UNIT 8

FORMATION OF SEDIMENTARY ROCKS

Structure

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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.

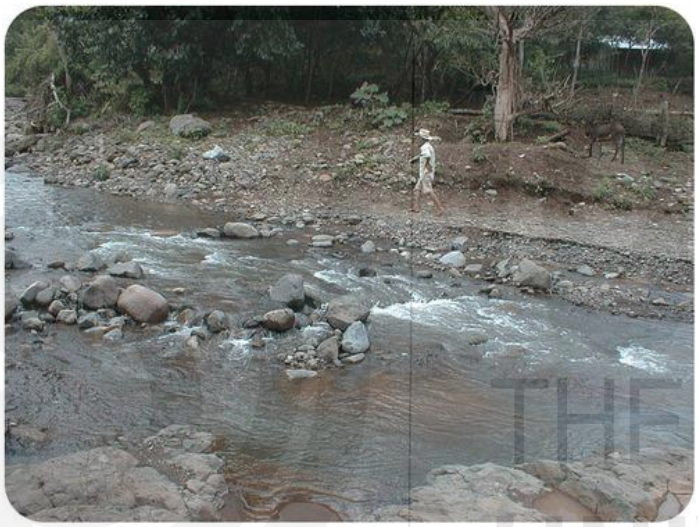

Fig. 8.1: Sediments produced by weathering and their transportation by stream.

- **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.

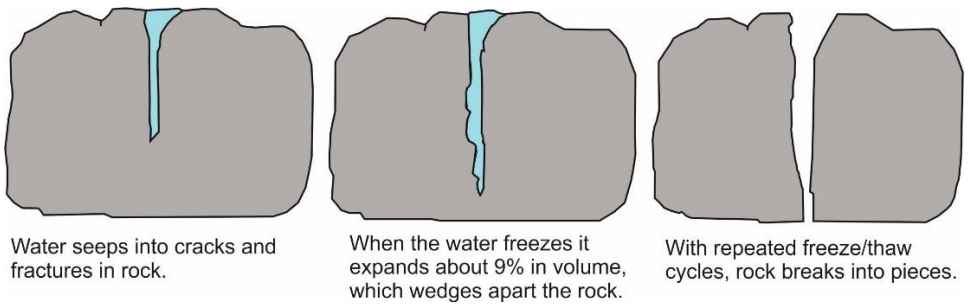

Fig. 8.2: Frost action in a rock.

- **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.

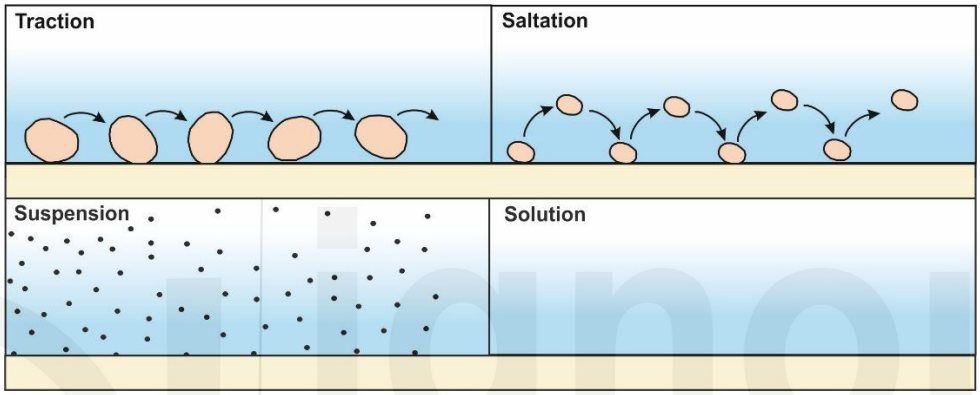

Fig. 8.4: Mode of Sediment Transport.

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.

