LECTURE 6

6.0 NATURE AND CLASSIFICATION OF SEDIMENTARY ROCKS

6.1 INTRODUCTION

Welcome to Lecture 6. In the last lecture we looked at the nature and classification of igneous rocks. We established that igneous rocks do vary in both texture and composition, and that the two properties can be used to classify them. As you are aware, rocks are so common that people don't even notice them and, like many other objects, take them for granted. What most people don't realize is that rocks and minerals are the building blocks of our planet. Rocks have sometimes been referred to as the "documents" containing evidence of all the processes that affected the Earth in the past. Sedimentary rocks, which will form the topic for lecture 6, are a category of rocks that give information about the conditions that prevailed when the sediments were being deposited. These rocks, which result from the consolidation, compaction or cementation of sediments, provide the most complete record of the history of the Earth – and they make up about 75% of all the earth's exposed rocks.

OBJECTIVES

At the end of this lecture, you should be able to:

(a). Describe the mode of formation of the sedimentary rocks
(b). Give an account of sediment erosion and transport
(c). Discuss the concept of rounding in sedimentary rocks
(d). Outline the classification of sedimentary rocks.
(e). Illustrate the common structures and textures in sedimentary rocks.
(f). Give examples of common sedimentary rocks and their composition

6.2 SEDIMENTARY ROCKS DEFINED

What are sedimentary rocks?

Sedimentary rocks are formed on the earth's surface under normal surface temperature and pressures. They result from the accumulation of the products of weathering of other rocks and organic materials. Weathering is a general term used for the physical and chemical breakdown of rocks at the earth's surface by rain, wind, abrasion etc. Products of weathering are either transported or may accumulate where they are formed. The processes of transforming loose fragmented rocks into a compact solid cohesive mass is called **lithification**. This process is also known as **consolidation**, and the resultant rock is said to be **consolidated**. Sandstone is a consolidated rock, while sand is an example of an unconsolidated rock.

6.3 METHODS OF SEDIMENT EROSION AND TRANSPORT

There are five main agents of sediment erosion and transport. These are:

- Rivers – (or fluviatile effects)
- Sea – (marine effects)
- Glaciers – (glacial effects)
- Wind – (Aeolian effects)
- Landslides

6.3.1 RIVERS

A river usually flows across rocks that may be soft and friable due to weathering process. Fragments of the loose rocks usually break away and are carried by the river. The material may be transported through rolling along the river-bed (i.e, referred to as the bedload for larger masses or through actual suspension within flowing water especially for the smaller particles (referred to as the suspended load). The faster the river flows the larger the materials or particles it can carry.

The transport of rock fragments in the river has two main effects:

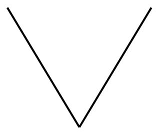
(i) The moving fragments usually smash into and wrap against the solid bedrock of the riverbed and its sides. In consequence, it breaks off (erodes more material) which is carried away by the river.

(ii) The moving fragments are themselves broken up and abraded by these collisions and thus they become smaller and less angular in shape. They can also hit other moving fragments to cause mutual abrasion. As a result of this there is always the tendency for the river to cut and erode downwards into its bed while fragments that it transported in the process become smaller and more rounded in outline.

EFFECTS ACROSS A RIVER PROFILE

1. Near the Source

Usually steep slopes in the mountain give energy to the flowing water such that there is great erosion and down cutting. The river usually flows in deep V-shaped ravines (Fig. 6.1). High energy enables large fragments to be carried away and many of these are not transported far. Majority of these fragments are still angular in shape.

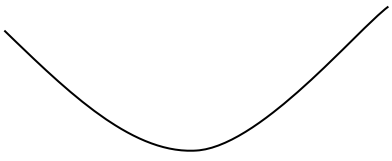


V-shape profile at the river source area

Figure 6.1 Profile of a river at its source area.

2. Midway between the source and the Sea

Here the slopes are not so steep and therefore there is less tendency for down-cutting and there is more lateral erosion on the banks. Here you observe shallow profiles (Fig. 6.2). Many of the fragments have been transported over long distances and thus are more rounded. The river flows more slowly on shallower slopes and it can only move smaller fragments.



