Notes on Engineering Geology for B.Tech (Civil) – III year students

UNIT: 1 PHYSICAL GEOLOGY

INTRODUCTION

GEOLOGY (in Greek, Geo means Earth, Logos means Science) is a branch of science dealing with the study of the Earth. It is also known as earth science. The study of the earth as a whole, its origin, structure, composition and the nature of the processes which have given rise to its present position is called as geology. Geology comprises the following branches:

1. Crystallography
2. Mineralogy
3. Petrology
4. Geophysics
5. Geochemistry
6. Structural Geology
7. Stratigraphy
8. Physical Geology
9. Geomorphology
10. Paleontology
11. Hydrogeology
12. Engineering Geology
13. Photo Geology
14. Economic Geology
15. Mining Geology

Crystallography: The study of the characters of crystals is known as crystallography. Crystals are bodies bounded by flat faces (surfaces), arranged on a definite plane due to internal arrangements of atoms.

Mineralogy: The study of the characters of minerals (eg: quartz, pyroxene, amphibole, mica, chlorite, garnet) is known as Mineralogy. A mineral is a naturally occurring homogeneous substance, inorganically formed with a definite chemical composition, with a certain physical properties and crystalline structures.

Note: Coal, oil etc are considered as minerals THOUGH they arises by organic matter under exceptional conditions .

Petrology: The study of rocks in all their aspects including their mineralogies, textures, structures (systematic description of rocks in hand specimen and thin sections); origin and their relationships to other rocks.

Geophysics: The section of the earth which include the structure, physical conditions and evolutionary history of the earth as a whole.

Geochemistry: The study of chemical composition of minerals and rocks of the earth.

Structural Geology is the study of rock structures such as folds that have resulted from movements and deformation of the earth's crust.

Stratigraphy: The study of the stratified rocks especially their sequence in time, the character of the rocks and correlation of beds at different localities.

Physical Geology: It deals with the geological processes which bring about changes in the crust and upon the surface of the earth. It also deals with the surface features of the earth (land forms) or its topography

Geomorphology: The description and interpretation of land forms.

Palaeontology is the study of ancient life, determination of environment, evolution of organisms etc..

Hydrogeology-- the study of the geological factors relating to earth's water.

Mining Geology deals with the method of mining of rocks and mineral deposits on earth's surface and subsurface.

ENGINEERING GEOLOGY: the principles and methods of geology is adopted for the purpose of civil engineering operations. Broadly speaking, engg geology has two divisions:

(1) The study of raw materials
(2) The study of the geological characteristics of the area where engineering operations are to be carried out such as Groundwater characteristics; the load bearing capacity of rocks; the stability of slopes; excavation; rock mechanics etc for civil engineer.

SCOPE OF GEOLOGY: In Civil Engineering

- Geology provides necessary information about the construction materials at the site used in the construction of buildings, dams, tunnels, tanks, reservoirs, highways and bridges.

- Geological information is most important in planning stage, design phase and construction phase of an engineering project.

- Geology is useful to know the method of mining of rock and mineral deposits on earth's surface and subsurface.

- Geology is useful for supply, storage and filling up of reservoirs with water.

IMPORTANCE OF GEOLOGY FROM CIVIL ENGINEERING POINT OF VIEW

- Before constructing roads, bridges, tunnels, tanks, reservoirs and buildings, selection of site is important from the point of stability of foundation.

- Geology provides a *systematic knowledge of construction materials and* their properties.

- The knowledge about the nature of the rocks in tunneling and construction of roads.
- The *foundation problems* of dams, bridges and buildings are directly related with geology of the area where they are to be built.
- The *knowledge of ground water* is necessary in connection with excavation works, water supply, irrigation and many other purposes.
- The knowledge of *Erosion, Transportation and Deposition* (ETD) by surface water helps in soil conservation, river control.
- *Geological maps* and sections help considerably in *planning* many engineering projects.
- If the geological features like faults, joints, beds, folds are found, they have to be suitably treated. Hence, the *stability of the rock structures* is important.
- Pre-geological survey of the area concerned reduces the *cost* of planning work.

Minerals, Rocks and soils constitute earth materials. They play a vital role in the site evaluation and operations in civil engineering practice.

Whether it is tunneling, hydro-electric projects, ground water development, foundation for structures, study of slope stability etc.. a basic understanding of the earth materials is essential.

Thus, study of minerals, rocks and soils forms the first step in civil engg point of view. Hence, a civil engineer should know the introduction of Geology and its branches and importance of a few branches such as Physical Geology, Petrology; Structural Geology and so on ……

IMPORTANCE OF PHYSICAL GEOLOGY, PETROLOGY & STRUCTURAL GEOLOGY

IMPORTANCE OF PHYSICAL GEOLOGY: It deals with the geological processes which bring about changes in the crust and upon the surface of the earth. It also deals with the surface features of the earth (land forms) or its topography. The earth is concentrically divided into a number of spheres viz., (1) Atmosphere ; (2) Hydrosphere and (3) Lithosphere .

