastic or non-clastic depending upon whether composed of grains from pre-existing rocks or the grains developed an interlocking mosaic of crystals from a chemically or biochemically produced fluid.
- Udden- Wentworth particle size scale is used to classify clastic sediments and sedimentary rocks.
- Different methods are used to determine the grain size of sedimentary particles. Most common method for sandy sediments is the sieving by mechanical shakers.
- Histogram and frequency curves can be constructed to depict the size distribution of sediments.
- Grain size parameters such as mean, sorting, skewness and kurtosis can be determined from the frequency cumulative curves.
- Most useful aspect in grain size distribution is sorting. It reflects the energy condition of the transporting medium from which the sediment was deposited.
- Degree of rounding of grains gives clues to the amount of time sediment has been in the transportation cycle.
- Packing refers to the arrangement, spacing and density patterns of clastic grains in the rock. It is a function of grain size, sorting, grain shape and degree of compaction.
- Matrix is the fine grained (detrital) groundmass on which grains are embedded or float. Cement is chemically precipitated authigenic mineral in the pore space between the grains.

9.14 ACTIVITY

- Pick up handful of sand and try to identify various minerals. Also try to find out the grain size.

9.15 TERMINAL QUESTIONS

1. Define sorting and discuss its significance.
2. How packing of grains effects porosity and permeability of rocks?
3. What is the difference between matrix and cement?

9.16 REFERENCES

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9.17 FURTHER/ SUGGESTED READINGS

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9.18 ANSWERS

Self Assessment Questions

1 a) The mode and distance of transport, energy condition and depositional processes.

b) > 256mm - 4 mm (Granule, Pebble, Cobble and Boulder).

c) Frequency Cumulative Curve is generated by plotting grain size against cumulative weight percent.

2 a) It is the most commonly occurring particle size in distribution of grain size and represents the highest point (peak) of the frequency curve.

b) Sphericity is the degree to which the shape of a sedimentary particle approaches that of a sphere.

Terminal Questions

1. Refer to section 9.6
2. Refer to section 9.9
3. Refer to section 9

UNIT 10

SEDIMENTARY STRUCTURES

Structure

10.1 INTRODUCTION

We have learnt that sedimentary rocks are derived from pre-existing rock-masses (as such they are also referred as secondary rocks) formed from the consolidation of loose sediments or chemical precipitation from solution or an organic matter consisting of secretions or remains of plants and animals. They are formed due to decay and disintegration of pre-existing rocks by natural agencies like ocean, running water, glacier, lake, wind etc. in the depressions that occurred on the land area.

The surface of the Earth, including its seafloor, is covered with sediments and sedimentary rocks. They form a surface veneer or 'cover' on bedrock ranging in thickness from practically non-existent (in places where bedrock crops out at the Earth's surface) to few kms. Sediments, loosened materials that ultimately formed sedimentary rocks, are usually deposited in layers one on top of the other. They record the conditions that existed at the time of deposition and subsequent changes.

Sedimentologists can infer the sources and the environment of deposition of the sediments using evidences provided by the study of its texture, structure and mineral content. In unit 9 we have read about sedimentary textures that is concerned with the size, shape of grains, their sorting, three-dimensional arrangement of the grains and the porosity that make up sediments or sedimentary rock. In this unit we shall learn about sedimentary structures. The textures and the structures of the sedimentary rocks are controlled by the nature and its intensity of the transportation undergone by the sediments. The depth of water in the basin also affects the resultant textures and the structures of the sediments.

Expected Learning Outcomes

After reading this unit you should be able to:

- ❖ acquaint with the primary and secondary sedimentary structures;
- ❖ discuss mechanical structures like bedding, cross stratification, ripple marks;
- ❖ describe chemical structures such as concretions, stylolites, dendrites and solution structure; and
- ❖ explain the organic structures i.e. track and trails, burrow marks and stromatolites.

10.2 SEDIMENTARY STRUCTURES

As we know the textures of sedimentary rocks is used to refer to the inter-relationship between the constituent grains which occur in a group, their disposition defines the term **sedimentary structure**. Sedimentary structures are important attributes of sedimentary rocks. They occur on the upper and lower surfaces of beds as well as within beds. They can be used to deduce the processes and conditions of deposition, the directions of the currents which deposited the sediments. Now in this section we will learn about the structures present in sedimentary rocks that are both organic and inorganic in origin. Sedimentary structures are large-scale features which show variety of interesting and significant geometries that are produced by physical, chemical and biological processes operating on sediments during and after their deposition (Pettijohn, 1957; Potter and Pettijohn, 1964). Sedimentary rocks exhibit a variety of structures which have depositional characters produced at the time of deposition of sedimentary rock, i.e. syn-sedimentary structures or after the deposition, i.e. post-depositional. These structures are, therefore, classified on the basis of mode and time of their formation. Depending on the kind of mechanism of formation and relative time of deposition, the structures are classified into:

- primary structures or mechanical structures,
- secondary structures, can be further divided into chemical and organic.

10.3 PRIMARY STRUCTURES

Primary structures are formed during the deposition of the constituent sediments. Physical (or mechanical) processes operating during the deposition develop these structures like bedding, cross stratification, ripple marks, etc. and therefore they are also termed as **mechanical structures**. They are inorganic in nature.

Primary structures are significant and may help us in determining:

- paleocurrent conditions,
- rate of supply of sediments,
- mode of transportation,
- environment of deposition, and
- top and bottom of beds

Now let us note their characteristics. Primary sedimentary structures include the following:

10.3.1 Bedding and Stratification

We have read that clastic sedimentary rocks formed as a result of deposition of insoluble mechanically transported material is in the form of bedded deposits, sheets and layers of various sizes. Sedimentary rocks are generally layered rocks because of the deposition of similar or dissimilar in colour, grain size or mineral composition, sediments one over another in a basin. Individual layer of a sedimentary rock is called **bed**. Bed thickness varies both vertically and laterally. Their organisation upward, increase or decrease in thickness reflect gradual change in depositional environment. Each bed is separated from the adjacent bed by developing a surface of contact which give rise to a plane called **bedding plane**. They may be horizontal or inclined (Fig. 10.1). Beds may be thin, of the order of few cms or may be meters or even many meters thick. Parallel layers of different grain sizes or compositions are separated from each other by planes of weakness and indicate successive depositional surfaces that formed at the time of sedimentation. **Layering** is the linear deposition of constituent sediments like small fragments of parent materials. If the individual layers are less than one cm thick, they are called lamination. **Lamination** is a characteristic structure of fine-grained sedimentary rocks like clays and shales (Table 10.1). Individual layers are called **laminae**. They may be parallel or non-parallel, continuous or discontinuous and curved, either wavy or planar (Fig. 10.2). Both laminae and beds are defined by changes in grain size, composition and colour that may be more or less distinct. **Stratum** (Pl. strata) is an umbrella term which is used to cover both bed and laminae. Stacking up process of strata one over another is known as **stratification**.

Let us summarise. Bedding and lamination define stratification. Bedding is thicker than 1 cm whereas lamination is thinner than 1 cm. Bedding is composed of beds; lamination is composed of laminae. Parallel (also called planar or horizontal) lamination is a common internal structure of beds. It relates to a process by which sediments are laid down one after another so as to appear like one set over other set. Often terms bedding, stratification and layering are used interchangeably. Most commonly observed sedimentary structure is stratification.

Table 10.1: Scale of Stratification of Thickness. (Source: Inzram, 1954).

Thickness (cms.)	Terminology
>100	Very thickly bedded
30-100	Thickly bedded
10-30	Moderately bedded
3-10	Thinly bedded
1-3	Very thinly bedded
0.3-1	Thickly laminated
<0.3	Thinly laminated

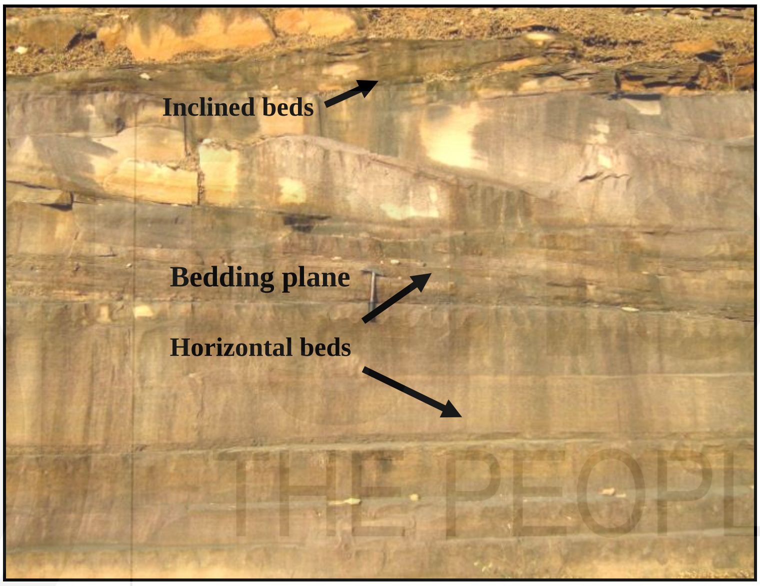

Fig. 10.1: Field photograph showing laminations, bedding plane, horizontal and inclined beds. (Photo credit: Prof. Meenal Mishra)

10.3.2 Cross-Bedding

It consists of sets of bedded material deposited by wind or water and inclined at angles even upto 35º from the horizontal (Fig. 10.3a and b). Crossed beds usually show truncated top and asymptotic bottom beds assuming some horizontality. It is formed due to change in the velocity and/or direction of flow of streams. Oblique lines of a cross bedded layer always meet the upper bedding at a higher angle and lower portion tangentially. In wind formed current beddings, the laminations are curved and of larger magnitude. Cross-stratification is also referred as **current-bedding** or **false bedding**.

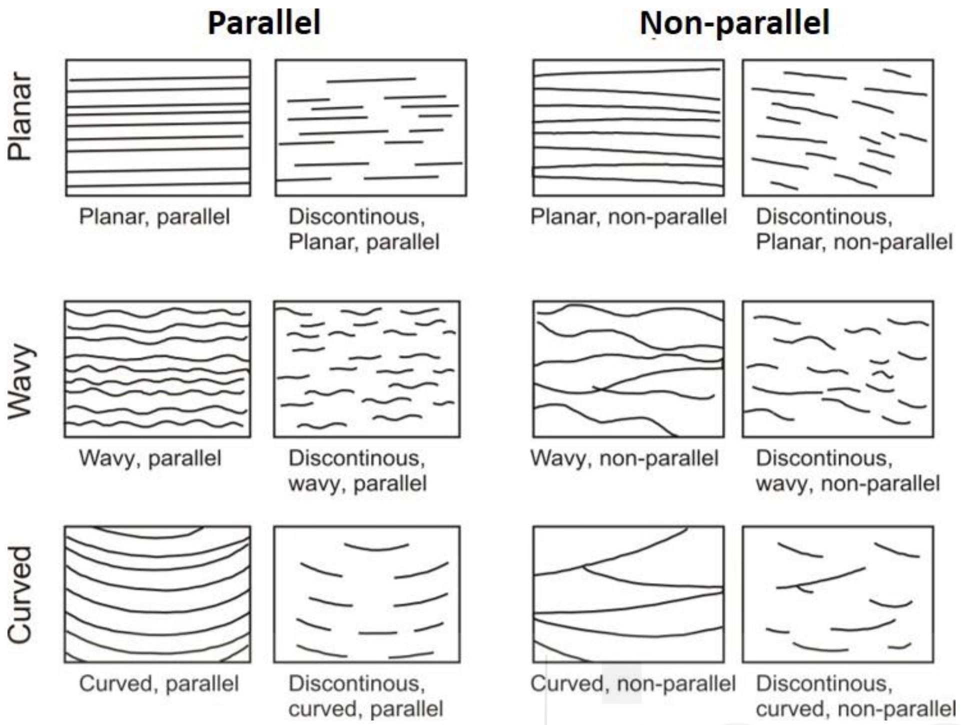

Fig. 10.2: Nature and terminology for geometry of bedding and lamination.

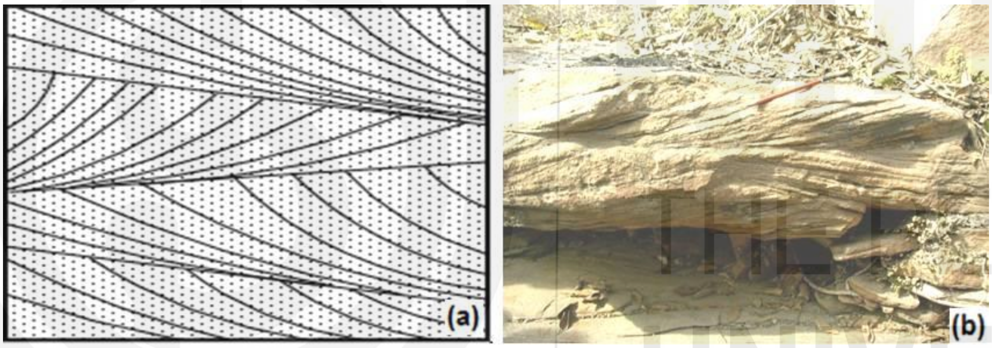

Fig. 10.3: Cross-bedding or current bedding: a) sketch; and b) field photograph showing current bedding in coarse sandstone.

Cross bedding consists of inclined dipping bedding, bounded by sub horizontal surfaces and each of these units is termed a **set**. A group of similar sets are termed **cosets**. Three sets of beds (or laminae) i.e. **topset** (upward), **bottomset** (towards sole) and **foreset** (inclined bedding in between the above two) comprises crossbedding or cross lamination (Fig. 10.4). Often top and bottom set are parallel and foreset meet the top set at higher angle. When the top and bottom beds show convergence at a point, it is said to be **wedge cross stratification**. In **tabular cross bedding** top and bottom sets are more or less parallel, but when the top and bottom sets tend to meet, they form **lensoid cross bedding**. The truncated top of the cross bedding indicate upside and asymptotic bottom is on the downside or basal side (Fig. 10.5).

Cross beds have been classified according to:

a) The angles of truncation of fore sets and the nature of lower bounding surfaces of the sets (Fig. 10.4), they are of following types:

- **Simple**: The angle of truncation is at 15º, with non-erosional lower bounding surfaces.

- **Planar**: The angle of truncation is over 15º having lower bounding surfaces as erosional plane.
- **Trough**: The angle of truncation is less than 15º and have curved erosional surfaces.

b) The attributes of top and bottom sets (Fig. 10.6), they are:

- **Tabular**: Cross beds having the top and bottom surfaces of the deposit are essentially parallel, indicating better sorted sediments.
- **Lenticular**: When all the layers in cross beds show an extreme irregularity in their shape and disposition and may be intersected by many other beds at different angles.
- **Wedge**: In this type of cross beds the individual layers exist in well-defined sets of parallel layers but bears angular relationship with each other.

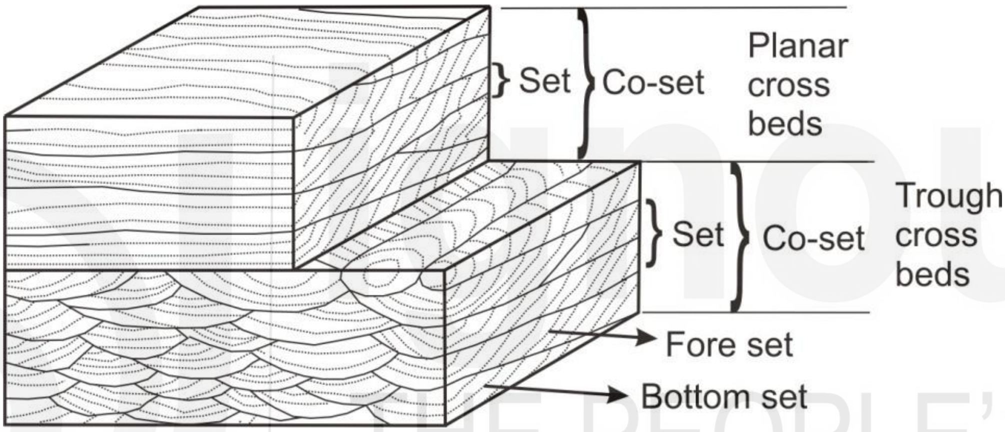

Fig.10.4: Sketch showing Planar and Tough Cross beds.