Shallow river profiles at mid way between the river source and sea

Figure 6.2. Profile of a river at its mid way section.

3**. Near the Sea**

The river energy is low and hence there is little down cutting and you find more flat profiles (Fig. 6.3). In this area only very small and rounded particles are carried.

Figure 6.3 Flat river profile near the sea.

6.3.2 EROSION BY THE SEA

This type of erosion often occurs around coasts where waves pick up rock fragments and smash them against cliffs or other structures. In such an environment, there is much rounding and reduction of the grain size. The eroded material usually forms the beaches or alternatively is carried back to the deeper sea.

6.3.3 GLACIAL EROSION

In such an environment rock fragments are usually incorporated into the ice of the glacier and as they move, these fragments usually rub against the rocks below and to the sides of the glacier, in the process wearing them away. Unlike the rivers, rock fragments carried within the ice do not become rounded. When the ice melts, these abraded and transported materials are carried away by the melt water. Glacial deposits are poorly sorted, because melting ice deposits material of all sizes together.

6.3.4 WIND EROSION

Wind erosion acts like rivers in that they pick up very small particles and roll the slightly larger ones along the ground. This process produces what is called **sand blasting** of bed rocks which further detache smaller fragments. The particle sizes involved here are small and rounding is very high. Wind-blown sediments are usually well sorted because after the storm the wind speed gradually reduces leading to the deposition of sediments in decreasing order of size.

6.3.5 LANDSLIDES

Landslides occur when eroded debris are moving downhill en mass under the influence of gravity. During this process they break off more material and reduce the general grain size a little during movement. There is very little rounding of grains since the process is not sufficiently prolonged.

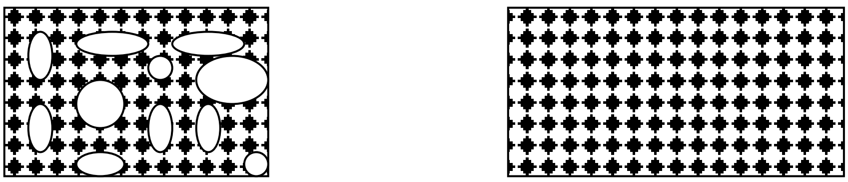
6.4 SEDIMENT GRAINSIZE, SORTING AND ROUNDING

Distinguish between well-sorted and poorly-sorted sediment.

From the preceding section on sediment erosion and transport, we can derive the following parameters:

(a) **Grain size of sediment** – this is the diameter in mm of the particles i.e. the grains that make up the rock. This can vary from less than 1 mm to 100 mm or more.

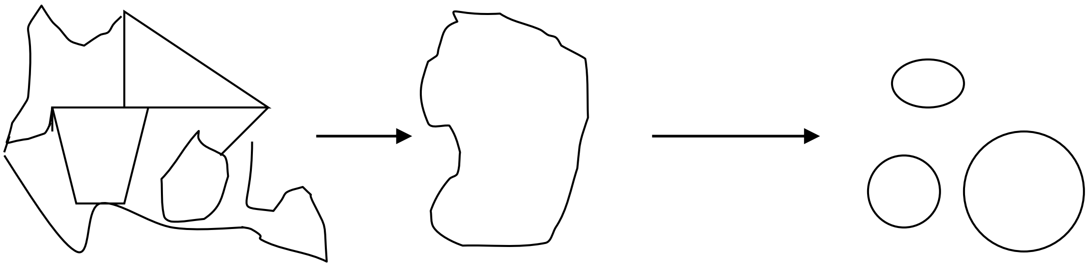
(b) **Sorting of the rock** – in sedimentary rocks all the grains of the rock may not be of the same size. The more or nearly they are of the same size, the better is the sorting. Figure 6.4 (a) shows a poorly sorted sediment with grains of varying sizes. Figure 6.4 (b) represents a well sorted sediment with grains of nearly same size.