The outermost sphere is Atmosphere which consists of several gases and vapours and envelopes the earth. Atmosphere is essentially a mixture of N_2 and O_2 with smaller quantities of vapour, CO_2 etc… Geologically atmosphere is important as the medium of climate and weather. Hydrosphere includes the natural waters of the earth ie., oceans, seas, lakes, rivers, streams and underground water. Lithosphere is the outer part of the earth's crust consisting of rocks and minerals.

The geological processes include Denudation, Deposition, Earth movements, Igneous activity and metamorphism.

Denudation: The sum of the processes which result in the general lowering of the land surfaces or when erosion takes place, fresh country rock surfaces will be exposed and this process is called DENUDATION. Denudation consists of weathering, transportation and erosion.

Weathering is the process by which rocks are broken down and decomposed by the action of external agencies such as wind, rain, temperature changes. Weathering is the initial stage in the process of denudation.

Transportation is the main agency by which materials are moved by means of Gravity, running water (rivers, streams); Ice (glaciers); Wind etc..

Erosion: Mechanical disintegration or chemical decomposition of rocks and their subsequent displacement is called as erosion or erosion is the destructive process due to the effect of the transporting agents. The chief agents of erosion are running water, wind etc..

Deposition : The material is transported mechanically and deposit (eg: sand).

Earth movements include the uplift and depressions of land areas & sea floors.

Igneous activity includes emission of lavas, gases, other volcanic products etc

Metamorphism: The process by which changes are brought about in rocks within the earth's crust by the agencies of Heat, Pressure and Chemical fluids.

Thermal metamorphism : heat alone acts
Dynamic metamorphism : involves stress to break up the rocks
Regional/Dynamothermal metamorphism: Both heat & pressure involves
Retrograde metamorphism : produces lower grade metamorphic rocks
Auto Metamorphism : chemical adjustment in newly solidified igneous rocks, brought about by a decrease in temperature .

Geological works of Rivers

A river is one of the major geological agent which carries out its work. The work is mainly divided into three stages, namely

1. River Erosion
2. River Transportation
3. River Deposition

River Erosion: Erosion means mechanical disintegration or chemical decomposition of rocks are transported from the site with the help of natural agencies like wind and running water (or) subsequent displacement. River is a powerful eroding agent and carries out its work in different ways such as hydraulic action, solution and abrasion / attrition etc.

- Hydraulic action: The physical breakdown of rocks take place naturally and greater the movement greater will be the erosion. In the initial and youth stages, the rivers acquire more considerable kinetic energy. When such water dashes against rock forcefully, it will break and this will be more effective if

1. The rocks are already weathered.
2. They are porous and are not well cemented.
3. Those posses fractures, cracks etc.

- Solution: This process, is a part of hydraulic action which involves only chemical decay of rocks. This is an invisible process and very effective under favourable conditions.

- Attrition: This is a mechanical weathering process. When the rock fragments hit the rocks which are already exposed, abrasion take place. Thus the rock fragments during abrasion undergo wear and tear which is called attrition.

During transportation, heavier and larger materials move slowly while finer and lighter material move fast.. When attrition take place the angular edges disappear and spherical, ellipsoidal stones etc are formed after a long journey.

River Transportation: A river transports its material physically as well as in a solution form. The transport system is divided into three groups.

1. **Bed load** comprises heavier particles of sand, pebbles, gravels etc.. which are transported mainly by their rolling, skipping, along the bottom of stream.

2. **Suspended load** consists of silt, fine sands, clay etc.. and such load is carried by river in its body of water in suspension. As the river is moved, the load is also carried along with it. Thus load is transported continuously without break till conditions are favourable. This type of natural suspension and separation of sediments account to their size is called Sorting.

3. **Dissolved load:** Material is transported in a solution condition. The ability to transport the sediments is influenced by river velocity, density etc..

River Deposition is the last phase of geological work of a river. Among the different kinds of river deposits, a few are listed below:

Alluvial cones and fans: River sediment is known as alluvium. If the deposit is spread over a small area but has a relatively steep slope, it is called an alluvial cone. On the other hand, if the deposit is spread over a large area and has a gentle slope, it is called an alluvial fan.

Placer deposits: The placer deposits are characteristically composed of heavier metals such as Gold, Platinum, Chromite, magnetite, Rutile, Ilmenite, Monazite etc. which are commonly economic minerals.
Eg: Rand placer deposit of South Africa is famous for gold.

Delta deposits: Most of the rivers reach this stage just before they merge with the sea. Rivers Ganga and Brahmaputra have built up the best deltaic regions of the world. Deltas are very fertile and valuable for agriculture.

Natural levees. During the time of floods, the river carries a very large scale of river dumps along its course on either side which are known as natural levees. Eg silt, clay .

MEANDER DEVELOPMENT

A meander in general is a bend in a (moving with smooth twists & turns) water coarse. A meander bend is formed when the moving water in a stream erodes the out banks and widens its valley. If the river encounters any obstacle, it shall not have the capacity to uproot it and therefore it takes a diversion and continues its downward coarse.. This is responsible for the formation of deposits known as placer deposits.