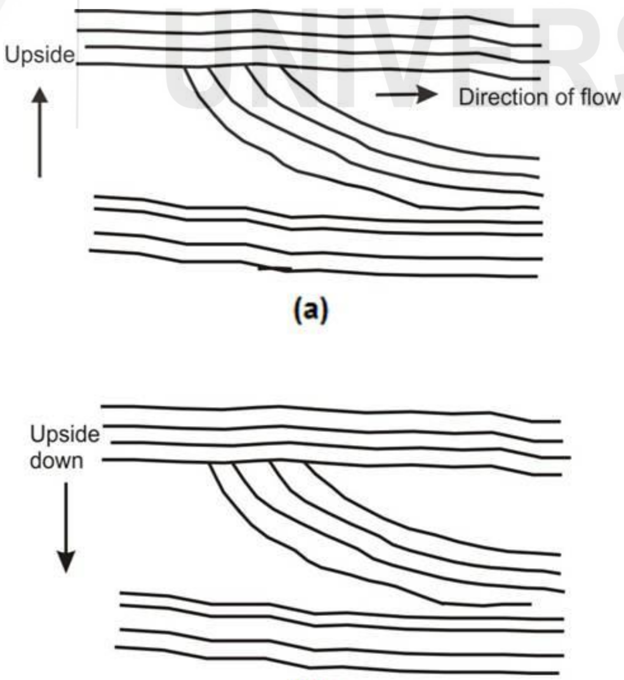

Fig.10.5: Sketch of cross bedding diagram showing: a) upside; and b) downside and direction of flow.

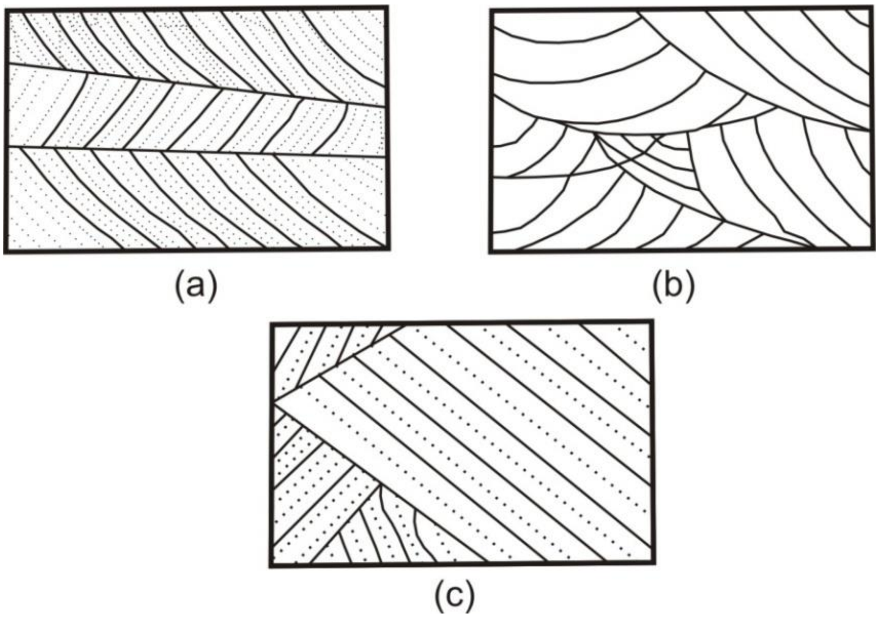

Fig. 10.6: Sketch showing: a) Tabular; b) Lenticular; and c) Wedge shaped Cross beds.

10.3.3 Graded Bedding

They show progressive variation of grain size from coarser at the bottom to finer towards the top of a bed, in a gradational manner (Fig. 10.7). Each layer of sediment within a graded bed contains a variety of grains, both coarse and fine, but the mean size of the grains gradually decreases upward. A graded bed comprises one set of coarse to fine beds, normally ranging from a few cms to several meters thick. Total thickness is upto many hundreds of meters. They may be deposited in deep-ocean waters by turbidity currents flowing along the ocean bottom. The larger, heavier, clasts settle down first followed by the smaller, lighter clasts producing vertically sorted "graded" beds with large clasts on the bottom and finer clasts on top. Gradational, fining-upward sequences are common features in standing water suspension deposits where seasonal variations are effective.

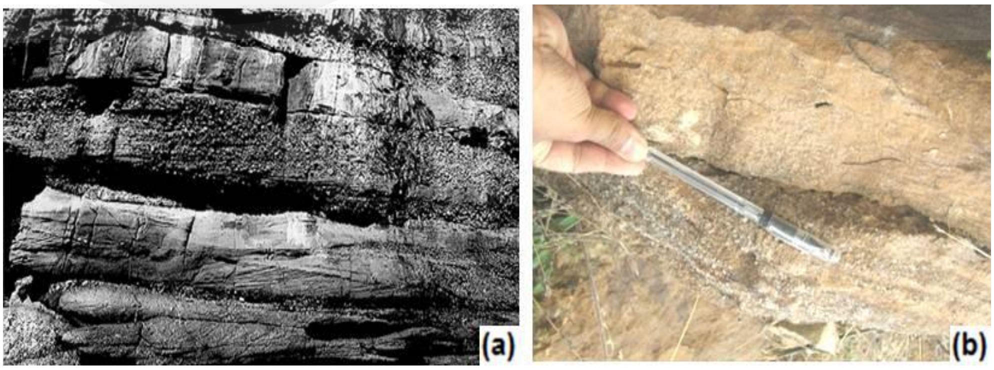

Fig. 10.7: Graded bedding: a) and b) field photograph of sandstone with coarse beds at the bottom to finer at the top. (Photo credit: Prof. Meenal Mishra)

10.3.4 Ripple Marks

A ripple mark is a wavy structure characterised by a crest and a trough. In other words, they are very small dune like features of sand or silt whose long dimension is at right angles to the direction of current movement. The crests generally run parallel to each other, which may be sharp, rounded or flattened. They form low, narrow ridges mostly 1-2 cm, separated by wider troughs (Fig. 10.8a). Ripple marks generally result from interplay of wind and wave action during the process of deposition of sediments in shallow waters. Various terms like ripple height, ripple length, lee side, stoss side, summit point, toe point, brink point, trough point, slip face, bottom set, ripple index and symmetry index are used to describe **ripple morphology** (Fig.10.9). Steeper face of a ripple dipping in the down current direction is called the **lee face**. Gently sloping face dipping in the opposite direction is the **stoss**. The crest of the ripple is called the **summit point**. Vertical height of the crest above the base is the **height of the ripple**. Horizontal distance from one crest to the next crest is the length or **wavelength of the ripple**. The **ripple index** is given by the ratio of wave length to wave height. Erosion of sediments from the stoss face of the ripple and deposition of the sediments on the lee side causes the ripple to migrate downstream. As the pressure increases in the down flow direction the layer of fluid at the bottom is forced upstream by a process called **flow separation**. Flow separation takes place at the crest and an eddy develops within the trough. The point where flow separation is initiated is called the **brink point**. The point of flow-reattachment is the **toe point** of the ripple.

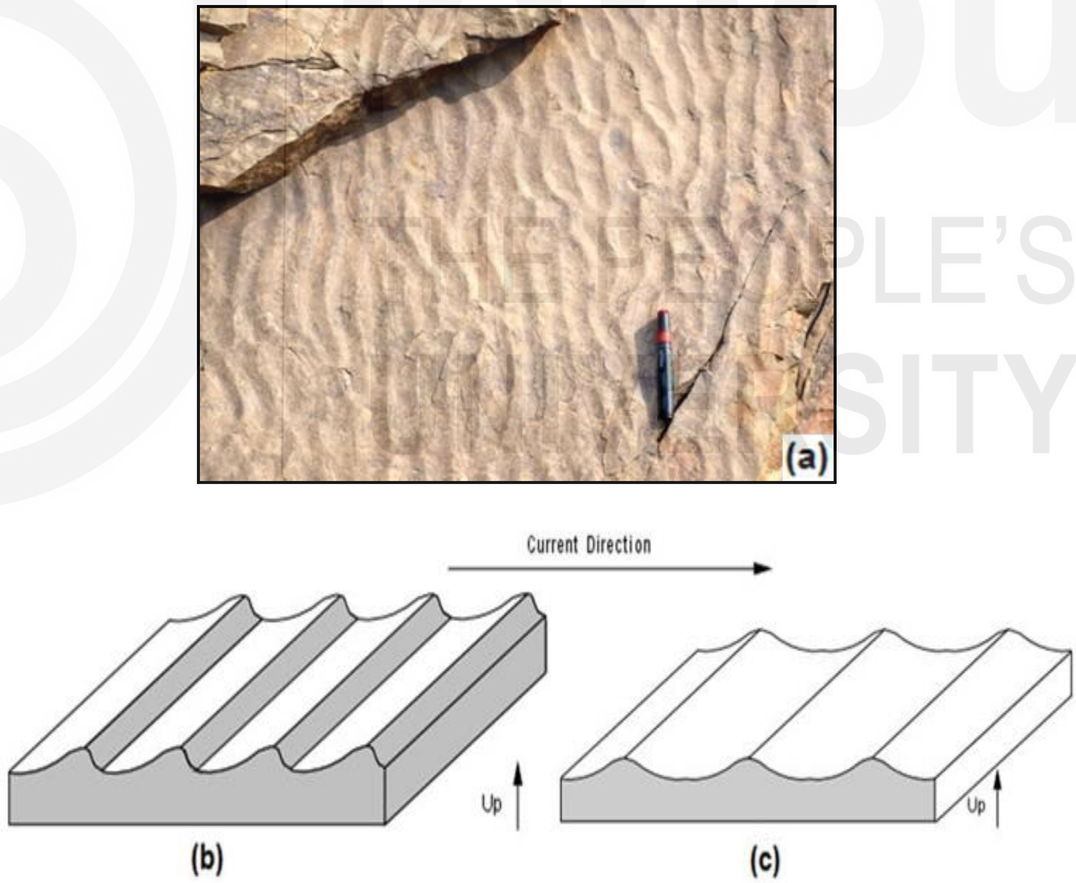

Fig. 10.8: Ripple marks: a) field photograph of ripple marks in sandstone; b) sketch of asymmetrical ripple marks showing flow direction; and c) sketch of symmetrical wave ripple marks pointing upward direction.

Shape of ripples is described as two-dimensional if the crests are straight, or three-dimensional, if the crests are sinuous, catenary, lunate or linguoid (Fig.

10.10). Ripple marks are common in both modern sands and ancient sandstones. There are two common types of ripple marks:

- **asymmetric, or current ripples** and
- **symmetric, or wave-formed ripples**

Current ripple marks are asymmetrical in nature, having parallel, long, more or less equidistant ridges trending in straight lines at right angles to the direction of flow lee-ward side. Current ripples are the commonest bedforms encountered within the lower flow unidirectional regime. Here both the crests and troughs are rounded. Aqueous ripples contain finer materials at the crest and coarser material at the troughs but in case of aeolian ripples coarser materials are found at crests (Fig. 10.8b and Fig. 10.11).

Wave-formed ripple marks also known as symmetrical ripples form when the water moves back and forth, such as tidal action. Symmetrical ripple marks can give an indication of beds disposition pointing ripple crest upwards (Fig. 10.8c and Fig. 10.11). These are shallow water features and are indicative of a stagnant body of water frequently agitated by waves.

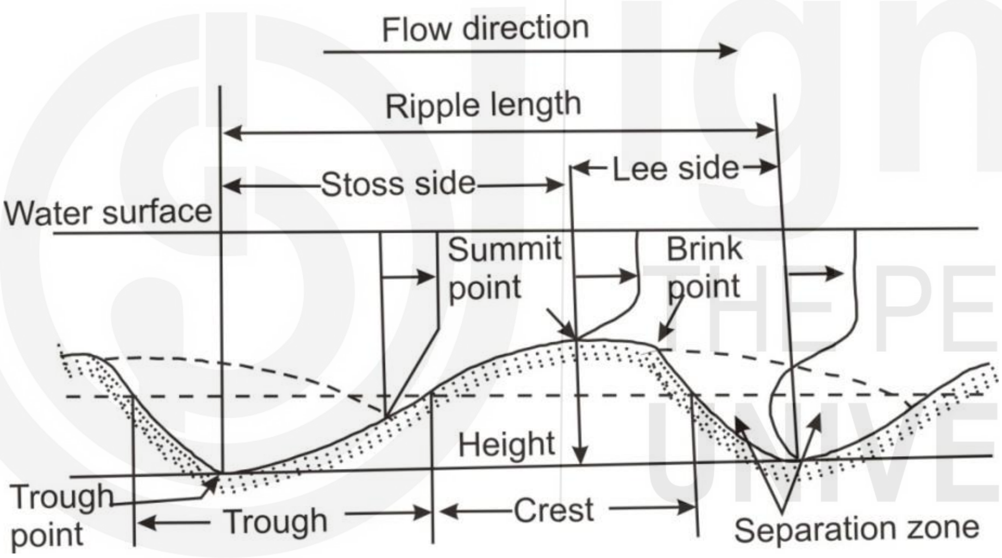

Fig.10.9: Schematic cross-section of a ripple.

Watch the following video to know more about planar bedding, cross bedding, graded bedding and ripple marks.

- **Sedimentary Structure of Clastic rocks**

Link: https://www.youtube.com/watch?v=llg5aAbaL0s&t=44s

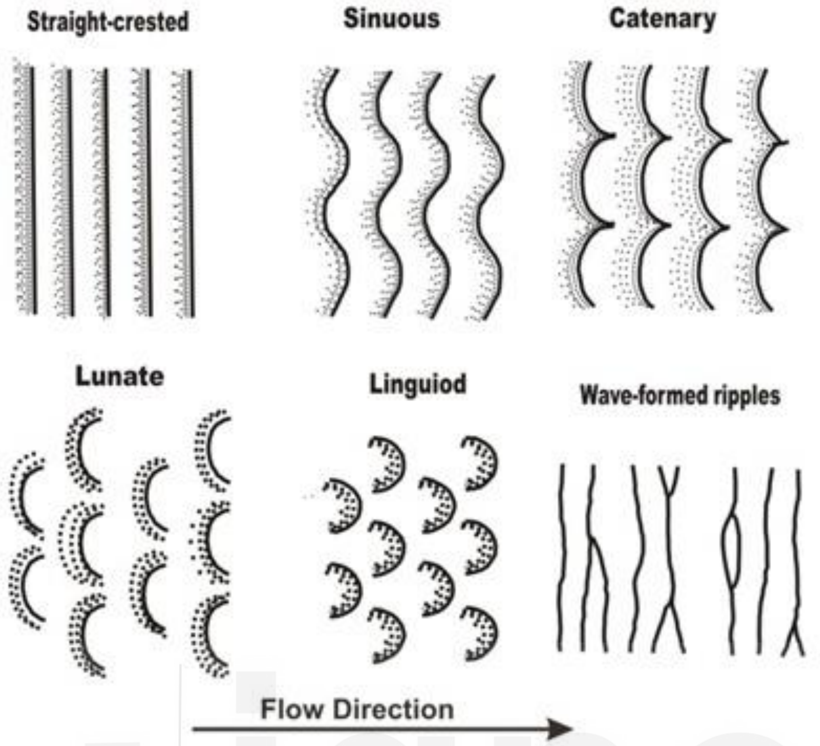

Fig.10.10: Sketches of the crests of ripples and dunes formed by unidirectional currents.