(a). Poorly sorted sediment (b). Well sorted sediment

Fig.6. 4 Degree of sorting in a sediment.

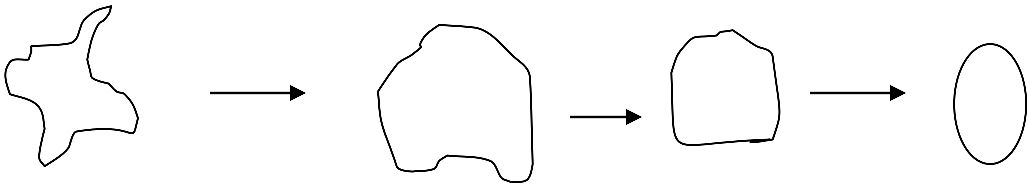
(c). **Rounding:** - as the rock fragments are being transported, they collide with other fragments and become less angular i.e. more rounded. Fig. 6.5 shows the progressive processes of rounding of fragments.



Original fragment Looses corners i.e. more rounded Smaller & more rounded

Figure 6.5 Rounding of fragments in sedimentary rocks.

The individual grains may also be described in terms of their roundness as shown in Fig. 6.6.



Angular Sub-angular Sub-rounded Rounded

Figure 6.6 Rounding of mineral grains in sedimentary rocks.

Roundness as a process depends on three factors:

1. The distance the grain/fragment has been transported i.e. the more the transport the rounder the grains become. This assumes that the original grains were angular.
2. Hardness of the material. Softer materials are more easily eroded or abraded
3. The physical composition of the material e.g. a rock fragment that will easily split into its constituent minerals or along its cleavages would soon be disintegrated by collisions during transport. Similarly a mineral grain with good cleavages will soon disintegrate. However, in the case of quartz which is a dominant constituent of many sedimentary rocks, the degree of rounding is

proportional to the length of the transport because quartz is hard and has no cleavages.

6.5 DIAGENESIS AND LITHIFICATION

By definition, **diagenesis** processes are those changes of various kinds occurring in sediments between the time of deposition and the time at which complete lithification (consolidation) takes place. The changes may be due to bacterial action, digestive processes of organisms, to solution and re-deposition by permeating water, or to chemical replacement. On the other hand, **lithification** is the process of converting loose unconsolidated sediment into a cohesive rock.

6.5.1 DIAGENESIS

Sediments are derived by weathering and erosion of the surface rocks of the crust. Sediments are usually transported to a place where they accumulate or deposited to become a sedimentary rock. The following are the processes invoved:

1. The sediments may not undergo transport but may be deposited at its point of weathering. This is a **sedentary rock.**
2. If this undergoes transport, it becomes a transported sediment
3. When it accumulates it is usually a loose mass e.g. sand and pebbles. These are the ones referred to as unconsolidated rocks.
4. After accumulation the diagenesis and lithification process convert the unconsolidated sediment into an indurated or consolidated sedimentary rock which is hard, compact and coherent.
5. **Diagenesis** process describes all the processes that occur between deposition/ accumulation and lithification. Diagenesis occur in relatively low temperature and pressure environments near the surface of the earth. Examples of these diagenetic processes are:
   (a) Reactions between percolating groundwater and connate water trapped between the rocks during deposition and the rock minerals themselves.
   (b) Organic activity which usually produces weak acids that dissolve carbonates and possibly re-depositing them elsewhere

(c) Bacteria reduce sulphates to sulfides and in the process releasing H_2S0_4 which also reacts with the carbonates.

(d) Animals like worms may burrow through the sediments and in the process destroy its original form e.g. worms ingest the soil forming new soil texture. In the process the sediments may undergo repeated changes after burial by deposition or further sediment.