By virtue of its relatively weak condition the river compulsorily undergoes a number of curves or bends which makes its path zig-zag. These bends are called meanders and the phenomenon is known as Meandering. Meandering is therefore a characteristic feature of the mature stage.

In due course of time these bends become more and more acute due to deposition of sediments along the inner curve and erosion along the outer curve. Ultimately under favourable conditions such as floods, these loops are cut off from the main course of the river. Such cut off bodies of water which are curved in plan are called **cut off lakes** or **horse shoe lakes** or **ox bow lakes**.

Delta: A delta is a landform that is formed at the mouth of a river where the river flows into an ocean, or sea. Deltas are formed from the deposition of the sediment carried by the river as the flow leaves the mouth of the river. Over long periods of time, this deposition builds the characteristic geographic pattern of river delta.

Development of delta: The favourable conditions for the formation of delta are:

1. The river should have large amount of load.
2. The river should have totally exhausted its energy at the time of its merger with the sea.
3. The oceans at the mouth of the river should not be turbulent otherwise as & when loose sediments are deposited they are washed away by the waves and currents of the sea.

During delta formation the prevailing conditions will be such that the river will be shallow and will change its direction and velocity frequently. Under such conditions deltas develop a typical structure known as **cross bedding**.

The delta will have gently incline bottom layers of fine sediments known as bottom set beds. These are overlain by steeply inclined middle layers of coarse sediments known as forest beds. Above these again gently dipping layers of the mixture of finer and coarser sediments occur. They are known as top set beds. Though all these three sets of beds are inclined towards the sea, they differ in the amount of inclination and hence they are not parallel. Such a peculiar bedding phenomenon is known as cross bedding.

VALLEY DEVELOPMENT

VALLEYS: In geology, a valley is a depression with predominant extent in one direction. A very deep river valley may be called a **canyon or gorge**. The terms U-shaped and V-shaped are descriptive terms of geography to characterize the form of valley. Most valleys belong to one of these two main types or a mixture of them, at least with respect of the cross section of the slopes or hills.

FORMATION AND DEVELOPMENT: A valley is an extended depression in the Earth's surface that is usually bounded by hills or mountains and is normally occupied by a river or stream.

Valleys are one of the most common landforms on the Earth and they are formed through erosion or the gradual wearing down of the land by wind and water. In river valleys for example, the river acts as an erosional agent by grinding down the rock or soil and creating a valley. The shape of valleys varies but they are typically steep-sided canyons or broad plains, however their form depends on what is eroding it, the slope of the land, the type of rock or soil and the amount of time the land has been eroded.

There are three common types of valleys which include V-shaped valleys, U-shaped valleys and flat floored valleys.

V-SHAPED VALLEYS/ RIVER VALLEYS: A V-shaped valley, sometimes called a river valley, is a narrow valley with steeply sloped sides that appear similar to the letter "V" from a cross-section. They are formed by strong streams, which over time have cut down into the rock through a process called down cutting. These valleys form in mountainous and/or highland areas with streams in their "youthful" stage. At this stage, streams flow rapidly down.

- An example of a V-shaped valley is the Grand Canyon in the Southwestern United States. After millions of years of erosion, the Colorado River cut through rock of the Colorado Plateau and formed a steep sided canyon V-shaped canyon known today as the Grand Canyon.
- The original natural large river valleys of the world such as Nile, Ganges, Amazon, Mississippi etc.

U-SHAPED VALLEYS/ GLACIAL VALLEYS: A U-shaped valley is a valley with a profile similar to the letter "U." They are characterized by steep sides that curve in at the base of the valley wall. They also have broad, flat valley floors. U-shaped valleys are formed by glacial erosion. U-shaped valleys are found in areas with high elevation and in high latitudes, where the most glaciation has occurred. Large glaciers that have formed in high latitudes are called continental glaciers or ice sheets, while those forming in mountain ranges are called alpine or mountain glaciers.

Due to their large size and weight, glaciers are able to completely alter topography. This is because they flowed down pre-existing river or V-shaped valleys during the last glaciations and caused the bottom of the "V" to level out into a "U" shape as the ice erode the valley walls, resulting in a wider, deeper valley. For this reason, U-shaped valleys are sometimes referred to as glacial troughs.

One of the world's most famous U-shaped valleys is Yosemite Valley in California. It has a broad plain that now consists of the Merced River along with granite walls that were eroded by glaciers during the last glaciations.

FLAT FLOORED VALLEYS: The third type of valley is called a flat-floored valley and are formed by streams, but they are no longer in their youthful stage, and are instead considered mature. The valley floor gets wider, because of the stream gradient (moderate or low), the river begins to erode the bank of its channel instead of valley walls.