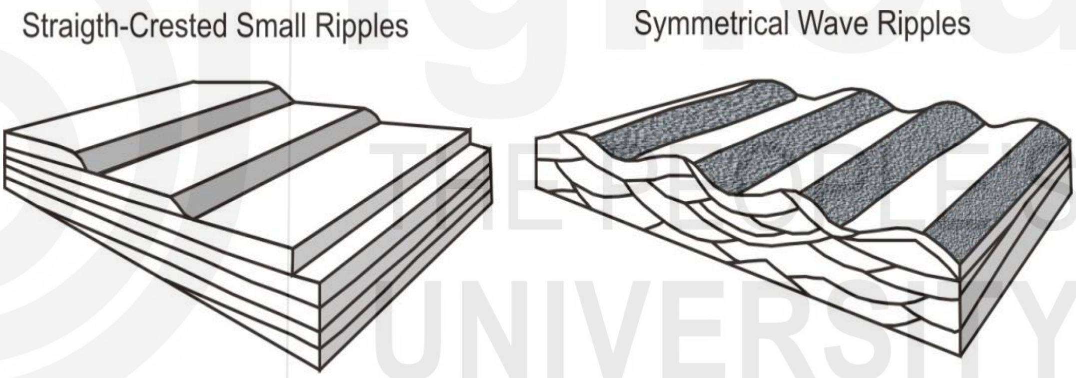

Fig.10.11: Sketch showing current ripple marks and wave formed ripple marks.

10.3.5 Mud Cracks

They are common structural features typically develop in clayey sediments due to prolonged exposure to the atmosphere and are also known as **shrinkage cracks** or **sun cracks** (Fig. 10.12a). As the sediment shrinks, cracks begin to form on it. The shrinkage opening is wider that narrows down towards the bottom (Fig. 10.12b) which are infilled by sand. In plan view they are polygonal and are generally about 0.5 m across. Presence of mud cracks indicates that the sediment was exposed at the surface shortly after deposition, since drying of the sediments would not occur beneath a body of water.

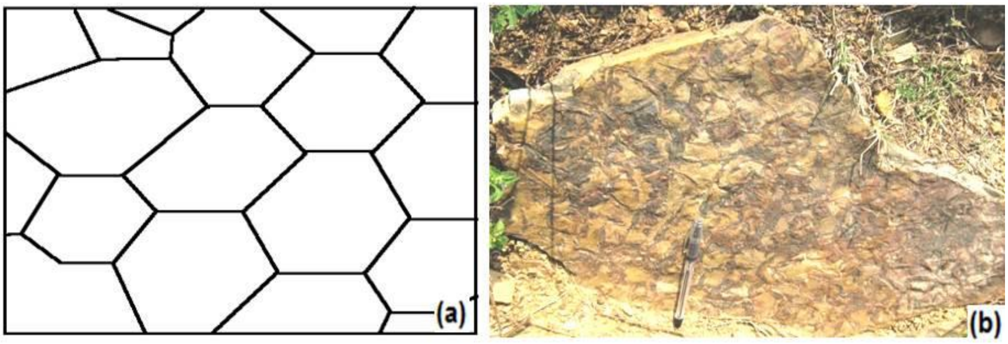

Fig. 10.12: Mud cracks: a) sketch of polygonal mud cracks; and b) field photograph of mud cracks in shale.

10.3.6 Rain Drop Imprints

These are irregular, small crater-shaped depressions with slightly raised edges seen on fine-grained dried soft sediment surfaces. Rain drops falling on the surface of fine-grained compacted clays often makes crater like depressions. Thus, they are shallow depressions surrounded by low ridges (Fig. 10.13) formed by the impact of hailstones, etc. These may get dried up and subsequently preserved under another layer of mud above them. Raindrop imprints cause very minor disturbance to the bed surface, but leave a very distinctive pattern. Rain prints are good indicators of subaerial exposure but are not exclusive to arid climates, though they may have a higher preservation potential in such conditions.

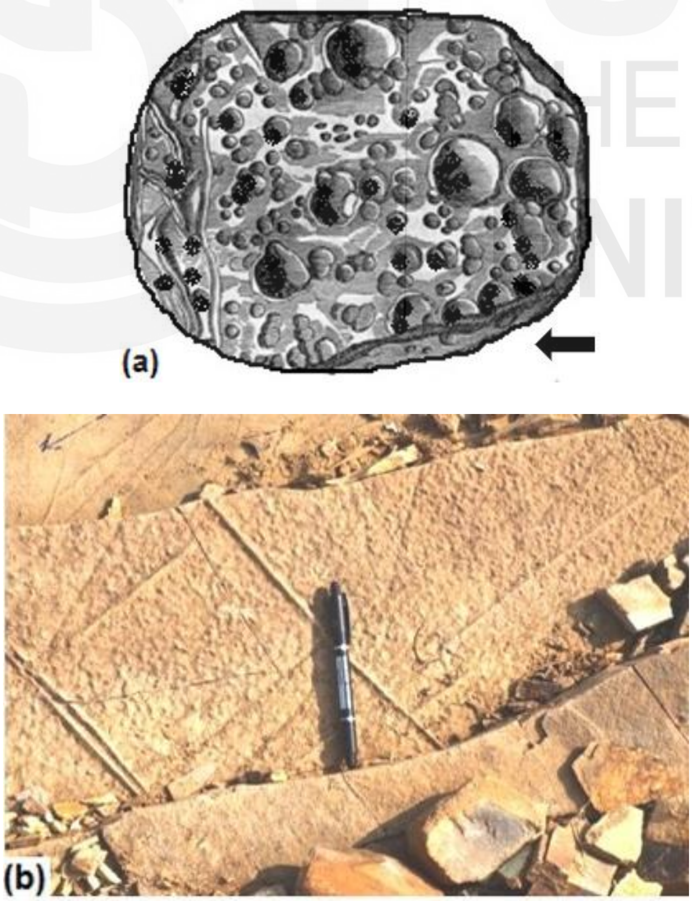

Fig. 10.13: Rain drop imprints: a) sketch; and b) field photograph showing rain drop imprints in fine sandstone.

10.3.7 Sole Structures

These structures are preserved on the base of a bed which is sharply differentiated lithologically from the bed below. They usually occur at the interface of two different lithologies. Sole marks are found most commonly in turbidite deposits. They also include flute cast which are grooves eroded by turbulent flow and later filled with coarse sediments. Flutes are elongated depressions that form on the bottom of the body water as the current erodes (Fig. 10.14). They occur in a variety of shapes, from narrow elongate to broad transverse scours, and either in isolated marks or in distinct clusters. **Flutes** are heel-shaped hollows, scoured into mud bottoms. Each hollow is generally in filled by sand, attached with the overlying bed. The rounded part of the flute is at the up current end. The flared end points are down current. Flutes are about 1-5 cm wide and 5-20 cm long. Flute marks are a characteristic structure of turbidites and are excellent indicators of current direction and tops/ bottoms of bed. Flutes are characterised by (i) up steam bulbous end and (ii) downstream flattening. Similar features, but when parallel grooves are oriented in the flow direction, term **groove casts** are used.

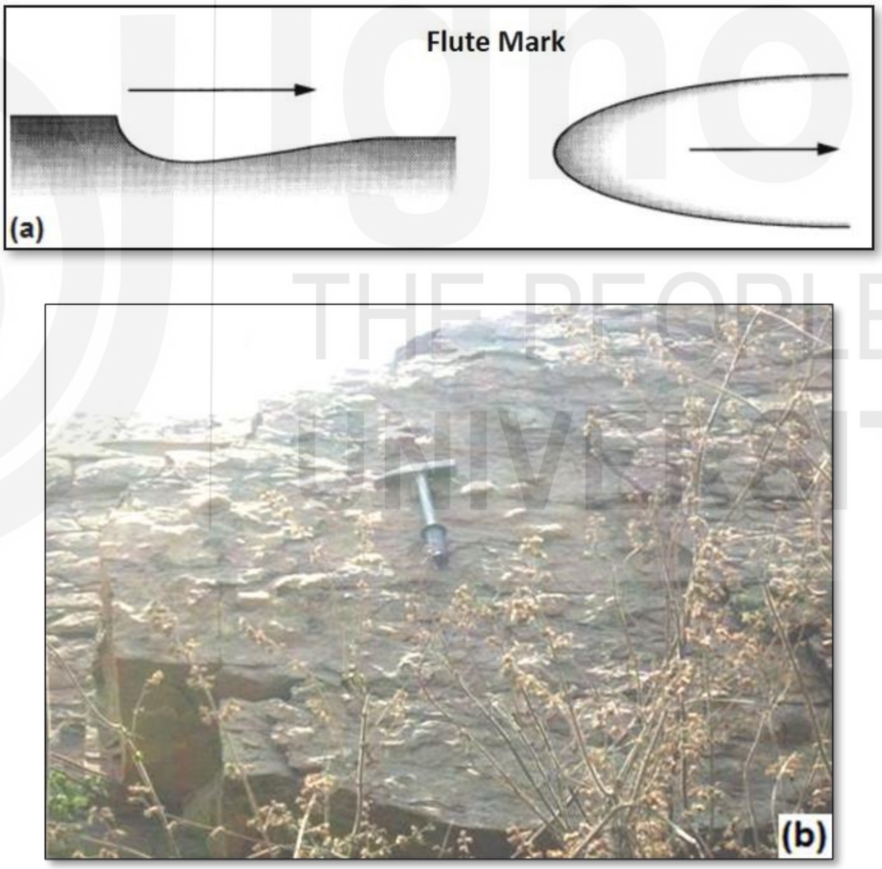

Fig. 10.14: a) Sketch; and b) Flute marks in sandstone.

> **Watch the following video to know more about clastic rocks.**
>
> - **Sedimentary structure of clastic rocks**
>
> **Link**: https://www.youtube.com/watch?v=llg5aAbaL0s&t=44s

In the previous sections you have studied about the structures present in clastic sedimentary rocks. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 1

a) What are primary structures?

b) What are ripple marks?

c) What are mud cracks?

10.4 SECONDARY STRUCTURES

Sedimentary structures, also classified as secondary sedimentary structures (Pettijohn and Potter, 1964) are formed sometime after deposition. These structures are products of chemical action or biological activity contemporaneous with sedimentation or shortly thereafter. They can be grouped broadly into two categories-

A. Chemical structures - originates due to chemical action, e.g. concretions, stylolites, dendrites and solution structure.

B. Organic structures - are formed due to biological activity of organisms, e.g. track and trails.

10.4.1 Chemical Structures

They are the product of chemical action contemporaneous with sedimentation or shortly thereafter and include:

1. **Concretions**: They are spherical to elliptical usually small bodies of diverse chemical nature than the rocks in which they occur. They are developed on accretion and subsequent precipitation of the dissolved carbonate material derived from the pre-existing rock. They grow around a nucleus which may be a fragment of silica or phosphate. For example, in Indo-Gangetic alluvium hard layers found are termed kankar. These are known as concretions. When the accreted material is precipitated in an open space like cavity or vug, it is referred to as **secretion**. Nodules are structureless irregular shaped bodies in a rock, such as chert in carbonates. They vary in size. Radiating cracks filled in by carbonate materials in large and oblate nodules are termed **septaria**.

Fig. 10.15: Geode.

You can see geode in Fig. 10.15. Geodes (Greek - ge-ōdēs, "earthlike") are spherical to sub-spherical hollow shell of chalcedony with an internally lined minerals commonly quartz but sometimes crystals of aragonite, chalcopyrite or sphalerite may as well project. More or less spherical concretions of the size of fish eggs (0.1 to 1.00mm) form oolites and the structure is **oolitic structures** whereas in pisolite, the individual size of a concretion is bigger (>2mm) like that of a peanut. Bauxites (Fig. 10.16) and limonites often have pisolitic structure.

Fig.10.16: Pisolitic bauxite.

2. **Solution action**: We have read about solution action in Unit 7 Geological Work of Wind and Underground Water of course BGYCT-131.They are formed as a result of solution activity commonly in calcareous rocks. Caves, stalactites and stalagmites (Fig. 10.17) are its features. Any material that is soluble, can be deposited as a colloid, or is in suspension and is capable of being melted may form a stalactite at the roof of a cave or cavern (the letter ‘c’ in it refers to ceiling from where stalactites hang). The saturated water dripping from the end of a stalactite falls to the floor of a cave and deposits more calcite into a mound forms a stalagmite at the bottom of the cave or cavern (the letter ‘g’ refers/points to ground where stalagmites are formed) in a cone like shape. Stalactites and stalagmites are commonly seen in Sahastradhara near Dehradun in Uttarkhand.

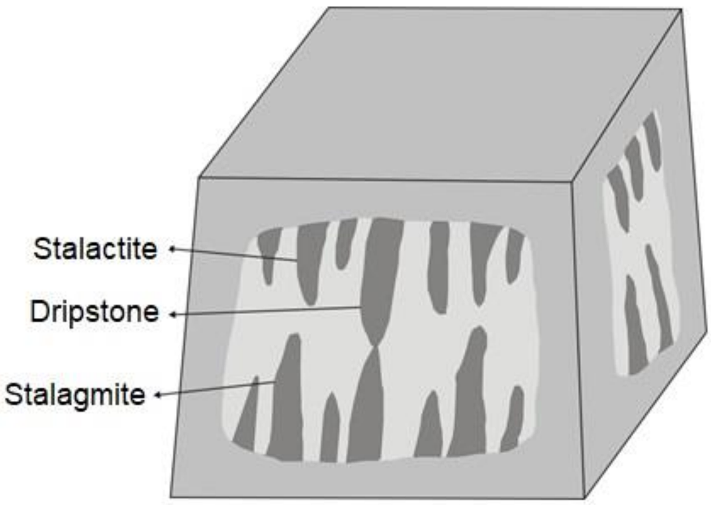

Fig. 10.17: A sketch of stalactite and stalagmite.

3. **Stylolites**: These are serrated surfaces within a rock mass along which mineral material has been removed by interstratal solution dissolution (Fig. 10.18a) circulating under pressure. Insoluble minerals, such as clays, pyrite and oxides, remain within the stylolites and make them visible. Stylolites usually form parallel to bedding. The pattern produced by stylolites resembles the pattern that of a heartbeat (Fig. 10.18a). They occur frequently in calcareous and gypsiferous rocks, but may rarely be also seen in dolomites. Stylolites vary in size from a few millimetres to several centimetres. Growth of a stylolite stops when permeability in the adjacent rock falls to a level that retards free flow of ions.

4. **Dendrites**: The term "dendrite" is used to describe branched projections of neurons. A nerve cell that receives and sends electrical signals over long distances within the body. The Dendrites that mimics the function of the human brain and nerves built on the so-called neurons. These are also known as pseudofossils. Dendrites occur due to filling along the fissures in the rock by percolating mineral solution (Fig. 10.18b). They form when water rich in manganese and iron flows along fractures and bedding planes giving rise to deposition in branch-like dendritic pattern. Dendrites are common on the surface of sedimentary rocks, especially limestone.

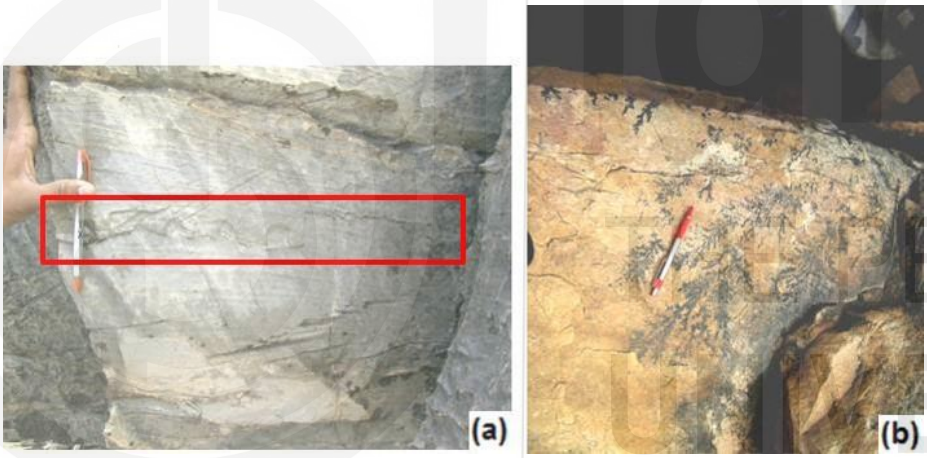

Fig. 10.18: a) Stylolites formed parallel to bedding plane in limestone; and b) Dendrites in sandstone. (Photo credit: Prof. Meenal Mishra)

10.4.2 Organic Structures

They include fossil impressions or structures produced by biological activities of organisms, as well as petrified remains of animals or plants. These structures commonly met in intrabasinal sediments but sometimes they are also reported from extrabasinal sediments.