6.5.2 LITHIFICATION

This is the final induration of the sediments where chemical and physical reactions convert it from an unconsolidated rock into a consolidated rock. This involves three main processes:-

A. **Compaction -** as more sediment is being deposited, there is an increase of weight or pressure that usually expels much of the connate water and forces the rock grains to come much closer together. As the grains are forced against each other, their outer surfaces usually dissolve and re-crystallize thus welding the grains together.
B. **Re-crystallization –** this includes pressure solution as described in (a) above, Percolating water can also dissolve material from one area and re-deposit it elsewhere or alternatively water can introduce substance into the sediments which then crystallize
C. **Cementation –** Deposition of substances from aqueous solutions usually occurrs in the voids or other spaces between the grains. When these solutions crystallize they bind the sediments and in the process they converted the loose aggregate into a solid coherent rock

6.6 CLASSIFICATION OF SEDIMENTARY ROCKS

How are sedimentary rocks classified?

Sedimentary rocks are divided into three classes which include:

1. Clastic rocks – consists of grains that of mechanical products of weathering
2. Chemical sediments – formed dominantly by chemical processes and more so from direct precipitation of compounds from solutions
3. Organic sediments – formed from organic debris such as mollusks, shells, plant debris etc.

6.6.1 CLASTIC ROCKS

Clastic sedimentary rocks are formed from the products of the mechanical breakup of other rocks. The clastic rocks are most often named and classified on the basis of the average grain size of the particles that form the rock (Table 6.1).

Table 6.1 Classification of clastic sedimentary rocks.

COARSE **>2 mm**	**MEDIUM** **2-0.05 mm**	**FINE** **0.05-0.005 mm**
Conglomerate Breccia Calcirudite (***Rudites***)	Quartzite Sandstone Greywacke Arkose Calcarenite (***Arenites***)	Shale Mudstone Siltstone (***Lutites***)

6.6.1.1 RUDITES

Conglomerate – is a relatively coarse-grained rock**,** with fragments above 2 mm in diameter, and sometimes larger. Most of the grains are rounded

Breccia - Similar size as conglomerates but most of the clasts fragments are angular

Calcirudite -It is dominantly calcareous ($CaCO_3$) with grains over 2 mm in diameter

6.6.1.2 ARENITES

Quartzite – it consists almost entirely of quartz grains.

Sandstone – usually consists of sand-sized sediment particles of quartz grains but also with other minor components such as carbonate cement

Greywacke – It is a poorly sorted sandstone usually dark in colour, containing rock fragments as well as quartz

Arkose – a sandstone with at least 25% of the mineral composition being feldspar and the rest is mainly quartz

Calcarenite – This is a rock with sand sized grains but dominantly of carbonate composition

6.6.1.3 LUTITES

These are fine grained sedimentary rocks (0.05-0.005) and includes the following:

Siltstone – silt sized particles which are slightly coarser than clay

Mudstone – it has clay-sized particles which usually are too small to be seen by the naked eye and which consists mainly of quartz and clay minerals

Shale – is made up of finer-grained sediments whose grains cannot be seen with the naked eye. Its grains are similar to mudstone but it is usually fissile rock i.e. it splits easily into thin sheets.

The **rudites, arenites and lutites** are used as overall sedimentary size grades e.g. if a rock particle size is between 2 mm and 0.05 mm it is then referred to as an arenite or arenite grade sedimentary rocks. In general, regardless of grain size, clastic sedimentary rocks tend to have, relatively, considerable pore space between grains.

6.6.2 CHEMICAL SEDIMENTS

Chemical sediments are basically formed by chemical processes usually from direct precipitation of solutions. There are two main divisions of chemical sediments:

- Precipitates, and
- Evaporites

6.6.2. 1 PRECIPITATES

(a). Crystalline limestone:

Crystalline limestone is precipitated according to the following reaction:

$$\underset{\text{Solution}}{Ca(HCO)_2} \rightarrow \underset{\text{solid}}{CaCO_3} + \underset{\text{water}}{H_2O} + \underset{\text{gas}}{CO_2}$$

The loss of CO_2 from the solution may be caused by the rise in temperature. An example of the occurrence of the above chemical process is the carbonate deposition along the Bahama island banks in the Pacific ocean. The carbonate deposition is caused by agitation as a result of water hitting the cliffs.

Other types of carbonate deposition occurs on the lips of waterfalls due to the lowering of pressure; as well as in caves due to evaporation to form structures such as stalactites and stalagmites as shown in Fig. 6.7.