Over time, the stream continues to meander and erode the valley's soil, widening it further. With flood events, the material that is eroded and carried in the stream is deposited which builds up the floodplain of the valley. During this process, the shape of the valley changes from a V or U shaped valley into one with a broad flat valley floor. An example of a flat-floored valley is the Nile River Valley.
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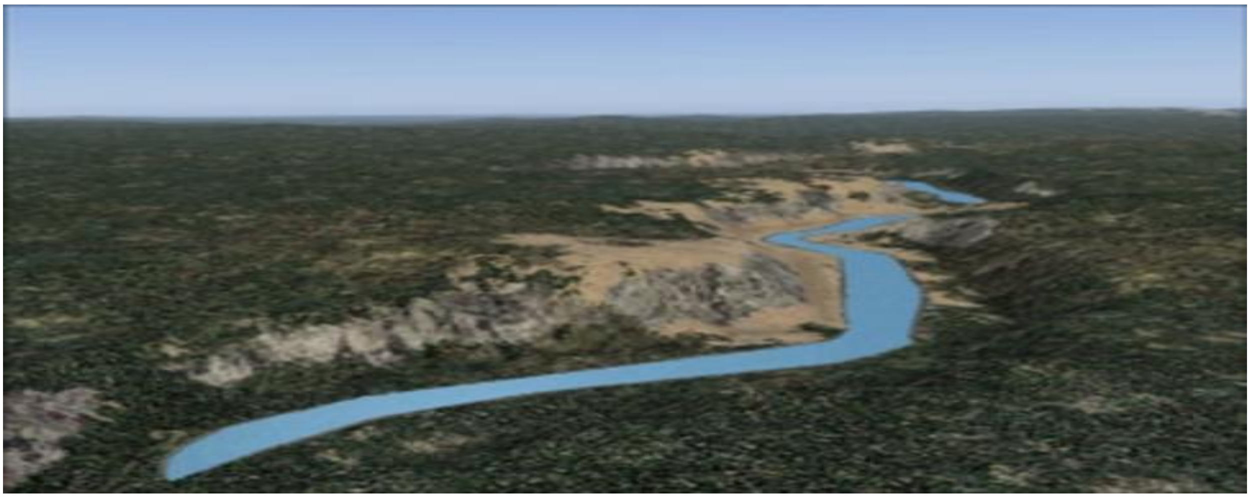


IMPORTANCE OF PETROLOGY: Rocks are divided according to their origin into 3 groups viz., IGNEOUS, SEDIMENTARY and METAMORPHIC. The study of rocks in all their aspects including their mineralogies, textures, structures; origin and their relationships to other rocks plays a major role in civil engineering operations.

Igneous Rocks are formed when hot molten rock material called magma solidifies (or) igneous rocks form through cooling and crystallization of molten rock material. If the molten material is below the Earth's surface, it is called magma or else it comes out about the surface , it is known as lava.

The molten material of rock is semi-solid in nature and consists of liquid , gas and earlier formed crystals. The volatiles (elements and compounds which are dissolved in a silicate melt) are dominantly water vapour, CO_2 and elements like O_2, Si, Al, Ca, Na, K, Fe and Mg.

Sedimentary Rocks are formed due to weathering and erosion of the pre-existing rocks. Sedimentary rocks are classified on the basis of the character of the material and process which leads to its deposition. In addition, the depositional environment plays a major role in the formation of sedimentary rocks ie. deposited the material by wind action or water action.

Sedimentary rocks			
Greywacks	arkose	sandstone	limestone
Chert	Conglomerate	shales	Dolomite
Siltstone	Mudstone/claystone	Breccia	

Arkoses are indicative of erosion under arid conditions and rapid burial conditions whereas Greywacks are a common rock type of geosynclines

Metamorphic Rocks are formed through the transformation of the pre-existing rocks under increased temperature and pressure conditions. This process of transformation is known as metamorphism. Formation of metamorphic rock from a pre – existing (igneous or sedimentary) rock is controlled by the following parameters:

Composition of the rock ; Temperature ; Pressure ;
Chemically active fluids (common fluid is water)
Foliation (under differential stress conditions)
Non-foliation (under hydrostatic stress)

Examples for metamorphic rocks are:

Quartzite	Hornfels	Marble
Amphibolite	Eclogite	Schist
Gneiss	Khondalite	Slate
Phyllite		

Among the igneous and metamorphic rocks; Granites; Quartzites; Gneisses and Basalts are suitable for construction of a dam. Pure sandstones have good compressive strength but presence of inter layers of shales decrease its strength.
Limestones usually contains cavities in them. Adequate treatment in terms of grout – filling of the cavities is to be taken in such cases.

Schists, Phyllites, Shales, Siltstones and clay stones are relatively incompetent and need proper attention. Clay , if present is totally excavated since clay is incompetent as it swells on saturation with water. Contacts of igneous intrusive (dyke) and the host rocks often are fractured and jointed and hence such site is studied with proper care.

Eg: Nagarjuna sagar dam:. Contact of a dolerite dyke with the host rock (granite gneisses), a weak zone was identified along the contact. Excavation followed by back – filling with grout was adopted.