1. **Tracks and Trails**: These markings are indicative of activity of organism over soft sediments. They may be due to feeding, crawling, dwelling, grazing, resting their bodies over soft sediments. The nature and morphology of the trace fossils, is controlled by the behavioural characters of animals. Examples include dinosaur footprints or bird tracks. These structures imprinted on the surface are categorised as trace fossils or ichno-fossils. Trace fossils are common in sandstones and shales, but these have been reported from carbonate rocks also. Traces preserved wholly within the bed are called 'full relief'. Those occurring at the interface of two layers of

rocks are called ‘semirelief’. When occurring at the upper surface of a sandy bed are termed ‘epirelief’ and those occurring on the lower surface (sole) of a rock layer are termed ‘hyporelief’.

2. **Burrow Marks**: They are also known as bioturbation marks. When the organism moves through the soft sediments it makes a burrow. Bedding in many sedimentary rocks is broken or disrupted by roughly cylindrical tubes a few cms in diameter that extend vertically through several beds. These sedimentary structures are remnants of burrows and tunnels excavated by worms, and many other marine organisms that live on the bottom of the sea. These organisms rework on existing sediments, burrowing through muds and sands. They ingest sediment for the bits of organic matter that it contains and leave behind the reworked sediment, which fills the burrow (Fig. 10.19a). Such burrows can be excellent top and bottom indicators and thus help reconstructing the sedimentary environment.

3. **Stromatolite**: Stromatolites also known as algal stromatolites are sedimentary structures and are composed of sand-silt and clay sized sediment particulates. They can be traced back 3.5 billion years. They are laminated structures produced by the finer sediment trapping usually by an algal mat, binding, and precipitating activity of phototropic microbes including cyanobacteria / blue-green algae (Fig. 10.19b). They may shape like small mound or be columnar, concentrically structured.

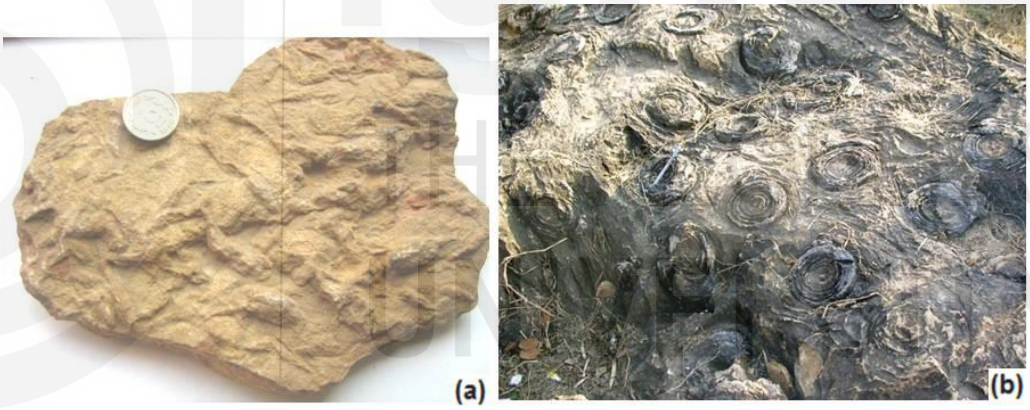

Fig. 10.19: a) Burrow marks in sandstone; and b) Stromatolitic structure in limestone.

The common stromatolites are the ones related to algal growth, but they are not fossil algae. Their growth forms (Fig. 10.20) may be of following types:

i) almost flat along the bedding,

ii) arched hemispherical,

iii) cabbage like,

iv) a pile of stacked inverted vertical column like tumbles,

v) expanding upward club like.

Stromatolites are found in limestones of all ages ranging from Precambrian to Recent, and are particularly useful in correlating Proterozoic formation.

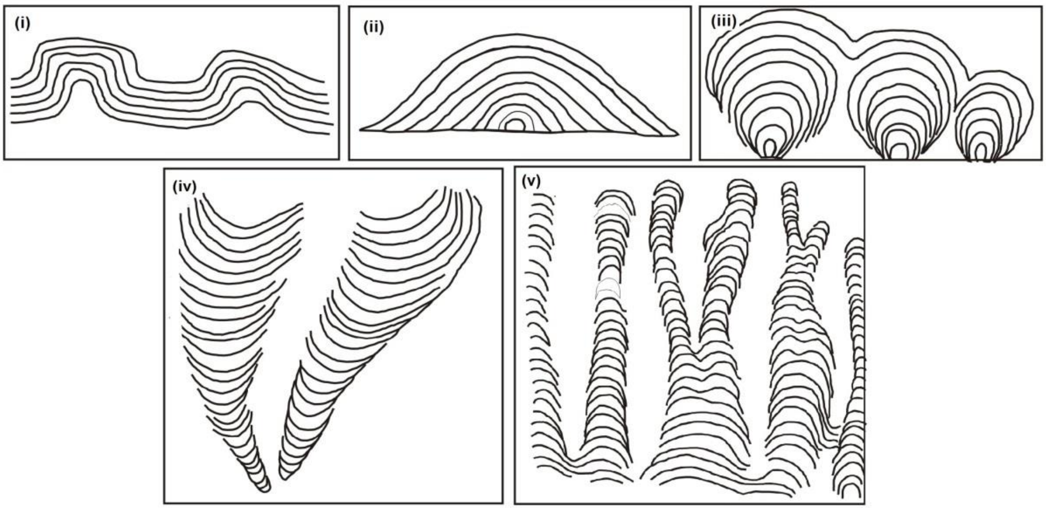

Fig. 10.20: Stromatolitic forms.

4. **Coral Reefs**: They are dome to elongate, massive to bedded forms accumulate largely as a result of organic buildups within otherwise horizontal or nearly flat-lying strata. They are built during carbonate deposition by organisms that biogenetically precipitate carbonate materials.

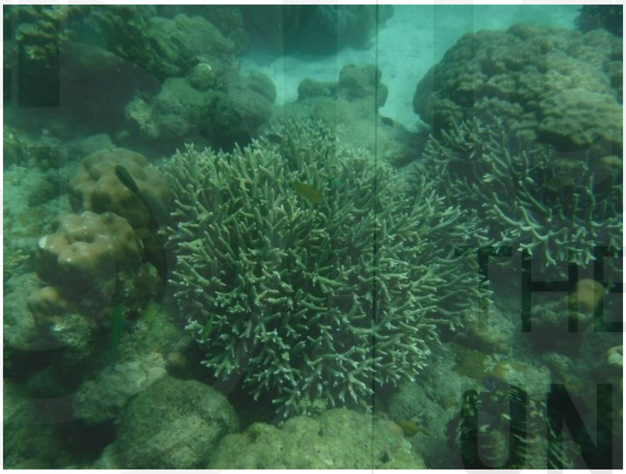

Fig. 10.21: Coral Reef.

5. **Casts and Molds**: Organisms buried in sediment slowly decay, leaving a hollow space that contains an exact imprint of the organisms' shape and size. Later when this hollow space is filled with materials, it takes the shape of the mold, forming a cast.

Watch the following video to know more about stylolite and various organic structures.

- **Sedimentary Structure of Non-Clastic rocks**

  Link: https://www.youtube.com/watch?v=3iL__lYkFRM

In the previous sections you have studied about the chemical and organic structures present in non-clastic sedimentary rocks. Before going to the next section spend 5 minutes to check how you are progressing.

SAQ 2

a. What are secondary structures? Give examples.

b. What are burrow marks?

c. What are stromatolites?

10.5 SUMMARY

Let us summarise about what we have learnt in this unit:

- Sedimentary structures can be classified into primary or secondary structures, depending on the mechanism of formation.
- Sedimentary structures are large-scale features which show variety of interesting and significant geometries that get produced by the physical/mechanical, chemical and biological processes.
- Primary structures also known as mechanical structures. They are formed due to mechanical action of waves. Primary sedimentary structures include bedding and stratification, cross-bedding, graded bedding, ripple marks, mud cracks, rain drop imprints, sole structure.
- Individual layer of a sedimentary rock is called bed. Each bed is separated from the adjacent bed by a plane called bedding plane.
- Cross bedding or cross stratification is formed due to change in the velocity and/or direction of flow of streams. It also referred as current bedding or false bedding.
- Ripple mark may be symmetrical or asymmetrical. The shape of ripples is described as two-dimensional if the crests are straight, or three-dimensional, if the crests are sinuous, catenary, lunate or linguoid.
- Secondary structures are the products of chemical action or biological activity.
- Chemical structures such as concretions, stylolites, dendrites and solution structure results due to chemical action.
- Organic structures like track and trails, burrow marks, stromatolites, reefs, casts and moulds etc. are formed due to biological activity of organisms.

10.6 ACTIVITY

1. Draw neat well labeled diagrams of any four primary structures.
2. Draw the schematic cross-section of a ripple as given in figure 10.6.

10.7 TERMINAL QUESTIONS

1. Describe the primary sedimentary structures.
2. Differentiate between current ripple and wave-formed ripple marks.
3. Explain briefly the structures found in secondary sedimentary rock.

4. What are concretions?

Audio/Video Material Based Questions:

- List types of bedding.
- List types of ripple marks.
- Differentiate between symmetrical and asymmetrical ripple marks.
- Distinguish between: (a) Normal and reverse grading; (b) Oolite and peloid.
- Name the types of stromatolites.

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10.10 ANSWERS

Self Assessment Questions

1 a) They are formed due to mechanical action of current therefore they are also known as mechanical structures. They are also known as inorganic structures. Bedding, cross stratification, ripple marks etc. are its example.

b) Ripples are like small dunes undulations formed due to current or wave action and are composed of sand or silt whose long dimension is at right angles to the current. They form low, narrow ridges mostly 1-2 cm, separated by wider troughs Ripple marks are of two types: i) asymmetrical and ii) symmetrical ripples.

c) Mud cracks are also known as shrinkage cracks or sun cracks and are typically developed in clayey sediments due to prolonged exposure to the atmosphere. The presence of mud cracks indicates that the sediment was exposed at the surface shortly after deposition, since drying of the sediments would not occur beneath a body of water.

2 a) Secondary structures are the products of chemical action or biological activity contemporaneous with sedimentation or shortly thereafter. They are divided broadly into: (i) chemical structures produced on chemical action, i.e. concretions, stylolites, dendrites and solution structure; (ii) organic structures formed due to biological activity of organisms, i.e. track and trails.

b) Burrow marks are also known as bioturbation marks. Burrows are excavations made by animals into soft sediment. Bedding in many sedimentary rocks is broken or disrupted by roughly cylindrical tubes a few cms in diameter that extend vertically through several beds. These sedimentary structures are remnants of burrows and tunnels excavated by worms.

c) Stromatolites are sedimentary structures and are composed of sand-silt and clay sized sediment particulates. They are produced by the sediment trapping, binding, and precipitating activity of phototropic microbes.

Terminal Questions

1. Please refer subsection 10.2.1 for primary sedimentary structures.
2. Please refer subsection10.2.1 for difference between current and wave-formed ripple marks.
3. Please refer to subsection 10.2.2 for secondary sedimentary structures.
4. Please refer to subsection 10.2.2 for concretions.

UNIT 11

CLASSIFICATION OF SEDIMENTARY ROCKS

Structure

11.1 INTRODUCTION

In previous units we have learnt that sedimentary rocks are formed by the consolidation of materials derived from mechanical weathering and erosion of pre-existing rock masses or chemical precipitation from solution or from organic matter consisting of secretions or remains of plants and animals. We have also learnt that sedimentary textures are concerned with the size, shape of grains, their sorting, three-dimensional arrangement of the grains and the porosity that make up sediments or sedimentary rock. Sedimentary structures are large-scale features which show variety of interesting and significant geometries that are produced by physical, chemical and biological processes.

Textures and structures of sedimentary rocks are controlled by the nature and intensity of the transportation undergone by the sediments. In this unit we shall learn how sedimentary rocks have been variously classified on the basis of their mineralogical composition, environment of deposition, mode of formation and textural and structural parameters. We would also discuss megascopic and petrographic details of important siliciclastic rocks such as conglomerate, breccia, sandstone, shale, siltstone and carbonate rocks such as limestone.

Expected Learning Outcomes

After reading this unit, you should be able to:

- ❖ discuss the mineral composition of sedimentary rocks;
- ❖ classify the sedimentary rocks based on mineralogical and chemical compositions;
- ❖ classify the sedimentary rocks based on texture, size and shape of grain and depositional basin; and
- ❖ describe some of the common sedimentary rocks.

11.2 CLASSIFICATION

We have read in Units 8 and 9 of this block about the processes of formation of sedimentary rocks and their textures. Let us now utilise these concepts to classify the sedimentary rocks. We have also read while discussing textures that the clastic/detrital rocks are divided on the basis of particle size, origin and depositional basin. Let us now discuss them.

11.2.1 Based on Mineralogical Composition

Sedimentary rock can include any mineral because of their detrital nature. Mineral composition depends on:

- source of the material;
- intensity of mechanical and chemical weathering; and
- distance travelled.

Minerals of sedimentary rocks fall into two categories:

- insoluble residues of rock decomposition;
- detrital minerals/particles derived from pre-existing rocks.

The insoluble residues include the following:

- clay minerals, e.g. kaolinite, produced by chemical weathering;
- micaceous minerals including mica (muscovite and biotite) and chlorite;
- aluminium hydroxides like bauxite and gibbsite;
- ferric oxide and hydroxide.

Detrital minerals such as quartz, K feldspar like orthoclase and microcline, plagioclase feldspar and certain accessory minerals like zircon, rutile, tourmaline, garnet, hematite, and magnetite are derived from pre-existing rocks.

Quartz is stable under conditions present at the surface of the Earth, and because it is also a residual product of chemical weathering. Quartz is most abundant mineral in sandstones. The second most abundant mineral in mudrocks (Table 11.1). Feldspar is most common mineral in igneous and metamorphic rocks. Although feldspar eventually breaks down to clay minerals and quartz, it is still the third most abundant mineral in these rocks.

Carbonate minerals, either precipitate directly or by organisms, make up most chemical and biochemical sedimentary rocks, but subordinately carbonates also occur in mudrocks and sandstones.

Table 11.1: Mineral composition of mudrocks and sandstones.

Mineral Composition	Mudrock %	Sandstone%
Clay minerals	60	5
Quartz	30	65
Feldspar	4	10-15
Carbonate minerals	3	<1
Organic matter, hematite and others	<3	<1

We can classify minerals found in sedimentary rocks, based on their origin into two classes:

- **Allogenic minerals**: These minerals are formed elsewhere and transported into the area of deposition;
- **Authigenic minerals**: These minerals are formed at the site of deposition, either by direct chemical precipitation or by later diagenetic processes.

Table 11.2: Minerals in order of increasing stability (igneous minerals are marked with asterisk *).

Stability under surface conditions	Mineral
Unstable	Olivine*
	Pyroxene*
	Plagioclase*
	Hornblende*
Less Unstable	Sphene
	Epidote
	Kyanite
	Sillimanite
	Magnetite
	Garnet
Very Stable	Muscovite*
	Clay minerals
	Quartz*
	Tourmaline
	Zircon*

Allogenic minerals are derived from pre-existing rocks formed under different conditions (may be igneous sedimentary and metamorphic). Conditions at the Earth's surface differ from the conditions under which they were formed and become unstable in the new environment and therefore they get detached or released. This is known as **Goldich stability series**, about which you have read in Unit 5 of BGYCT-131 course. The order of stability of minerals in Goldich stability series is inverse to the order of crystallisation of minerals in Bowen's reaction series. For example, quartz the last mineral in that series is most stable and olivine the first mineral to form is resistant for obvious reasons. These minerals can be classified (Table 11.2) in which they occur in the same order that occur in Bowen's reaction series.