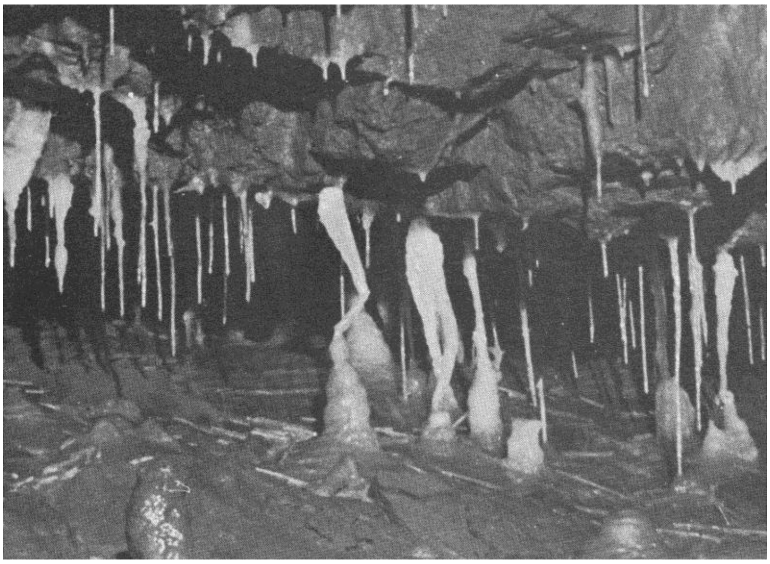


Figure 6.7 Miniature stalactites and stalagmites in a cave

Examples of precipitated limestone rocks are:

1. **Calcite mudstone** – fine grained rock almost glassy in texture
2. **Oolites** – consists of small spheres of carbonate
3. **Organic limestone** – carbonate precipitated by organisms such as molluscs and also the skeleton of marine organisms such as shelly reefs or crenoids.

Fossils are mostly found in sedimentary rocks – can you explain why?

(b). Siliceous Deposits

Siliceous deposits consists dominantly of silica (SiO_2). Silica in solution is usually incorporated into the skeletons of marine organisms such as radiolaria and sponges. Siliceous deposits can also be deposited from high temperature volcanic springs or sometimes precipitated directly from sea water like chert and flint (crypto-crystalline silica) i.e. the crystals are only visible by ray methods**.** **Chert** in particular is a dense, microcrystalline hard rock, that fractures with splinterly conchoidal fracture. **Flint** is similar to chert only that it has dark colour and a smoother fracture surface. The colored form of chert is named **Jasper**. Chert and flint are often found in nodules in limestone beds with the original layers or banding passing right through them.

Silica frequently replaces other minerals, cell by cell, grain by grain, through the action of ground water. A mineral which has been **silicified** will often retain the appearance of the original, combined with the hardness of silica. Such a mineral is also described as an **agate**. Colorful agatized minerals are often made into jewelry, for they will take a high polish. Wood and other organic matter are often replaced by silica.

(c). Ferruginous Deposits

The ferruginous deposits are usually rich in iron and usually deposited in marshes, lakes, and lagoons as well as in the sea. The more common examples are **the iron rich oolites** as well as the impregnation of other rocks with **haematite** and **limonite nodules**. We have also rounded masses of pyrite and marcasite and siderite ($FeCO_3$).

> Name and give the composition of three chemical sediments of precipitate origin.

6.6.2.2. EVAPORATES

When a sea has no outlet, the water will gradually evaporate if the climate is dry. As it does so, the dissolved salts become more and more concentrated; familiar examples of this are the Dead Sea (Israel) and Lake Magadi (Kenya). Each of these has a higher salt content than the ocean. Eventually these may dry up completely, leaving beds of salts which are collectively termed **evaporates**.