The goal is to give:

1) A meaningful sampling of the approaches and philosophy behind petrologic studies for stability of civil engineering constructions;
2) An appreciation for the diversity, complexity and geological significance of the rocks that comprise the earth for long durable constructions;
3) A basis for understanding the importance of petrology in the civil engg. constructions and
4) To provide *an opportunity* to further development for particular construction.

IMPORTANCE OF STRUCTURAL GEOLOGY: Geological structures are the evidences of crustal deformation. Depending on the process involved, the following various types of structures develop in the geological formations.

FOLDS: Folds are best displayed by stratified formations such as sedimentary or volcanic rocks or their metamorphosed equivalents. Folds can be seen in Gabbro, Granite gneiss, iron formations etc..

FAULTS: When formations subjected to stress deform resulting in the development of fractures or a fracture in rock along which there has been an observable amount of displacement can be seen.

JOINTS: Joints are fractures or openings in the rock formations. These differ from the faults in that there is no displacement along them.

UNCONFIRMITIES: An unconformity represents a long interval of non – deposition during which erosion takes place.

The earth's crust is broken into 13 major plates which are in constant movement (1 to 2 cm per year) due to the convection currents in the interior of the earth. The movements of tectonic plates in the earth crust affect the solid rocks which cause folds; faults, joints etc… study of these aspects are very important to a civil engineer in construction projects. Strike and dip of beds or formations (layers) or joints also important for site location.

Importance of geological structures in Civil engineering operations:

- The formations at the dam site should be dipping towards upstream or horizontal. This will counter the seepage compared the situation where the formations dip in the downstream direction.
- Foundations will have greater stability as the load is normal to the horizontal formations or formations with low dips.
- Presence of faults in the formations is not suitable for a dam site.
- Extensive joints in the rocks also threatens the safety of the structure
- Presence of folds (anticlinal or synclinal structures) in the foundation material contributes to the seepage problem.

A **dam** is a barrier across flowing water that obstructs, directs or slows down the flow, often creating a reservoir, lake or impoundments. Most dams have a section called a *spillway or weir* over which water flows, either intermittently or continuously.

Dam failures are comparatively rare, but can cause immense damage and loss of life when they occur. **Common causes of dam failure include:**

- Spillway design error (South Fork Dam)
- Geological instability caused by changes to water levels during filling or poor surveying (Malpasset).
- Sliding of a mountain into the dam lake; in the case of Vajont Dam, filling the reservoir caused geological failure in valley wall (Lawn Lake Dam, Val di Stava)
- Extreme rainfall (Shakidor Dam)
- Human, computer or design error (Dale Dike Reservoir,)
- Internal erosion, especially in earthen dams.

CAUSES FOR FAILURE OF DAMS ------ CASE STUDIES

The most common causes of dam failures includes the following considerations:

1. Failure due to earthquake
2. Failure due to landslide
3. Failure due to chemical weathering of foundation rocks (Alkali-Silica Reaction , Sulfate & Chloride on concrete)
4. Failure due to physical weathering (temperature variations, or by heavy rain, or by physical breaking).
5. Failure due to increase of fractures in geological structures (fault, folds & unconformities).

1.The **St. Francis Dam** was a concrete gravity-arch dam, designed to create a reservoir. The dam was built between 1924 and 1926 under the supervision of William Mulholland

The dam Height is 195 feet (59 m) & its l**ength is** 608 feet (185 m). The dam was constructed on the foundation of Schists and conglomerates and in turn, separated by a distinct fault. In addition, conglomerates also had veins of gypsum, a soluble mineral and hence both Schists and conglomerates are unsuitable to serve as a foundation to such a dam. Several temperature and contraction cracks appeared in the dam when the reservoir had reached full capacity. Enormous leakage of stored water occurred through the conglomerate and the dam failed by sliding in 1928 resulting more than killing of 450 people

Huge concrete block from the west abutment of the dam was carried out by dam water . The block is approximately 63 feet long, 30 feet high, and 54 feet wide. It was concluded that the disaster was primarily caused by the landslide on which the western abutment of the dam was built.

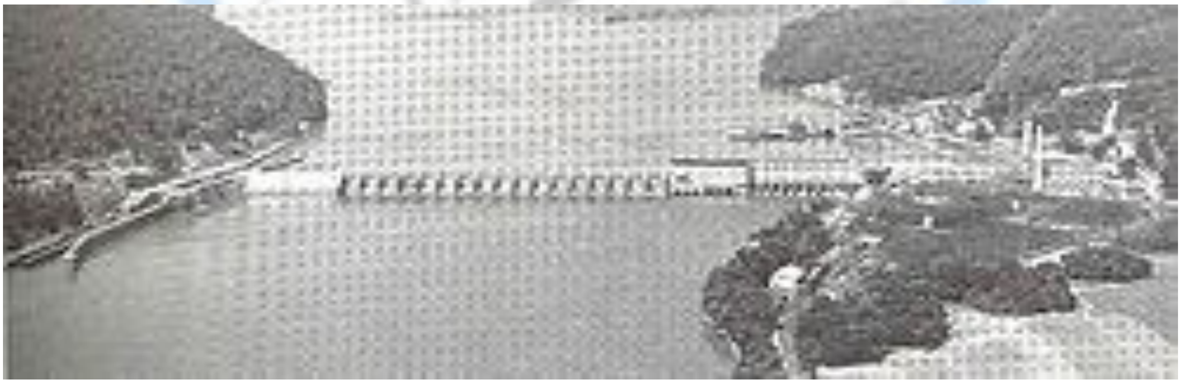
1. **Hales Bar Dam** was a hydroelectric dam located on the Tennessee River in