Authigenic minerals are formed where they are found or occur. They form during sedimentation by precipitation or recrystallisation *in situ* and not derived from elsewhere (allogenic). Examples of authigenic mineral are quartz, glauconite, carbonate, orthoclase, clay, etc.

Sedimentary rocks comprise of light minerals that have specific gravity less than 2.85 and of heavy minerals that have specific gravity more than 2.85. It is observed that light minerals are very less in number as compared to category of heavy minerals. Heavy mineral assemblage may have many types of minerals but they constitute about one percent of the arenaceous sediments (Pettijohn, 1957). Thus, participation of heavy minerals in building up of the sedimentary rocks is negligible. Most commonly occurring minerals in the sedimentary rocks are quartz, feldspars, clay minerals, calcite and dolomite. Sedimentary rocks classified on the basis of frequently occurring minerals are summarised in Table 11.3.

Table 11.3: Classification of sedimentary rocks based on mineralogical composition.

Predominant Minerals	Other Minerals	Rock Name
Quartz	Sericite, feldspars, and minerals forming matrix	Sandstone
Quartz with feldspar	Sericite, feldspars, and minerals forming matrix	Feldspathic sandstone or arkose
Clay minerals with quartz, limonite, goethite	Minerals forming matrix	Shale, argillite, mudstone, clay beds
Calcite, dolomite	Some matrix minerals, aragonite, siderite	Limestone, dolomitic limestone

11.2.2 Based on Chemical Composition

Identification of minerals becomes difficult when the grain size becomes too fine. Therefore, chemical analysis becomes necessary. On the basis of chemical composition, these rocks are sub-divided into following:

i) **Siliceous deposits**: Silica is the chief constituent. Chemical composition of sandstone, limestone and shale are shown in Table 11.4. Some common examples are flint, chert, jasper etc. The study of chemical compositions shown in Table 11.4 helps to classify the sedimentary rocks into three major groups:

- Highly siliceous group
- Moderately siliceous group
- Highly calcareous group

Highly and moderately siliceous groups are based on SiO_2 % while highly calcareous group has very high CaO % and very low SiO_2%.

Table 11.4: Chemical composition (average values) of sandstone, limestone and shale (modified after Pettijohn, 1957).

Oxides (%)	Sandstone	Shale	Limestone
SiO_2	78.33	58.10	5.19
Al_2O_3	4.77	15.40	0.81
CaO	5.50	3.11	42.57
MgO	1.16	2.44	7.89
CO_2	5.03	2.63	41.54

ii) **Carbonate deposits**: These are precipitated from carbonate rich waters under different conditions. For example, many deposits of limestone, dolomite and magnesite are of chemical origin formed from sea water rich in calcium carbonate and magnesium carbonate.

iii) **Ferruginous deposits**: These are mostly iron carbonate deposits. The most common forms are banded iron formations and ironstones. Ironstone is formed when iron and oxygen combine in solution and deposit as a chemical sedimentary rock. Hematite is the most common sedimentary iron ore mineral (Fig. 11.1a).

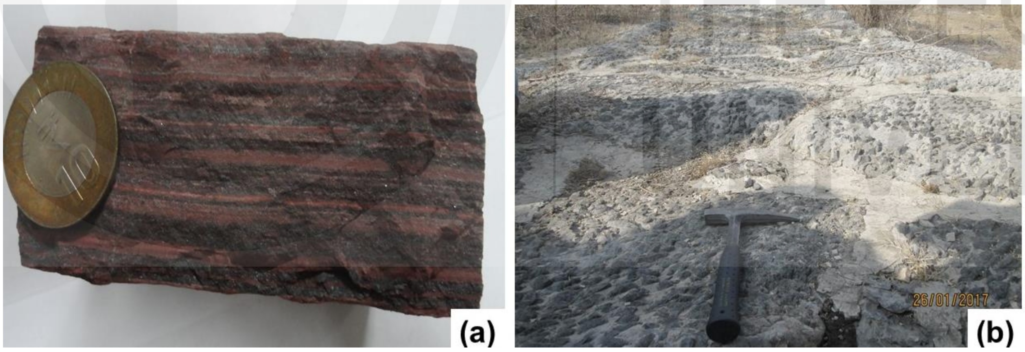


Fig. 11.1: a) Banded hematite-ironstone; and b) Phosphatic rock with nodules from Jhamarkotra. (Photo credit: Ganga Prasad Bhartiya)

iv) **Phosphatic deposits**: These are composed of phosphate minerals. Phosphorite, phosphate rock or rock phosphate is a non-detrital sedimentary rock that contains high amounts of phosphate minerals. Phosphate rock contains a group of calcium phosphate minerals (apatite) and is the primary source for phosphorus in phosphate fertilisers. Sedimentary phosphate deposits are formed by deposition of phosphate-rich materials in marine environments (Fig. 11.1b). Special term guano is used for excreta of certain sea birds or bats. It is phosphatic and nitrogenous in nature and is used as fertiliser, an organic material. It occurs on some coasts or islands often visited by seafowls.

11.2.3 Based on Texture

We have read in previous Unit 9 Textures of Sedimentary Rocks, that two major textures are used in the classification of sedimentary rocks:

- clastic
- non-clastic.

Sedimentary rocks showing **clastic texture** consists of discrete fragments and particles that may be, cemented and compacted together. They often result due to the accumulation of materials that originates and is transported as solid particles derived from pre-existing rocks both mechanically and/or chemically weathered. There are many processes by which the products of weathering are transported, deposited, and transformed into solid rock. The sedimentary rocks that they form are called **detrital** or **terrigenous** sedimentary rocks. For example, gravel, sand and clay, etc. Chemical sedimentary rocks for example, coquina (limestone composed of shells and shell fragments) exhibits clastic texture. The same applies for some varieties of oolitic limestones.

Some chemical sedimentary rocks have a **non-clastic** or **crystalline texture** in which the minerals form a pattern of interlocking crystals. These crystals may be microscopically small or large enough to be visible without magnification. Non-clastic textures are found mostly in rocks that have precipitated chemically from water called chemical sedimentary rocks, such as limestone, dolomite and chert. Other non-clastic sedimentary rocks include those formed by organisms called biochemical rocks, such as coquina and those formed from organic material, such as coal.

11.2.4 Based on Size and Shape of Grains

We have discussed in previous unit that the grain size of sedimentary rocks is a parameter used for classification of sedimentary rocks. On the basis of size and shape of grains clastic/ terrigenous rocks can be classified as given in Table 11.5.

Table 11.5: Classification of terrigenous/clastic rocks.

Class	Constituent Particles	Examples
Rudaceous	Boulder, cobble, pebble	Conglomerate, breccia
Arenaceous	Granule, sand	Grit, sandstone
Argillaceous	Silt, clay	Mudstone, shale

a) **Rudaceous**: They are characterised by presence of extremely large sized constituents in them. They contain a framework of coarse clastic material and voids, filled by finer clastics like sand, silt and clay. Rocks or minerals are cemented together in a matrix giving rise to a conglomerate, or a breccia. **Conglomerate** (Fig. 11.2a) contains abundant number of large clasts (> 2.0 mm). The rocks or minerals may be rounded to sub-rounded, or angular to sub-angular in shape. Depending upon their actual sizes, these are termed as a boulder, a cobble, or a pebble. **Breccia** (Fig. 11.2b) also consists of gravel size (> 2.0 mm) clasts. Breccia contain mostly angular fragments whereas rocks containing rounded or subrounded fragments are conglomerates.

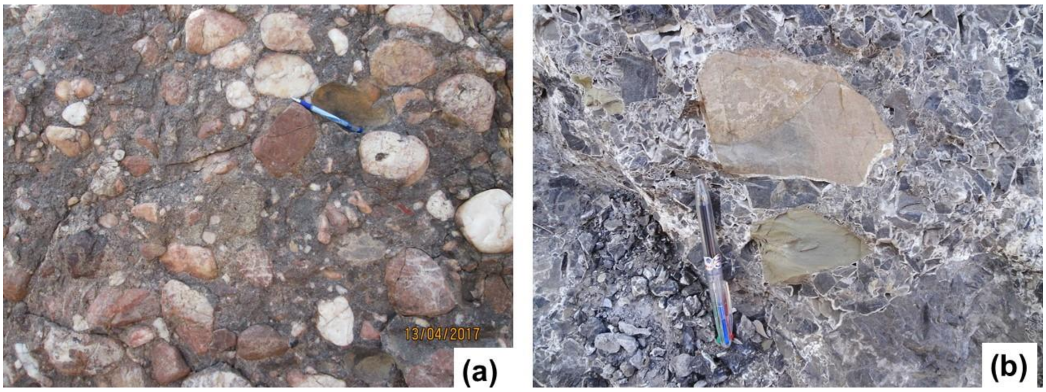


Fig. 11.2: Field photographs: a) Conglomerate with rounded and subrounded clasts of different composition; and b) Breccia with angular clasts. (Photo credit: Ganga Prasad Bhartiya)

b) **Arenaceous**: They are the most commonly developed group among all the sedimentary rocks. They consist of grains varying between sizes of 2 and 1/16 mm and are called **arenites**. These rocks are commonly known as the **sandstones**, as the grains varying between sizes of 2 and 1/16 mm are called sand (Fig. 11.3a). You have learnt about it in Unit 9 Textures of Sedimentary Rocks.

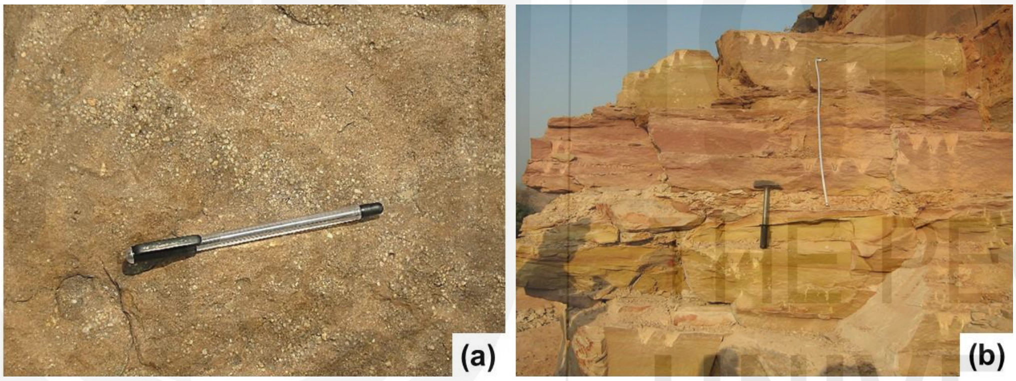


Fig. 11.3: Field photographs of sandstone: a) Notice the grain size variation in sandstone from medium to very coarse; and b) Thickly bedded reddish to buff coloured ferruginous sandstone. (Photo credit: Prof. Meenal Mishra)

A sandstone consists of a framework of detrital grains and voids. These voids may be partially or completely filled. Quartz grains are dominant in sandstone; however, feldspars are also present. Thus, the sandstone is classified on the nature and contents of the minerals occurring in them. The following parameters are considered in classification of the arenites:

- **Source index** is the ratio of feldspars to the rock fragments.
- **Maturity index** is the ratio of quartz to the feldspars and rock fragments.
- **Fluidity index** is ratio of sand to the matrix.

The classification of clastic or terrigenous sedimentary rocks proposed by Dott (1964) and Folk (1968) is given in Fig. 11.4. The demarcation between quartz arenite and quartz wacke is placed at 12.5% and the boundary between sandstone and mudstone has been put at 30%. Quartz and metaquartzite fragments have been grouped together and chert grains have been included in rock fragments.

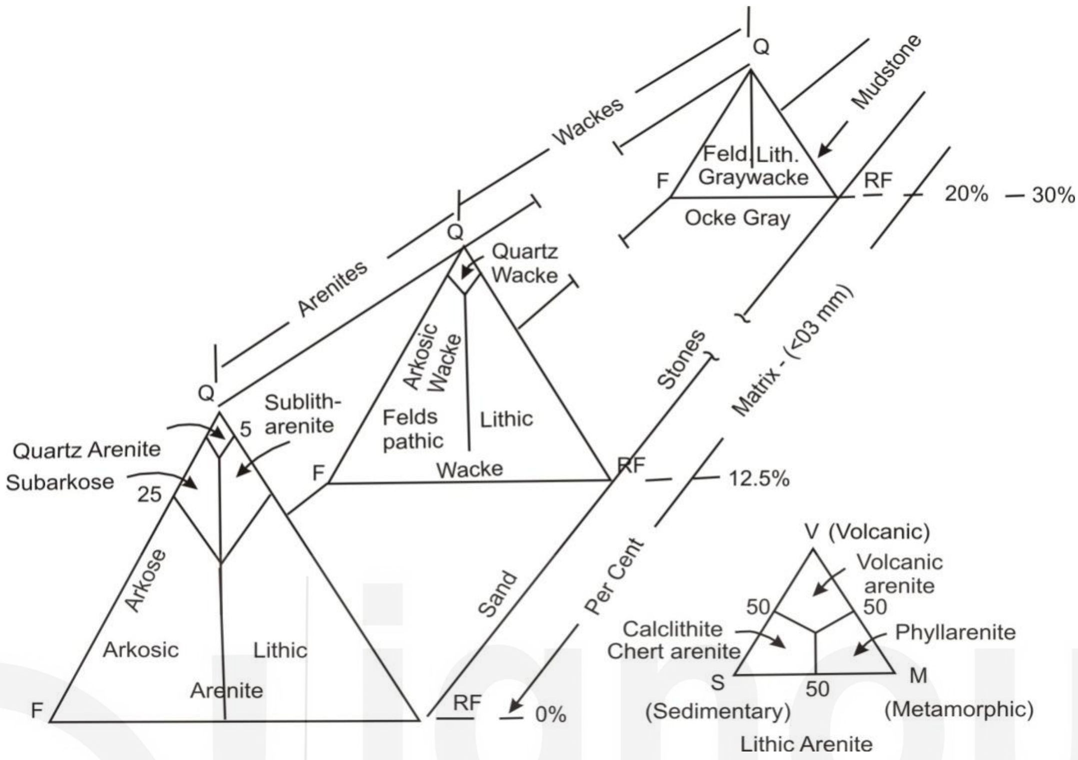


Fig. 11.4: Classification of sandstone (Dott, 1964) where: Q=quartz+ metaquartzite, F=feldspars, R.F=rock fragments. The small triangle shows subdivision of lithic arenites. (Source: Folk, 1968)

c) **Argillaceous**: They are rocks composed of grains sizes below or finer than 1/16mm. They are also called **mudrocks**. Those having grains between 1/16 and 1/256mm are termed **siltstones**. Silt size particles are mostly finely powdered clastic rocks (like rock flour), but the clay sized particles comprise both rock flour and clay minerals (hydrous aluminium silicates). The relation between several rocks of argillaceous group are shown in Fig. 11.5.