Sea water, in particular, usually contains numerous dissolved salts e.g. NaCl, $MgCl_2$, $CaSO_4$, Potassium chloride, (KCl), and magnesium bromide. If a body of sea water is extensively evaporated, these salts will crystalline out progressively from the least to the most soluble. Such conditions of extensive evaporation can be produced from the following terrains:

1. From shallow warm seas
2. From an area of the sea that has been cut off from the main sea
3. An inland lake during a drought season
4. A salt enriched lake e.g. L. Magadi and sometimes L. Nakuru

Starting with sea-water as an example, progressive sea evaporation produces the following:

1. At 50% evaporation loss, $CaCO_3$ and Ferrous oxide (Fe_2O_3) will be deposited.
2. At 80% evaporation loss calcium sulphate $CaSO_4$ which is anhydrite and gypsum ($CaSO_4.2H_2O$) will be precipitated.
3. At 90% evaporation loss, NaCl (rock salt) is precipitated.
4. Above 90% evaporation loss, the most soluble salts begin to crystallize. Examples include $MgSO_4$, $MgCl_2$, sylvite (KC)l, borax, soda ash etc.

Examples of Evaporate Rocks

Many of these are actually minerals but since they have extensive impurities they are referred to as rocks. Evaporite rocks show ancient conditions of extensive evaporation.

(a) Gypsum deposits ($CaSO_4 \; 2H_2O$) – when it is massive and translucent, it is referred to as Alabaster. If it occurs in fibrous veins, it is called ***satinspar***. If it occurs as clear crystals, it is called ***selenite***. If it occurs in earthy opaque form it is referred to as ***gypsum***.

(b) Anhydrite ($CaSO_4$) – it is usually precipitated above 25^{o}C

(c) Rock Salt (NaCl)

6.6.3 ORGANIC SEDIMENTS

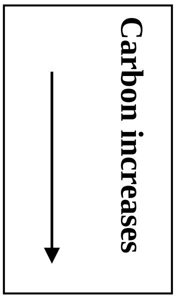
These include mainly organic limestone e.g. coral, peat and coal. These are classified as organic products or precipitates that are caused by organic processes.

What is a sedentary rock?

Coal

Coal is a **sedentary** sediment that accumulated and lithified without transport. Its essential component is carbon. Coal is formed, not from marine organisms, but from the remains of land plants. The process requires anaerobic conditions, in which oxygen is absent or nearly so, since reaction with oxygen destroys the organic matter. The first combustible product formed under suitable conditions is **peat**. Further burial, with more heat, pressure and time, gradually dehydrates the organic matter and transforms the spongy peat into soft brown coal (**lignite**) and then to the harder coals (**bituminous** and **anthracite**). As the coals become harder, their carbon content increases, and so does the amount of heat released by burning a given weight of coal. The hardest, high carbon coals (especially anthracite), then, are the most desirable as fuels because of their potential energy yield.

- Peat (with recognizable plant debris)
- Lignite (more compact, coherent and blacker)
- Bituminous coal (black and dusty)
- Anthracite (dense and shiny black)



Oil and Natural Gas

These are naturally occurring liquids and gases that consist of carbon and hydrogen. They are decomposition products of animal and plant material. Majority of oil and natural gas reserves are trapped within sedimentary rock basins.

> Do you know how oil and natural gas deposits are formed?

Formation of Oil and Gas Deposits

The production of large deposit of any fossil fuel requires a large initial accumulation of organic matter, which is rich in carbon and hydrogen. Another requirement is that the organic debris be buried quickly to protect it from the air so that decay by biological means or reaction with oxygen will not destroy it.

Microscopic life is abundant over much of the oceans. When these organisms die, their remains can settle to the sea floor. There are also underwater areas near the shore, such as on many continental shelves, where sediments derived from continental erosion accumulate rapidly. In such a setting, the starting requirements for the formation of oil are satisfied: There is an abundance of organic matter rapidly buried by sediment. Oil and natural gas are believed to form from such accumulated marine microorganisms. Continental oil fields reflect the presence of marine sedimentary rocks below the surface.