Marion Country, Tennessee, USA. The height of the dam is 113 feet with a length of 2315 feet. The Hales Bar Dam was constructed on the foundation of cavernous limestones. Such rocks are naturally weak both physically and chemically. To improve the site conditions and to reduce the seepage, the large openings were filled up by using more than 3000 tons of cement and 1100 barrels of asphalt. The dam was planned to complete in 1909, but numerous difficulties brought by the soft bedrock ie limestone upon which the dam was built.

Leaks began to appear almost immediately after completion. However. in 1919, engineers attempted to minimize the leakage by pumping hot asphalt into the dam's foundation. This was temporarily successful, but by 1931, a study leaking at a rate of 1,000 cubic feet per second was noticed .

In the late 1950s, however, the water below Hales Bar Dam, was again leaking, this time at an alarming 2,000 cubic feet per second. **Dye tests** carried out in 1960 suggested that many of the leakage channels had interconnected, increasing the possibility of a future dam failure.

Huge concrete block from the west abutment of the dam . The block is approximately 63 feet long, 30 feet high, and 54 feet wide



Hales Bar Dam in 1949, after various improvements

3. Kaila Dam, Gujarat, India: The Kaila Dam in Kachch, Gujarat, India was constructed during 1952 - 55 as an earth fill dam with a height of 23.08 m above the river bed and a crest length of 213.36 m. The storage of full reservoir level was 13.98 million cubic mts. The foundation was made of shale. The spillway was of ogee shaped and ungated. The depth of cutoff was 3.21 m below the river bed. Inspite of a freeboard allowance of 1.83 m at the normal reservoir level and 3.96 m at the maximum reservoir level the energy dissipation devices first failed and later the embankment collapsed due to the ***weak foundation bed*** in 1959.

4 . Kodaganar Dam, Tamil Nadu, India: This dam was constructed in 1977 on Cauvery River as an earthen dam with regulators. The dam was 15.75 m high above the deepest foundation, having a 11.45 m of height above the river bed. The storage at full reservoir level was 12.3 million cubic mts. The dam failed due to overtopping by flood waters which flowed over the downstream slopes. There was an ***earthquake*** registered during the period of failure although the foundation was strong. Water gushed over the rear slopes, as a cascade of water was eroding the slopes. Breaches of length 20 m to 200 m were observed. It appeared as if the entire dam was overtopped and breached.

5. Tigra Dam (Madhya Pradesh, India, 1917): This was a masonry gravity dam of 24 m height, constructed for the purpose of water supply. A depth of 0.85 m of water overtopped the dam over a length of 400 m. This was equivalent to an overflow of 850 m3s-1(estimated). Two major blocks were bodily pushed away. The failure was due to ***sliding.*** The dam was reconstructed in 1929.

List of major dam failures

Dam/incident	**Year**	**Location**	**Details**
Austin Dam	1911	Pennsylvania, U S	Poor design, use of dynamite to remedy structural problems.
St. Francis Dam	1928	Valencia, California, Los Angeles , U S	Geological instability of canyon wall that could not have been detected with available technology of the time, that assessed developing cracks .
Malpasset	1959	Côte d'Azur, France	Geological fault possibly enhanced by explosives work during construction; initial geo-study was not thorough.
Baldwin Hills Reservoir	1963	Los Angeles, California, U S	Subsidence caused by over-exploitation of local oil field
Vajont Dam	1963	Italy	Filling the reservoir caused geological failure in valley wall, leading to 110 km/h landslide into the lake; Valley had been incorrectly assessed stable.

Buffalo Creek Flood	1972	West Virginia, U S	Unstable loose constructed dam created by local coal mining company, collapsed in heavy rain
Teton Dam	1976	Idaho, U S	Water leakage leading to dam failure.
Laurel Run Dam	1977	Pennsylvania, U S	Heavy rainfall and flooding that over-topped the dam.
Machchu-2 Dam	1979	Gujarat, India	Heavy rain and flooding beyond spillway capacity.
Perućа Dam detonation	1993	Croatia	detonation of pre-positioned explosives
Saguenay Flood	1996	Quebec, Canada	constant rain. Post-flood enquiries discovered that the network of dikes involvement
Ringdijk Groot-Mijdrecht	2003	Wilnis, Netherlands	Peat dam became lighter than water during droughts and floated away
Hope Mills Dam	2003	North Carolina, United States	Heavy rains caused earthen dam and bank to wash away
Big Bay Dam	2004	Mississippi, U S	A small hole in the dam, grew bigger and led to failure.
Shakidor Dam	2005	Pakistan	extreme rain
Taum Sauk reservoir	2005	Lesterville, Missouri, U S	dam continued to fill. Minor leakages caused for failure
Campos Novos Dam	2006	Campos Novos, Brazil	Tunnel collapse
Kyzyl-Agash Dam	2010	Kazakhstan	Heavy rain and snowmelt
Hope Mills Dam	2010	North Carolina, U S	Sinkhole caused dam failure
Delhi Dam	2010	Iowa, US	Heavy rain, flooding.
Ajka alumina plant accident	2010	Hungary	Failure of concrete impound wall
Fujinuma Dam	2011	Japan	Failure due to 2011 Tōhoku earthquake.