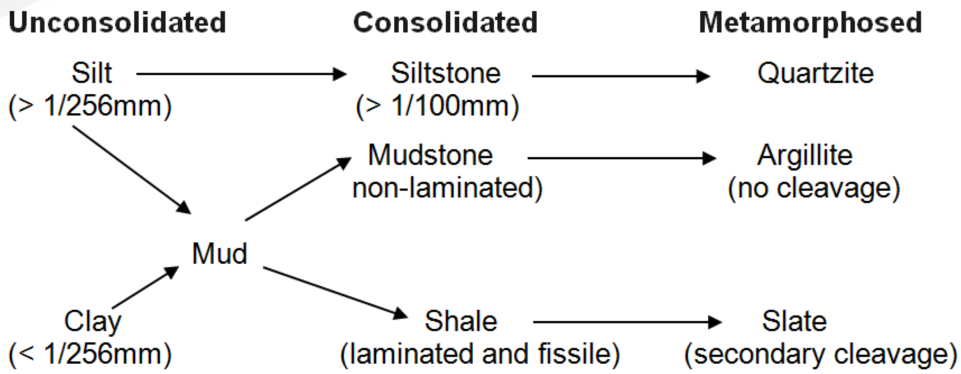


Fig. 11.5: Classification of argillaceous group. (Source: Pettijohn, 1984)

11.2.5 Based on Mode of Origin

Sedimentary rocks based on their mode and mechanism of accumulation and consolidation, have been classified into four broad groups:

a) **Residual sediments** are formed due to accumulation and consolidation of those materials which were left as residue during the operation of the processes of weathering and transportation. Common examples are laterite, bauxite.

b) **Mechanical sediments** include the fragments of minerals and rocks that produced by mechanical weathering such as sandstone, shale, siltstone, etc. You have learnt in Block 3 Earth Surface Processes of BGYCT-131 that rivers, oceans, winds and rain runoff all have ability to carry particles of eroded rocks Such material is called detritus, consists of fragments of rocks and minerals. When the energy of the transporting current is not strong enough to carry these particles, the particles drop out (Fig. 11.6a) and this type of sedimentary deposition is referred as **clastic sedimentation**.

c) **Chemical sedimentary rocks** are formed from soluble substances which are removed in solution and deposited to form chemical sedimentary rocks like limestone, chert, dolomite, ironstone, etc. Inorganic processes such as evaporation, precipitation and chemical activity can produce chemical sediments. This type of sedimentary deposition occurs when material dissolved in water chemically precipitates from water (Fig. 11.6b). This type of sedimentation is known as **chemical sedimentation**. One such example is dripstones (stalactites and stalagmites) that decorates many caves. Another is the salt left behind as a body of seawater evaporates and form rock salt. These are known as evaporites. You have read about dripstones and evaporites in Block 2 Earth Surface Processes of BGYCT-131 course.

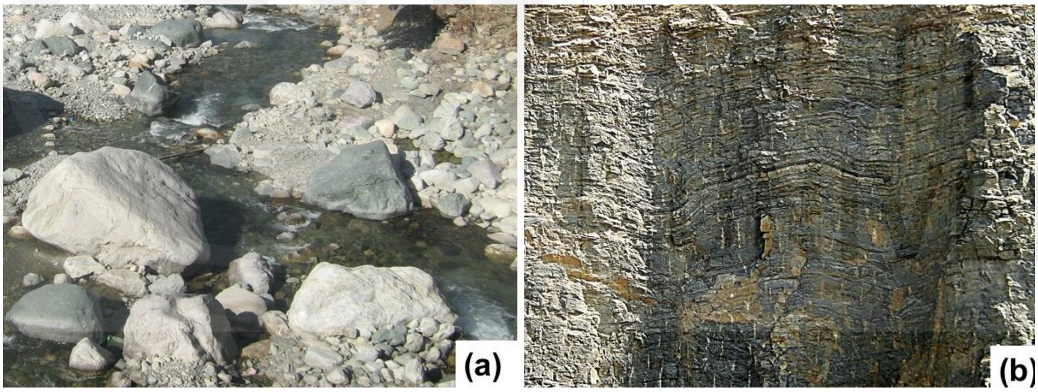


Fig. 11.6: a) Mechanically transported detrital sediments by running water; and b) Chemically precipitated limestone. (Photo credit: Prof. Meenal Mishra)

d) **Organic sedimentary rocks** are formed from the remains of plants that lived in moist environment rich in trees, shrubs, water and mud. The accumulation of dead plant debris takes place in swampy setting where they are quickly buried. Coal is a black combustible rock consisting of organic carbon that originated from the remains of plants accumulated on the floor of a swamp (Fig. 11.7a). The process of sedimentation wherein living organisms extract ions dissolved in water to make such things as shells and bones is called **biogenic sedimentation**. Organic (life) processes of water-dwelling organisms also form chemical sediments, said to be of **biochemical origin**.

Stromatolites are organo-sedimentary in origin (Fig. 11.7b). They are layered biochemical accretionary structures formed in shallow water. They are formed by trapping, binding and cementation of sedimentary grains by microbial mats of microorganisms, especially cyanobacteria.

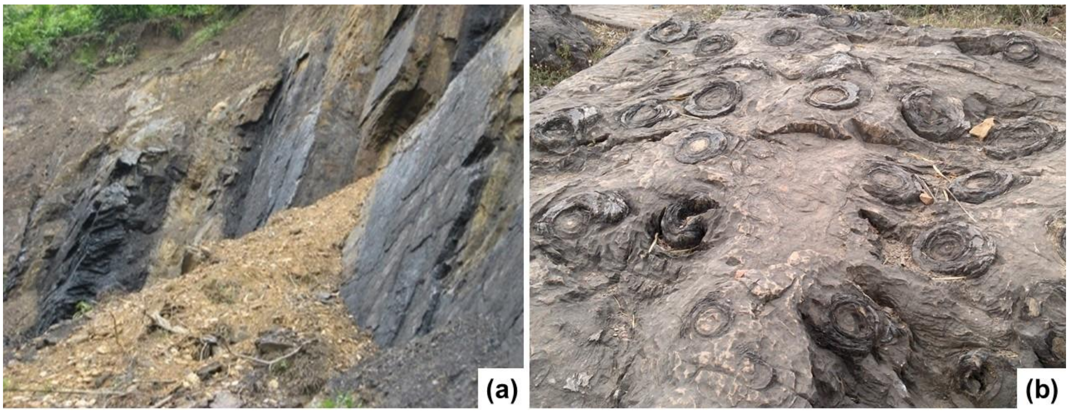


Fig. 11.7: a) Coal is organo sedimentary rock formed by biogenic precipitation; and b) Fawn limestone showing stromatolites (circular areas) at Salkhan fossil park in Sonbhadra District, Uttar Pradesh. [(Photo credit: Dr. Kakoli Gogoi for a) and Prof. Meenal Mishra for b)]

Watch the following video to know more about stomatolites.

- **Sedimentary Structure of non-clastic rocks**

Link: https://www.youtube.com/watch?v=3iL__lYkFRM

11.2.6 Based on Depositional Basin

Sedimentary rocks can be classified on the basis of placement of sediments *vis-à-vis* depositional basin where sediments accumulate. They may be:

a) **Extrabasinal or allochthonous sediments** are formed from the weathering of pre-existing rocks placed away from the basin and transported to the depositional basin. They are also called terrigenous or clastic rocks. This includes conglomerates, sandstones etc. Structures formed during deposition of enclosing sediments are given in Table 11.6.

Table 11.6: Extrabasinal rock types and structures.

Rock types	Geometry	Cohesive beds	Surface marks	Deformation
Rudite	Dunes, bars, ribbons	Graded, cross	Load casts	
Arenite	Dunes, bars, ribbons	Cross, ripple	Load casts, tool marks	Synsedimentary folds, faults
Lutite	-	Lamination	Flute casts, raindrop imprints	Synsedimentary folds, and faults

b) **Intrabasinal or autochthonous sediments** are those whose particles which are derived from within the basin and deposited. This includes carbonate, authigenic and carbonaceous rocks. Intrabasinal rocks contain more than 50% of carbonate minerals, such as calcite, dolomite magnesite, etc. Several schemes of classification have been proposed for limestones. Pettijohn (1973) proposed the following classification (Table 11.7).

Table 11.7: Classification of limestone. (Source: Pettijohn, 1973)

Autochthonous limestone	Allochthonous limestone
1. Associated with shales	Associated with orthoquartzites
2. Grades into calcareous shales	Grades into calcareous sandstones
3. Interstices filled with lime mud	Interstices filled with calcite cement
4. Bryozoan fossils	Rolled fossils
5. Unsorted as to size	Sorted as to size
6. Fossils articulated	Fossils disarticulated
7. Reef structures	Cross-bedded

Dunham (1962) proposed a classification of carbonate rocks according to depositional texture and is shown in Fig. 11.8. The textural properties are most significant for interpreting the depositional environment of the rocks.

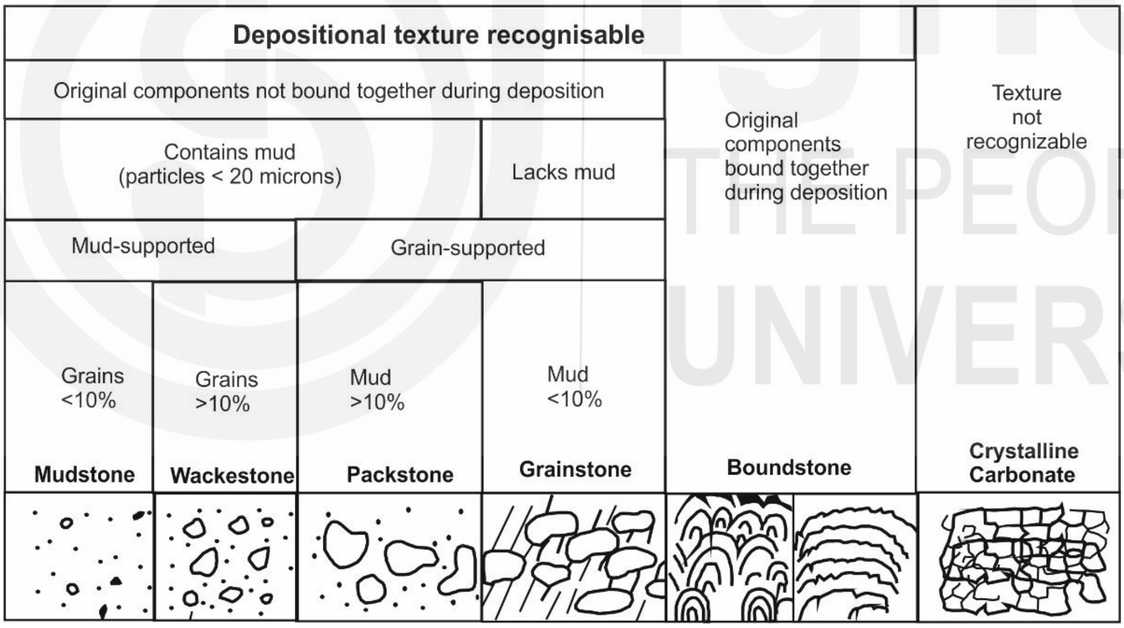


Fig. 11.8: Classification of carbonate rocks. (Source: Dunham, 1962)

Dunham's classification of carbonate rocks (Fig. 11.8) are defined on the basis of the following three criteria. They are:

1) supporting fabric of the original sediment,

2) presence or absence of mud (the fraction <20 μm in size), and

3) evidence that the sediments were organically-bound at the time of deposition.

On the basis of these three criteria, carbonate rocks are classified in the following six classes. They are:

i) **Mudstone**: It is a mud-supported carbonate rock containing <10% grains.

ii) **Wackestone**: It is a mud-supported carbonate lithology with >10% grains.

iii) **Packstone**: It is a grain-supported fabric with 1% or more fraction of mud.

iv) **Grainstone**: It is a grain-supported carbonate rock with <1% mud.

v) **Boundstone**: Where there is indication that the carbonate sediments were bound by organisms at the time of deposition.

vi) **Crystalline carbonate (limestone/dolomite)**: Where recrystalisation has resulted in the original depositional fabric of the carbonate rock. The depositional texture cannot be recognised.

In the previous sections we have discussed about the classification of sedimentary rocks based on mineralogical composition, chemical composition, texture, size and shape of grain and depositional basin. Before reading about common sedimentary rocks spend five minutes to check your progress.

SAQ 1

a) Distinguish between extrabasinal and intrabasinal sediments.

b) List the classification of sedimentary rocks based on their origin.

c) What are rudaceous rocks?

d) What is biogenic sedimentation?

11.3 COMMON SEDIMENTARY ROCKS

We have read about the basic concepts of sediment and sedimentary rocks, their texture, structure, mineral composition and classification. Now, let us study some of the common sedimentary rocks.

11.3.1 Clastic Rocks

Conglomerate, sandstone, breccia and shale are the most common clastic sedimentary rocks. Let us will discuss them.

1. **Conglomerate**: Conglomerate contains abundant amount of large clasts (> 2.0 mm) like pebble, cobble and boulders. The clasts are rounded indicating that they have undergone a long distance of transportation by running water or tumbled for some distance by waves (Fig. 11.2a). Their formation begins in high energy environment when abundant pebble and cobble-size clast deposited along a swiftly flowing stream or a coastal area with strong waves. Chemical cement and matrix during lithification bind the clasts into a rock. Matrix binding the large-sized particles may consist of sand and cement, which may be silica, clay, or even calcium carbonate. Particles are commonly large enough to reflect to their source; thus, they can be valuable in identifying the provenance or source areas of sediments. For example, conglomerates at the base of Bababudan and Chitradurga Groups of Karnataka are major known occurrences.

Types of conglomerate:

- **Oligomict conglomerate** consist essentially of one type of pebble, usually quartz and/or chert pebbles.
- **Polymict or Petromict conglomerate** consist essentially of a mixture of pebble types (Fig. 11.2a).
- **Tillite** consist of a mixture of rock pebbles of glaciated origin.
- **Autochthonous or intraformational conglomerate** are formed by the break-up, *in situ*, of a previously deposited layer of rock.

2. **Breccia**: Breccia is like a conglomerate, also consists of gravel size (> 2.0 mm) clasts except the fact that the majority of the fragments are angular with sharp edges in shape (Fig. 11.2b). The angular shape reveals that they have not been transported very far from the source area. Breccia forms where gravel size broken, angular clasts of rock or mineral debris accumulate. One of the most common locations for brecciated sediments is at the base of hill slope (alluvial fan) where mechanical weathering debris is found. Another is location of debris flow deposits which is the short distance stream deposits.

3. **Sandstone**: Sandstone of arenaceous group is the name given to rocks in which mechanically formed medium to coarse sand-sized detrital grains predominate (Fig. 11.3a, b and Fig. 11.9a, b). They form in a variety of environments and often contain significant clues regarding sorting, particle shape, and composition about their origin. Sand-sized particles range between 2 mm and 1/16 mm. Sandstones may have a variety of colours from grey, buff yellowish- brown, rusty brown to various shades of red (Fig. 11.3b). Bedding is usually obvious and sedimentary structures are common within the beds (Fig. 11.9a) and upon the bedding surfaces. You have learnt about sedimentary structures found in clastic rocks in previous Unit 10 Sedimentary Structures. They are formed in a different kind of depositional environments like beaches, deserts, floodplain, deltas, open ocean basin, continental shelf and slope.

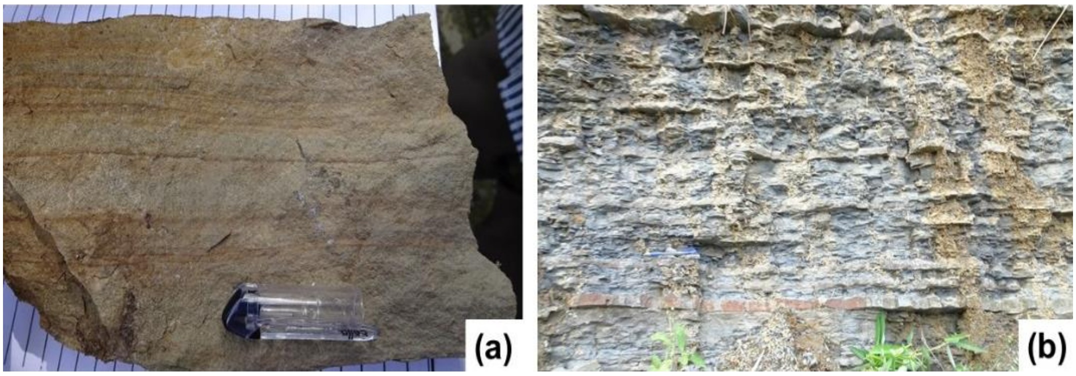


Fig. 11.9: a) Planar laminations seen in sandstone; and b) Interbedded sandstones (thick, compact and projecting layers) and siltstone (thin layers). (Photo credit: Ganga Prasad Bhartiya)

4. **Siltstone** is composed largely of silt-size particles and contains less clay-size material than shale and mudstone. The grain size of siltstone ranges

ranging from 1/256 to 1/16mm, i.e. between clay and sandstone (Fig. 11.9b).