6.7 STRUCTURES IN SEDIMENTARY ROCKS

Bedding

Bedding is the most distinctive feature of sediment sequence and this consists of beds or strata separated from each other by bedding planes. The bed thickness may vary from mm range to several meters and the most thinner ones are referred to as laminae. Fine laminae are characteristic of suspension deposits. If sedimentary rocks show beds then they are bedded or stratified rocks (see Fig. 6.8). Each bed represents a period of deposition such that the upper bedding plane represents the cessation of that period of deposition or perhaps a change in the type of sediment being deposited i.e. a line of parting which is the bedding plane usually forms during the time gap or composition change. The law of superposition states that in an undisturbed stratum, the higher bed is always younger than the lower one.

Figure 6.8. Bedding structure in sedimentary rocks.

Graded Bedding

Graded bedding usually occurs within a single bed where there is variation in grain size from large/coarse near the bottom to fine/small near the top.

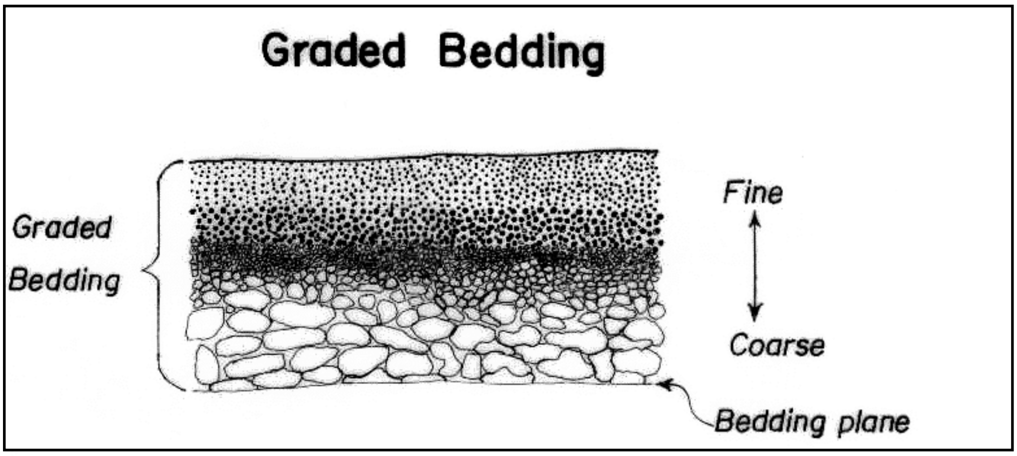


Figure 6.9. Graded bedding.

Cross bedding

Cross bedding occurs as a result of the sloping of the sub parallel planes within and at an angle to the main bedding plane. They are produced by deposition of sediments below moving water and strong winds and hence not all bedding structure is originally horizontal.

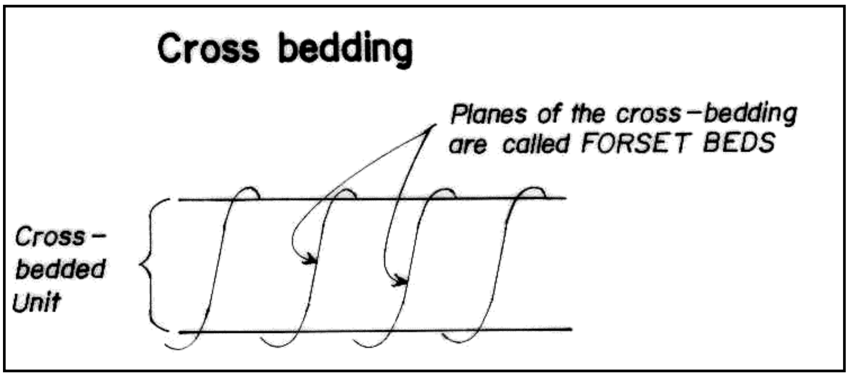


Figure 6.10 Cross-bedding structure

Cross bedding structure is caused by:

- A decrease in the energy of the depositing current during the deposition of the bed.
- Progressive settling of the various grain sizes i.e. the coarsest grains are deposited first in calm water.

Ripple Marks

The ripple marks occur on top of beds and are due to water movements over the bed during its formation e.g. on modern beaches. Their presence indicates higher water speeds involving the movement of coarse particles in the bed-load.