WEATHERING OF ROCKS - IT'S EFFECT & IMPORTANCE w r t DAMS, RESERVOIRS, TUNNELS

The process by which rocks are broken down and decomposed by the action of external agencies such as wind, rain, temperature changes etc is called as **weathering**.. (or) weathering is a process involving disintegration and decomposition of rocks. The disintegrated and the altered materials stay at the site of formation. If these materials are transported from the site with the help of natural agencies such as wind, running water etc, the process is called as erosion. Weathering is categorized as a mechanical, chemical, biological..

Mechanical weathering: In mechanical weathering, the process involves only fragmentation or break down of the rock into smaller fragments / pieces. In nature, the physical breaking of rocks are caused by several processes. Waterfalls, landslides during their fall cause extensive breakdown of rocks. Thus gravity contributes to mechanical disintegration of rocks. However, all the processes involve widening of the fractures, resulting in the detachment of blocks surrounded by the weak planes. The different types of processes in mechanical weathering are:

Frost wedging: The presence of water in the cracks of the rocks freezes during the night time and melts during the day time. Freezing of water involves an increase in the volume because of which the walls of cracks are wedged ultimately resulting in the detachment blocks surrounded by the weak planes.

Expansion and contraction process: Solar radiation causes heating, which results in thermal expansion during day time and drop in the temperature during the night time causes contraction. The expansion and contraction are confined only to the surface layers of the rock and results often in the fracturing and detachment of top layers of the rocks.

Fracturing through pressure releases: Rocks at depth are confined under high pressures. However, if the rock material is uplifted due to tectonic processes to relatively lesser depths, it is subjected to lesser pressure conditions. So, the release of pressure leads to the deformation of rock and generates the fractures.

Effect of vegetation: During the growth of vegetation in rocky terrains, the roots penetrate into the existing weak planes and gradually the cracks are widened leading to physical breakdown of rock masses.

Mechanical or **physical weathering** involves the breakdown of rocks through direct contact with atmospheric conditions, such as heat, water, ice and pressure.

Chemical weathering: Chemical weathering involves chemical reactions resulting in the alteration of the rock leading to the formation of new alteration products. Water is the best fluid that directly affects rocks by way of Dissolution; Leaching (making porous); Hydration; Oxidation, Hydrolysis etc

Dissolution / Carbonation: In case of carbonate rocks such as limestone, dolomite, marble when the river water traverses in these rocks; carbonates are dissolved, resulting in the reduction of their sizes.

Surface water contain O_2 and its combination with water results in the formation of carbonic acid. Production of carbonic acid lowers the pH, resulting in the attack some of the minerals which are present in the rocks.

Leaching: means removable of soluble content from the rocks by water. Water is the powerful leaching agent which affects leaching for the most of the materials when come in contact with water. Eg: laterite is a porous rock and very weak when compared to its fresh parent rock.

Hydration is the process where in hydroxyl molecules are injected into the molecular structures of minerals thereby bringing about the decomposition of minerals.

$K_2\ Al_2O_3\ 6\ SiO_2$ + $H_2O + CO_2$ $\longrightarrow$ $K_2CO_3 + Al_2O_3\ 2\ SiO_2\ 2H_2O + 4\ SiO_2$
(K – feldspars) (Hydration) (Kaoline) (silica)

Due to hydration process, anhydrous pyroxenes are changed over to amphiboles while Amphiboles may be altered to Biotite. Biotite change over to Chlorite whereas Anhydrite ($CaSO_4$) alters to Gypsum ($CaSO_4\ 2H_2O$)) during hydration.

Oxidation: The decomposition of minerals in a rock during chemical weathering is brought about by O_2 in water. For eg pyroxene changes into limonite because of oxidation through the following reaction.
$4FeSiO_3$ + O_2 + $2H_2O$ $\longrightarrow$ $4\ FeO\ (OH)$ + $4\ SiO_2$
(pyroxene) (limonite) (silica)

Pyrite (FeS_2) converts into Haematite (Fe_2O_3) during oxidation process

Hydrolysis: In case of decomposition of minerals, instead of water molecule, only hydrogen of water enters into the mineral structure. This is called hydrolysis.