Predominant mineral is quartz in the framework grains. The sediment particles are clasts, or pieces, of minerals and fragments of rock, thus sandstone is a clastic sedimentary rock. Sandstone has two different kinds of material in it besides the sediment particles: matrix and cement. **Matrix** is the relatively fine-grained (silt and clay size) sedimentary particles in between coarse-grained particles (Fig. 11.10b). Whereas **cement** is the binding material present between the grains. It can be siliceous (Fig. 11.10a) or carbonate precipitated from moving solutions in the formations. Thus, cement is authigenic (formed during sedimentation by precipitation or recrystallisation) and is introduced later on. Sandstone with a lot of matrix is called poorly sorted. Sandstones are classified on the basis of the composition of their grains. Four components that are considered for classification of sandstone are quartz grains, feldspar grains, rock/lithic fragments and matrix. Graywackes are poorly sorted and have subangular to subrounded gravels in which stable and unstable heavy minerals may be present. According to classification by Dott (1964) sandstones with < 12.5% matrix are arenite and above 12.5% are wackes (Fig. 11.4) called a **greywacke** or **wacke** ("wacky"). When the content of feldspar is more than that of rock fragments it is termed as **feldspathic graywacke** and when the content of rock fragments is more than that of feldspars, it is termed as **lithic graywacke**. **Arenite** or **quartz arenite** is a well-sorted sandstone with little matrix. They contain at least 95% quartz grains and are compositionally mature sandstones. Quartz grains are rounded to well rounded, well sorted and thus giving rise to high textural maturity (Fig. 11.10a). Feldspars, rock fragments and matrix percentage is very less. Highly feldspathic sandstone composed of 75 percent of feldspar and quartz grains is called **arkose** (Fig. 11.10b). Compositionally, therefore, arkose may be similar to granite and because of this some arkose are also called as **granite-wash**. Sandstones containing more rock fragments than feldspars, abundant quartz, some mica and fewer matrix are referred as litharenites. They are similar to greywackes but matrix percentage is low, hence litharenites (Fig. 11.10c) are also called subgreywackes. Chief rock fragments include shale, slate and phyllite. If the clasts are composed dominantly of volcanic clasts, it is known as **volcaniclastic sandstone** (Fig. 11.10d). Sandstones are used extensively as building and decorative stones. **Itacolumite** is a variety of sandstone that shows bending or flexibility in thin slab. It is also known as **flexible sandstone** and is seen as pockets in Delhi quartzites near Charkhi Dadri in Haryana.

5. **Shale**: Shale also known as mudrock is fine grained argillaceous sedimentary rock. It consists of silt-and clay-size particles (Fig. 11.11a and b). These fine-grained detrital rocks account for over half of all sedimentary rocks. The particles in these rocks are so small that they cannot be readily identified without appreciable magnification. Therefore, shale is more difficult to study and analyse than most other sedimentary rocks. The deposition of shale indicates environment of quiet and non-turbulent currents, when the movement of water as current wave is significantly reduced. As the medium

is virtually fatigued or tired and cannot carry the sediment load forward anymore. Thus, leading to load dropping as deposit. Such environments include lakes, river, floodplains, lagoons, and portions of the deep-ocean basins. Even in these quiet environments, there is usually enough turbulence to keep clay-size particles suspended for very long time to almost indefinitely. Consequently, much of the clay is deposited only after the individual particles combine to form larger aggregates. Sometimes the chemical composition of the rock provides additional information. Black/carbonaceous shale contains abundant organic matter (Fig. 11.11b and 11.16a). When such a rock is found, it strongly implies that deposition occurred in an oxygen-poor (reducing) environment such as a swamp, where organic materials do not readily oxidise and decay. Shale exhibits the ability to split into thin layers along well-developed, closely spaced planes. This property is termed as **fissility**. Mudstone is related to shale but it lacks fissility. Certain shales are quarried to obtain raw material for pottery, brick, tile, and china clay. Moreover, when mixed with limestone (referred as marl), shale is used to make portland cement. In future, oil shale (oil trapped in tiny pore spaces) a type of shale, may become a valuable, energy resource.

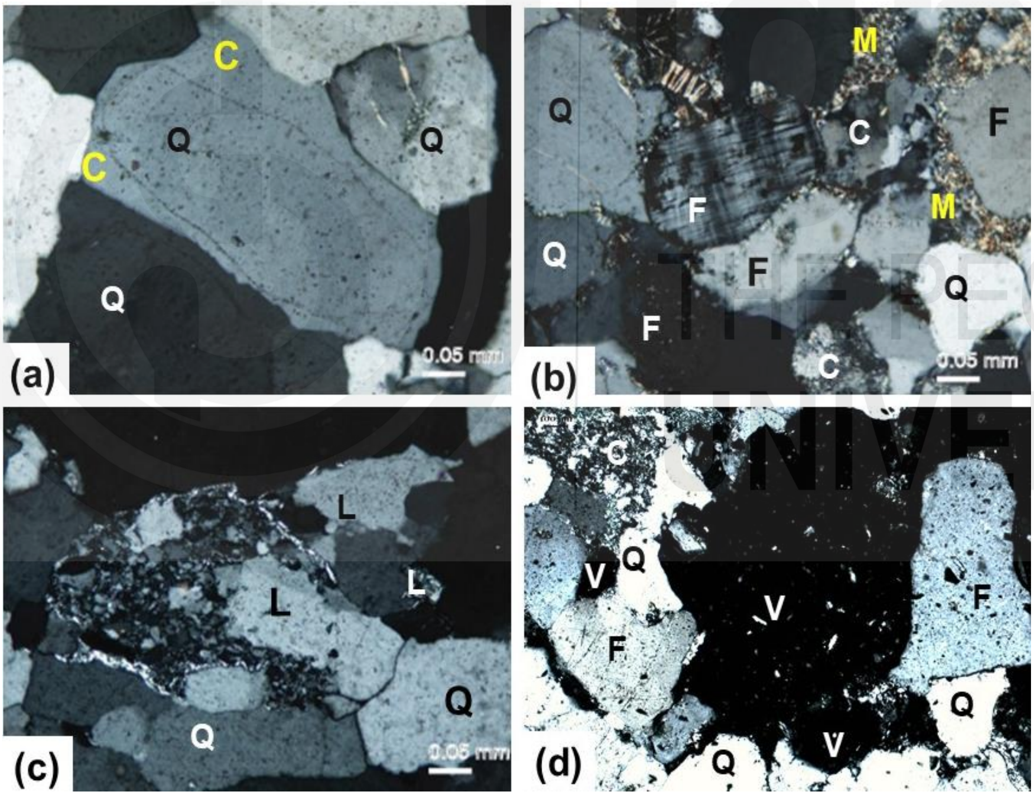


Fig. 11.10: Representative photomicrographs illustrating major classes of sandstones: a) Quartz arenite (>90% quartz); b) Feldspathic arenite (F-feldspar; Q-quartz); c) Lithic arenite (V-volcanic rock fragments, Q=quartz, Ch=chert); and d) Volcaniclastic sandstone (V-volcanic rock fragments, P-plagioclase, M-matrix, C-cement). (Photo credit: Prof. Meenal Mishra)

Fig. 11.11: Field photograph of shale: a) Notice the layering and fissile nature; and b) Horizontal beds of black carbonaceous shale. (Photo credit: Prof. Meenal Mishra)

11.3.2 Non-clastic Rocks

Limestone and dolomite are the most common non-clastic sedimentary rocks. Others examples include ironstone, phosphates, chert and evaporites.

Let us discuss them in brief.

i) **Limestone**

Limestone is a sedimentary rock that contains 50% or more carbonate minerals, of which at least 50% is a calcium carbonate. Limestone is the most abundant chemical sedimentary rock. It can be identified by performing acid test. When dilute HCl is poured on limestone/dolomite it effervesces. It has variable shades of colours, but the common colour is grey (Fig. 11.12a). It is composed chiefly of the mineral calcite ($CaCO_3$). The term **dolomite** or **dolostone** is used for rocks in which grains of dolomite dominate over calcite (Fig. 11.12b). Limestone can form either by inorganic chemical means or as result of biochemical processes like stromatolitic limestone (Fig. 11.7b).

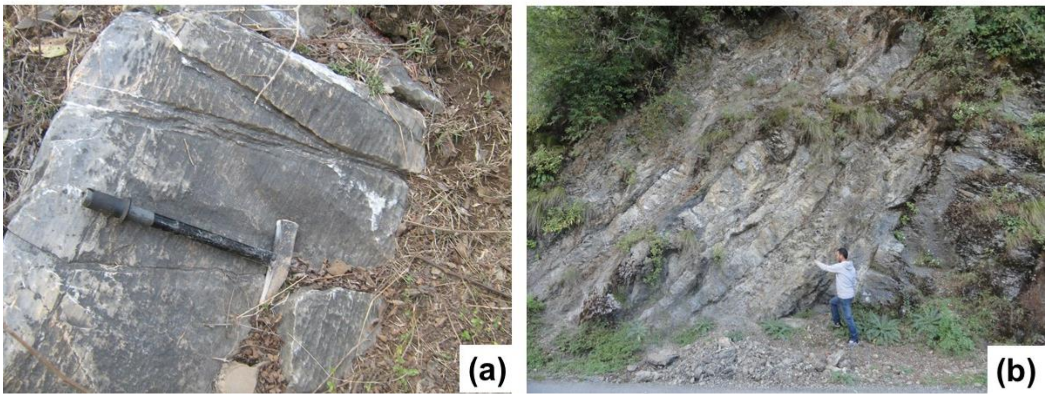


Fig. 11.12: a) Limestone showing elephant skin weathering; and b) Thickly bedded dolomite. [Photo credit: Prof. Meenal Mishra for (a) and Harshita Joshi for (b)]

Regardless of its origin, the mineral composition of all limestone is similar, yet many different types exist. Some of the more common varieties are:

- **Chalk** is soft limestone with a very fine texture that is usually white or light grey in colour. Chalk is also fossiliferous, but the organisms that comprise it are far too small to be identified with a hand lens. Chalks are composed of carbonate microfossils like foraminifera or nannofossils like coccoliths.
- **Coquina** is poorly-cemented limestone that is composed mainly of broken shell debris (Fig. 11.13a). Its name is derived from a type of bivalve (the coquina shell), that is common on beaches in southern Florida. It is used for any limestone that is primarily composed of shell remains (mostly bivalves). Coquinas are usually readily identifiable by their colour (yellow to white), and their very porous nature.
- **Fossiliferous limestone** contains abundant fossils like shell and skeletons of the organisms (Fig. 11.15). Most important textural feature of limestones is their fossiliferous nature.
- **Lithographic limestone** is dense limestone with a very fine and uniform grain size that occurs in thin beds which separate easily to form a very smooth surface.
- **Oolitic limestones** (or **oolites**) are an example of a non-fossiliferous limestone (Fig. 11.14a and b). These white to grey limestones are composed of exceptionally well sorted, spherical calcium carbonate grains of concentric nature called **ooids** that are between 1 and 2 mm in size.
- **Travertine** is limestone that forms by evaporative precipitation in a cave, such as stalactites, stalagmites. Travertine forms at hot springs.
- **Tufa** is limestone formed by precipitation of calcium-laden waters at a hot spring, lake shore, or other location (Fig. 11.13b).

In thin section the grain size of limestone can be whether coarse grained known as sparry calcite or fine grained termed as micrite. The allochems can be detrital grains, pelloids, ooids, intraclasts and bioclasts. The rock may be of clast- supported or matrix-supported and may contain sparry calcite cement or micritic matrix. You will study the thin sections of limestone in Experiment 8 of BGYCL-136 course.

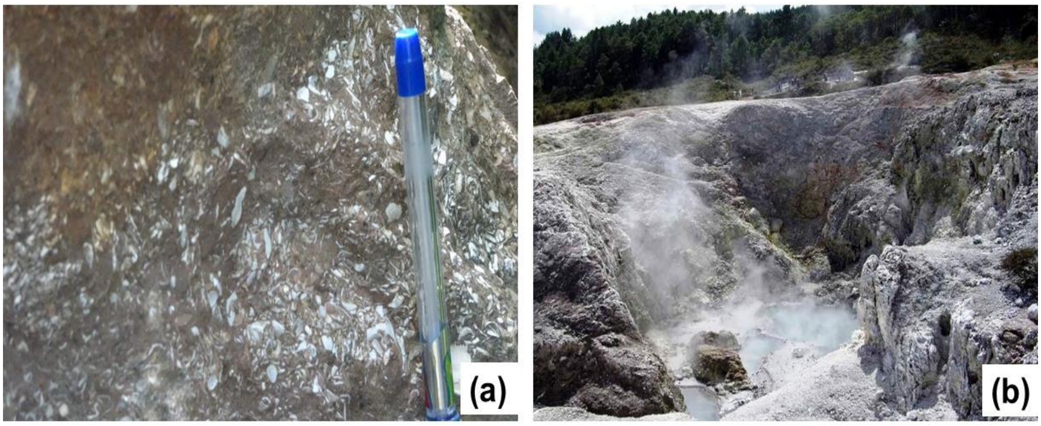


Fig. 11.13: a) Coquina or shelly limestone comprising broken shell debris; **and b) Tufa forming terraces around geyser in action.** [Photo credit: Ganga Prasad Bhartiya for (a) and Dr. S. D. Shukla for (b)]

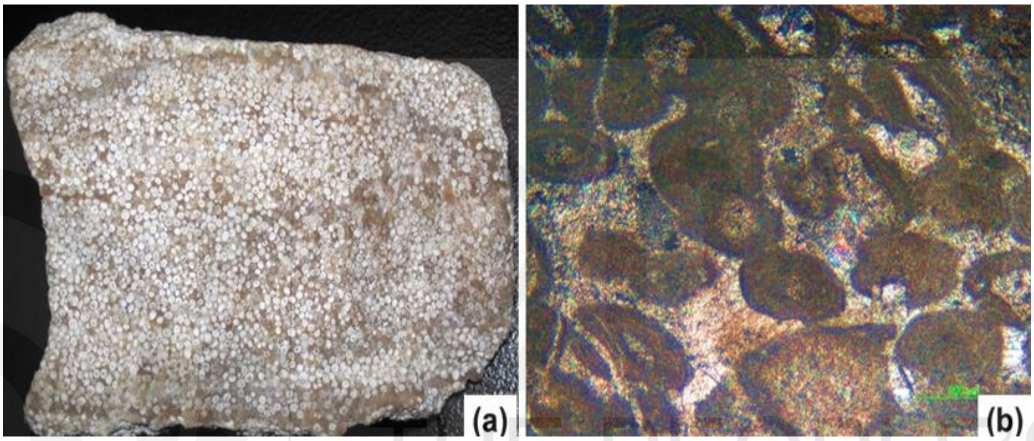


Fig. 11.14: a) Hand specimen of oolitic limestone (Source: https://upload.wikimedia.org/wikipedia/commons); **and b) Oolitic limestone made up largely of sand-sized, rounded pellets of calcium carbonate in thin section of oolitic limestone.** (Photo credit: Prof. Meenal Mishra)

Many varieties of limestone are produced under a diverse depositonal condition. Those forms having a marine biochemical origin are by far the most common. Corals are one important example of organisms that are capable of yielding large quantities of marine limestone. These relatively simple invertebrate animals secrete a calcareous (calcium carbonate) external skeleton. The best-known reef is Australia's Great Barrier Reef. Limestones having inorganic origin form when chemical changes or high-water temperatures increase the concentration of calcium carbonate to a point that it precipitates. Limestones and dolomites find important applications in many industries.