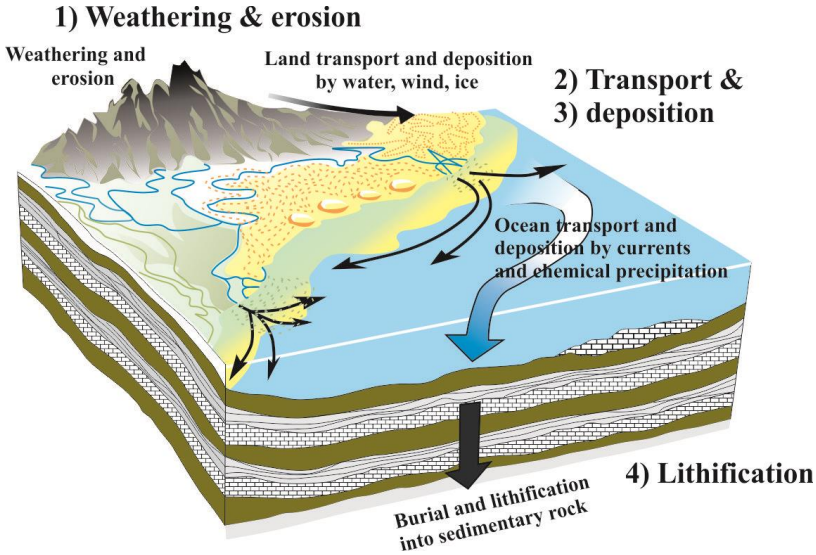

Fig. 8.5: Block Diagram Showing Sedimentary Processes.

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.

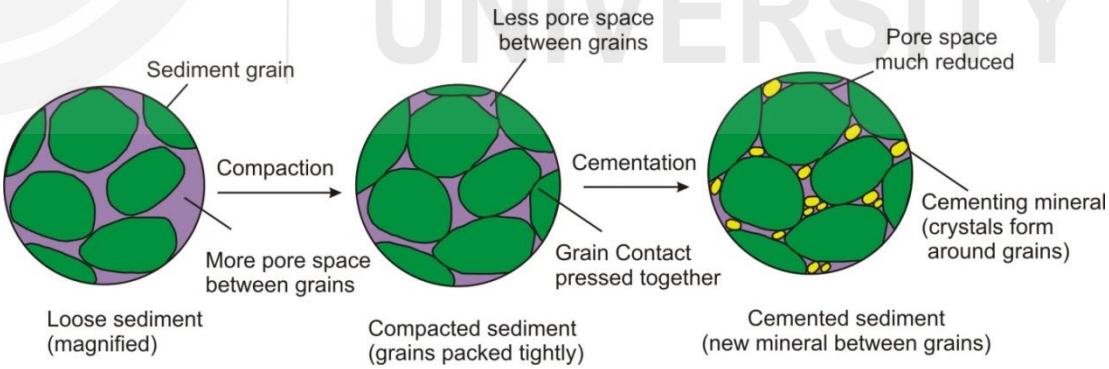

Fig. 8.6: Compaction and Cementation of Sediments.

- **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

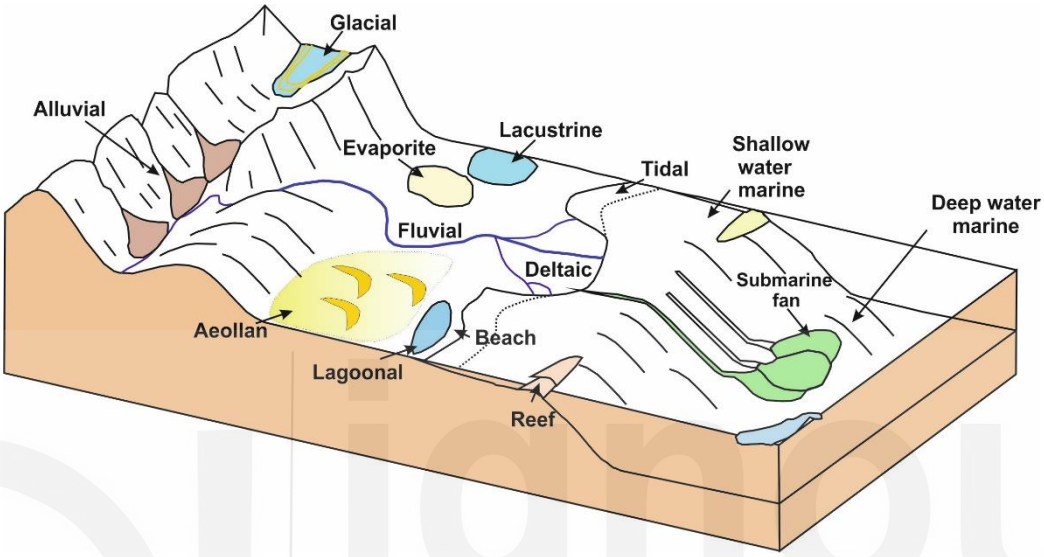

Fig. 8.7: Schematic diagram showing different types of depositional basins.

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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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

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