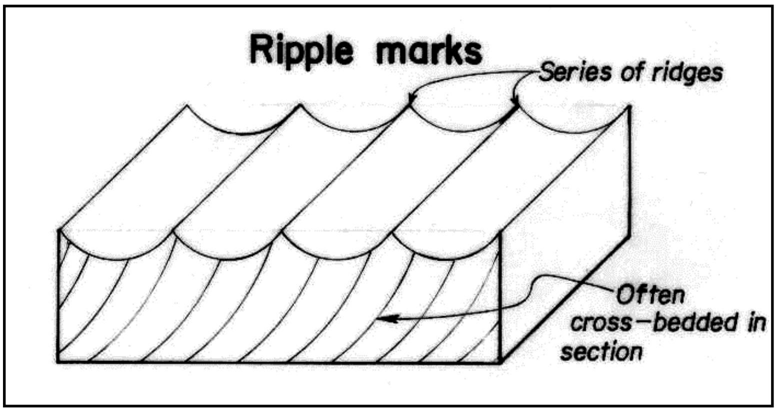


Figure 6.11 Ripple marks structure.

Mud Cracks

Mud cracks also occur on top of beds where drying out of sediments causes them to contract forming polygonal cracks e.g. those in dried up lake beds and in tidal mud flats.

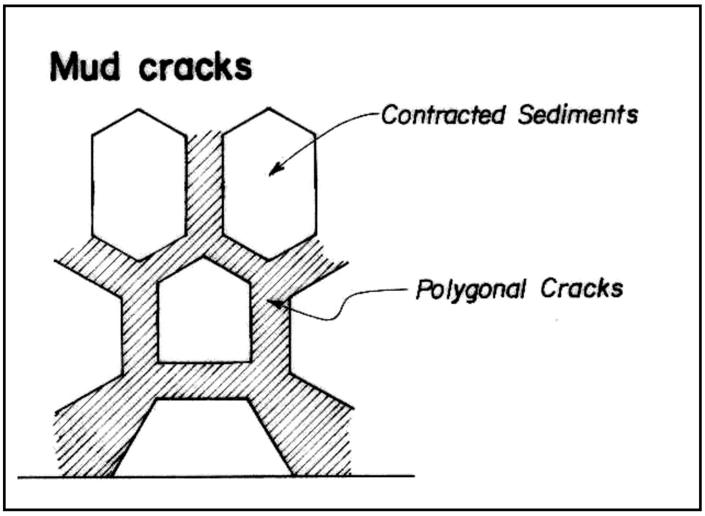


Figure 6.12 Mud cracks structure.

Summary

Sediments are loose, unconsolidated accumulations of mineral or rock particles. When sediments are compacted or cemented together into a solid cohesive mass, they become sedimentary rocks. The set of processes by which sediments are transformed into rock is collectively described as lithification.

Solid weathered material, or sediment can be moved by water, wind or ice. In water, material moved along close to the ground(e.g. along a river bed) is known as bedload, while that carried within the fluid medium (water, air) is called suspended load.

The forms of sedimentary structures indicate the conditions of deposition. For example, fine laminae are characteristic of suspension deposits, whereas ripple marks and cross-bedding indicate higher water speeds involving the movement of coarse particles in the bedload.

Wind can transport only fine particles in suspension, but it can move coarse particles along the ground. Wind-blown sediments are usually well sorted because after a storm the wind speed gradually reduces leading to the deposition of sediments in decreasing order of size. In contrast, ice can transport a wide size range of particles. Glacial deposits are poorly sorted, because melting ice deposits material of all sizes together.

The soluble products of weathering are carried to the sea, where calcium and bicarbonate now may be removed from solution by marine organisms. These and other ions may also be deposited by direct precipitation. Removal by marine organisms leads to the formation of fossiliferous limestone; direct precipitation forms either muddy limestones or evaporates, which include minerals, such as halite (NaCl) and gypsum ($CaSO_4$.2H2O).

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