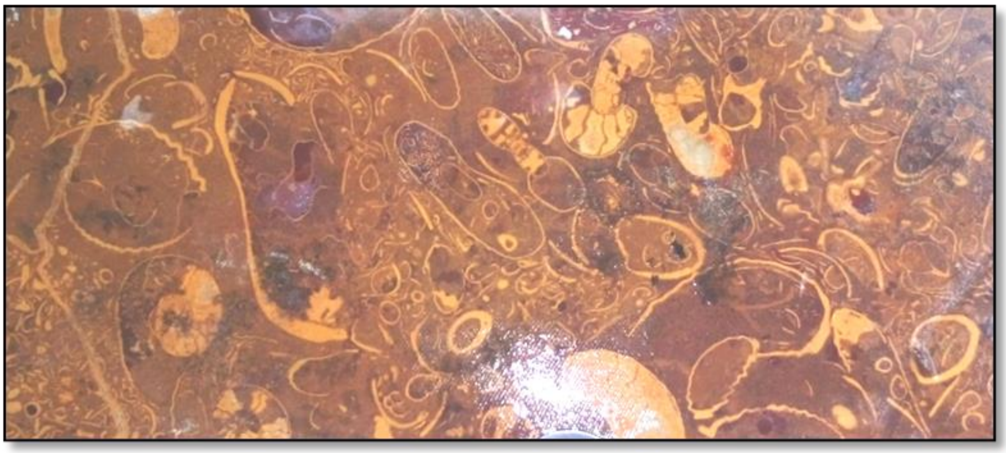


Fig. 11.15: Hand specimen of fossiliferous limestone from Jaisalmer district.
(Photo credit: Prof. Meenal Mishra)

ii) **Dolomite:** Dolomite is very similar to limestone and composed predominantly of the mineral dolomite. It is formed when limestone or lime mud is modified by magnesium-rich solution in supratidal environment. Calcite is recrystallized to a new mineral dolomite. The process of forming dolomite from lime mud (calcite) is known as **dolomitisation**. The term '**dolostone**' is used for a carbonate rock having almost equal amount of calcite and dolomite in its composition (Fig. 11.12b).

iii) **Chert:** The hard parts of all the marine organisms are not made out of calcite. Some of the marine organisms like radiolaria and diatoms are made of silica. When they die their tiny shells (or tests) settle slowly to the bottom where they accumulate as chert. Chert is a cryptocrystalline sedimentary rock composed of silicon dioxide. It forms by the precipitation of silica and occurs commonly as nodules, concretionary masses (Fig. 11.16a) and layered deposit. Chert is sometimes a primary deposit, sometimes formed by the confluence of disseminated silica in a rock, and sometimes as a secondary replacement material. Chert forms through either biochemical or chemical sedimentation. Most biochemical chert is formed in much the same way as chalk; through the accumulation of microfossils in a marine environment.

iv) **Evaporites**: In arid regions, lakes and inland seas typically have no stream outlet and the water that flows into them is removed only by evaporation. Under these conditions, the water becomes increasingly concentrated with dissolved salts, and eventually some of these salts reach saturation levels and start to crystallise (Fig. 11.16). Although all evaporite deposits are unique because of differences in the chemistry of the water. Sea water contains enormous amount of dissolved chemical substances, reason why it tastes salty. If sea water is evaporated, the concentration of the ions dissolved in it will increase. In most cases minor amounts of carbonates start to precipitate when the solution is reduced to about 50% of its original volume. Gypsum ($CaSO_4 \cdot H_2O$) precipitates at about 20% of the original volume and halite (NaCl) precipitates at 10%. Other important evaporite minerals include sylvite (KCl) and borax ($Na_2B_4O_7 \cdot 10H_2O$). Common examples are rock gypsum ($CaSO_4.2H_2O$) and rock salt (NaCl). **Rock Salt** (also known as 'halite') forms from the evaporation of ocean or saline lake water in areas of arid climate (Fig. 11.16b).

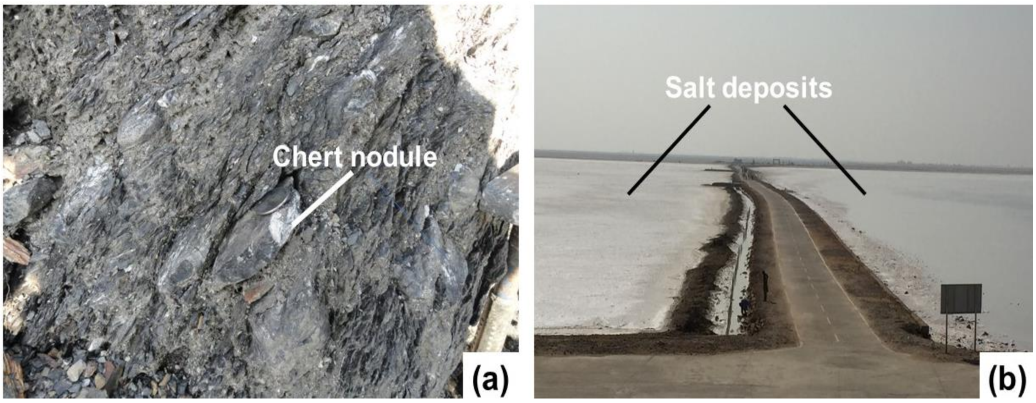


Fig. 11.16: a) Chert nodules interbedded with black carbonaceous shale; **and b) Salt deposits, Rann of Kutch.** [Photo credit: Harshita Joshi for (a) and Prof. Meenal Mishra for (b)]

In the previous sections we have discussed about the different types of clastic rocks like sandstone, siltstone and shale and non-clastic rocks like limestone and dolomite. Before proceeding to next section, you are advised to spend five minutes to check your progress.

SAQ 2

a) What are conglomerate and breccia?

b) Define matrix and cement.

c) List common varieties of limestone.

11.4 SUMMARY

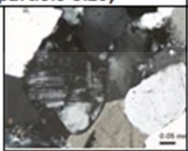
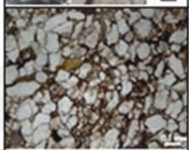
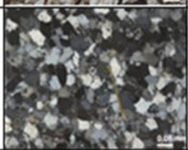
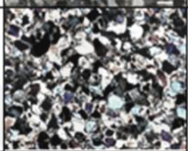
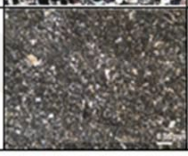
In this unit we have read about the classification of sedimentary rocks. Let us summarise about what we have learnt in this unit:

- Particle size of clastic sediment ranges from boulders to pebbles to particles of sand, silt, and clay in clastic sedimentation.
- Minerals found in sedimentary rocks can be classified based on their origin into allogenic minerals and authigenic minerals.
- Sedimentary rocks can be also classified based on mineralogical composition, chemical composition, texture, size and shapes of grain, mode of origin, depositional basin.
- On the basis of origin of sedimentary rocks, they are classified as allogenic and authigenic minerals.
- On the basis of chemical composition, they are sub-divided into: siliceous, carbonate, ferruginous, phosphatic deposits.
- On the basis of textures, sedimentary rocks are classified into- clastic and non-clastic.

- Terrigenous rocks are classified on the basis of size and shape of grains into rudaceous, arenaceous and argillaceous.
- The sedimentary rocks based on their mode and mechanism of accumulation and consolidation, have been classified into four broad groups: Residual sediments, Mechanical sediments, Chemical sedimentary rocks and Organic sedimentary rocks.
- Sedimentary rocks can be classified on the basis of depositional basin as extrabasinal or allochthonous and intrabasinal or autochthonous.

Let us summarise the common sedimentary rocks in the Table 11.8 given below:

Table 11.8: Clastic and non-clastic sedimentary rocks.

Detrital Sedimentary Rocks			
Classic Texture (particle size)		Sedimentary Name	Rock Name
Coarse (> 2mm)		Gravel (Rounded particles)	Conglomerate
		Gravel (Angular particles)	Breccia
Medium (1/16 to 2mm)		Sand (If abundant feldspar is present the rock is called **Arkose**)	Sandstone
Fine (1/16 to 1/256 mm)		Mud	Siltstone
Very fine (<1/256 mm)		Mud	Shale or Mudstone

Chemical and Organic Sedimentary Rocks			
Composition	Texture	Rock Name	
Calcite, $CaCo_3$	Nonclastic: Fine to coarse crystalline	Crystalline Limestone	
		Travertine	
	Clastic: Visible shells and shell fragments loosely cemented	Coquina	Biochemical Limestone
	Clastic: Various size sheels and shell fragments cemented with calcite cement	Fossiliferous Limestone	
	Clastic: Microscopic shells and clay	Chalk	
Quartz, SiO_2	Nonclastic: Fine to coarse crystalline	**Chert** (light coloured) **Flint** (dark coloured)	
Gypsum, $CaSO_4 2H_2O$	Nonclastic: Fine to coarse crystalline	Rock Gypsum	
Halite, NaCl	Nonclastic: Fine to coarse crystalline	Rock Salt	
Altered plant fragments	Nonclastic: Fine-grained organic matter	Bituminous Coal	

11.5 ACTIVITY

- Redraw the triangular plot proposed by Dott (1964) for classification of sandstone.

11.6 TERMINAL QUESTIONS

1. How sedimentary rocks are classified on the basis of mineralogical composition?
2. Elaborate the classification of sedimentary rocks based on size and shape of grains.
3. Discuss the classification of sedimentary rocks based on mode of origin.
4. Differentiate between the following pairs; (i) conglomerate and breccia; and (ii) sandstone and shale.

Audio/Video Material Based Questions:

- How are chert nodules formed?
- What are palaeotuff?
- What are evaporites?

11.7 REFERENCES

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- https://upload.wikimedia.org/wikipedia/commons

  (Website accessed on 25th March 2020)

11.8 FURTHER/SUGGESTED READINGS

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- Tyrell, G. W. (1973) The principles of Petrology. John Wiley & Sons, 349p.
- You can see the following link for itacolumnitehttps://www.youtube.com/watch?v=YGWlEcm3L1Q

11.9 ANSWERS

Self Assessment Questions

1 a) Extrabasinal or allochthonous: sediments are formed by the weathering of pre-existing rocks outside the basin. Intrabasinal or autochthonous: are those whose particles were derived from within the basin of deposition.

b) Classified into two classes allogenic and authigenic minerals.

c) Rudaceous rocks consist of very coarse-grained sediments like gravel, pebbles, cobbles and boulders which when cemented form breccia and conglomerate.

d) The process of sedimentation wherein living organisms extract ions dissolved in water to make such things as shells and bones is called biogenic sedimentation.

2 a) Conglomerate consists largely of gravels, i.e. unconsolidated accumulation of large sized particles (>256mm - 4mm).

Breccia is like a conglomerate, except the fact that the majority of the fragments are angular with sharp edges. Probably angularities of the grains is due to a short distance of transport of the sediments.

b) Matrix is the relatively fine-grained (silt and clay size) sedimentary particles in between coarse-grained particles. Whereas cement is the binding material can be siliceous or carbonate precipitated from moving solutions in the formations.

c) Chalk, coquina, fossiliferous limestone, lithographic limestone, oolitic limestone, travertine and tufa.

Terminal Questions

1. Please refer to Table 11.1 of subsection 11.2.1.
2. Please refer to subsection 11.2.4.
3. Please refer to section 11.2.5.
4. Please refer to section 11.3.1.

GLOSSARY

Abyssal plain	:	The area of the deep-ocean floor, usually lying at the foot of the continental rise.
Authigenic	:	Formed during or soon after sedimentation by precipitation or recrystallisation.
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.
Biogenic sedimentary rock	:	Sedimentary rocks derived from living organisms such as fossiliferous limestones and coal.
Braided stream	:	A stream consisting of numerous intertwining channels.
Cement	:	It is a chemically precipitated binding material.
Cement	:	It is a natural material binding the fragments/particles of clastic rock.
Chemical weathering	:	The processes by which the internal structure of a mineral is altered by the removal and/or addition of elements.
Chert	:	A very fine-grained non-clastic rock composed of silica deposited with or without microfossils.
Clastic or detrital	:	Fragments or clasts of pre-existing minerals and rock.
Coccoliths	:	Microscopic calcite platelets formed by microscopic algae. Main component of chalk.
Conglomerate	:	A sedimentary rock with rounded, larger (≥2 mm) clasts.
Coquina	:	Limestone made of shell fragments cemented together.
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.
Dispersant	:	A liquid or gas used to disperse small particles in a medium.

Dissolved load	:	The portion of a stream's load carried in solution.
Elutriation	:	It is a process for measuring grain size of fine particles.
Evaporite	:	A chemical sedimentary rock that forms as water evaporates.
Facies	:	A specific set of features that used to analyse particular rock group. Facies can be based on mineralogy, biologic factors, fossils, rock types, etc.
Glauconite	:	This mineral is green in colour and closely associated to Mica Group. It is necessarily composed of iron and potassium hydrous silicate. This mineral is found in sedimentary rocks and is marine in origin. Glauconite word is prefixed with the rocks which are dominantly composed of glauconite mineral.
Goldich Dissolution Series	:	Working opposite of Bowen's reaction series. It states that minerals that are formed at conditions more dissimilar to the surface are more quickly prone to chemical weathering.
Graded bed	:	A sediment layer characterised by a decrease in sediment size from bottom to top.
Grading	:	A sequence of layers in a sedimentary rock which the sediment changes linearly in size, either getting coarser or finer.
Grain size	:	The average diameter of a grain of sediment, ranging from small, also known as fine-grained (e.g. clay, silt) to large, also known as coarse-grained (e.g. boulder).
Heavy minerals	:	Minerals with relatively more density than bromoform (2.9).
Imbrication	:	It refers to a primary depositional fabric consisting of a preferred orientation of clasts.
In situ	:	In its own place. This term is used for those rocks, soils and fossils that are remain in their own place where they are formed or precipitated.
Induration	:	It refers to the compactness of the rock.
Kaolinite	:	Clay mineral composed of hydrated aluminum silicate found in pseudohexgonal plates. Pure variety is pure whereas impure variety is brown or yellowish in colour.

Kurtosis : The sharpness of the peak of a frequency distribution curve.

Lithification : The consolidation of loosely deposited sediment into a hard rock.

Matrix : It is fine-grained silt or clay size particles in between coarse grains.

Mean : The arithmetic average of all particle sizes in a sample.

Median : It is the size of midpoint of the grain size distribution.

Micrite : Microcrystalline calcite present in some types of limestone.

Mode : It represents the highest point (peak) of the frequency curve.

Mud crack : A feature in some sedimentary rocks that forms when wet mud dries out, shrinks, and cracks.

Non-clastic : Sedimentary rocks formed from chemical or biochemical precipitation.

Oil shale : Oil which is found in low-permeability, high-porosity rocks such as shale.

Paleocurrent : Sedimentary structure showing the direction of flowing water in the geologic past.

Paleocurrent : Direction of flow preserved in the rock record.

Parting lineation : Subtle ridges formed in the upper flow regime on top of plane beds in the direction of flow.

Permeability : The measurement of a rock's ability to transmit fluids.

Porosity : It is the amount of voids or empty space between the grains of sediments.

Quartzite : Metamorphic rock formed due to metamorphism of limestone.

Roundness : It is a measure of the smoothness of particles.

Sandstone	:	Clastic sedimentary rock composed of primarily of quartz.
Skewness	:	It is a measure of the symmetry of grain parameter distribution.
Sorting	:	It describes the distribution of grain size of sediments.
Sphericity	:	It is a measure of how closely the grain shape approaches that of a sphere.
Suspended load	:	The fine sediment carried within the body of flowing water or air.
Stylolite	:	They are serrated surfaces within a rock mass at which mineral material has been removed by pressure dissolution, in a process that decreases the total volume of rock.
Terrigenous	:	Sediments derived from the erosion of rocks on land.
Texture (sedimentary)	:	It refers to the size, morphology, and arrangement of grains in a rock.
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 streamflow is of this type.
Weathering	:	The disintegration and decomposition of rock at or near the surface of the Earth.