$K\ AlSi_3\ O_8$ + H^+ $\longrightarrow$ $H\ AlSi_3O_8$ + K^+
Orthoclase feldspars ion Silicic acid ion

In addition, CO_2; O_2; N_2 of atmospheric gases which take part in the weathering of rocks.

Chemical weathering, involves the direct effect of atmospheric chemicals in the breakdown of rocks, minerals...

Biological weathering involves breakdown of rocks by living organisms (Bacteria & fungi). Living organisms release organic acids viz., Oxalic acid; Phenolic acid; Folic acid, Acetic Acid, Humic acid etc.. which cause decomposition of rocks. Some of the microorganisms penetrate into mineral crystals and remove specific ions from the inter layers. Eg: removal of K^+ from mica layers by fungi is an example of this type.

Man is also responsible for unnatural weathering of rocks for construction of buildings, dams, bridges etc…

Weathering effect over the properties of rocks:

- Weathered minerals exhibit change in color intensity or different colors.
- They will be less compact, and hence their specific gravity will be less.
- Their hardness will decrease so that the minerals become softer and weak.
- They become less transparent or tend to become opaque.
- The minerals loss their original shine and exhibit a dull luster.
- Weathered minerals loose their internal cohesion & become easily powdered.
- Weathered rocks usually appear as brown,red & yellow colors on the surface.

The degree of weathering is controlled by several parameters. These are:

A) Rock mass characteristics: The ultrabasic and basic igneous rocks (Peridotite, Dunite, Gabbro) decompose rapidly to acidic igneous rocks (Granite). Similarly, carbonate rocks weather rapidly due to chemical solvents. Among the metamorphic rocks, quartzite is most stable whereas weathering of schists and phyllite is relatively faster. Rocks with folding and faulting undergo rapid weathering. The weak zones facilitate mechanical and chemical weathering by natural agencies.

B) Climate: It includes temperature and rainfall. In general, weathering is faster in regions with high temperature and high rainfall

As the temperature increases the vibration of atoms and ions in the rock mineral structures are more ultimately leading to the development of cracks. Rate of chemical weathering doubles with an increase of temp by 10^{o} C.

Rainfall contributes to the growth of organisms (bacteria) which produces $CO_{2.}$

C) Relief: If the topography is undulating and the slopes are steep, the weathered material erode continuously from the site. Consequently fresh surface of the rocks expose.

D) Time: If the weathering has continued over a long period of time, thick zone of alteration develops. eg: Bauxite deposits results from the decay and weathering of aluminum bearing rocks often igneous rocks.

IMPORTANCE OF WEATHERING

Weathering transports smaller fragments, pieces etc after the process of weathering. Weathering initiates the erosion of rock, causing alterations in minerals as well as in the surface layers. Weathering is a process that applies major role of engineering mechanics, e.g. kinematics (study of bodies which are in motion), dynamics and fluid mechanics to predict the mechanical behavior of erosion. Together, soil and rock mechanics are the basis for solving many engineering geologic problems with references to dams, reservoirs and tunnels.

Advantages of weathering from civil engineering point of view:

- Weathering produces soil which is vital for agriculture and for the production of agricultural crops.
- Weathering makes rocks into porous and permeable which allow the movement of groundwater in case of hard rocks like granites.
- Economic minerals like bauxite deposits are also form due to weathering.
- Oxidation of chemical weathering is important in the formation of some ore deposits particularly sulphides.

Disadvantages of weathering from civil engineering point of view:

- Weathering is not a welcome process, because it reduces the strength, durability and good appearance of rocks.

- Therefore, the weathered rocks are unfit to be at the site of foundation in case of civil structures like dams and bridges.
- Since weathered rocks are characterized by loose characters ie strength, durability etc, they become unfit for the formation of road metal or as a building stone.
- Weathered rocks are being weak, therefore unsuitable for tunneling.
- Occurrence of weathered zone in the upstream side creates silting problem in case of reservoirs as the accumulation of rapid silt reduces the reservoir capacity.
- Loose boulders due to weathering along steep slopes may turn out landslides which is civil engineering hazard.

Engineering classification of weathered rock masses: The engineering classification of weathered rock masses can be categorized into **Qualitative and Quantitative** approached.

Qualitative approach is very useful for the preparation of weathering maps for project sites in civil engineering practice.

The degree of weathering in a rock mass is arrived on the basis of change in its strength, alteration on its surface and the development of fractures. The rock mass is categorized into 6 grades. Table shows the grades of weathering in a rock masses :

Description	Code	Grade	Basis of grading
Unweathered	UW	I	Rock mass is fresh. No alteration
Slightly weathered	SW	II	Discolouration present along cracks
Moderately weathered	MW	III	Increase in the extent of fracturing & partly modifies into soil
Highly weathered	HW	IV	Material is discolored. Loss of strength can be observed. More than half of the material is converted to soil
Completely weathered	CW	V	Lost original strength. Rock mass changed to soil
Residual weathered	RW	VI	Total conversion to soil. No original fabric

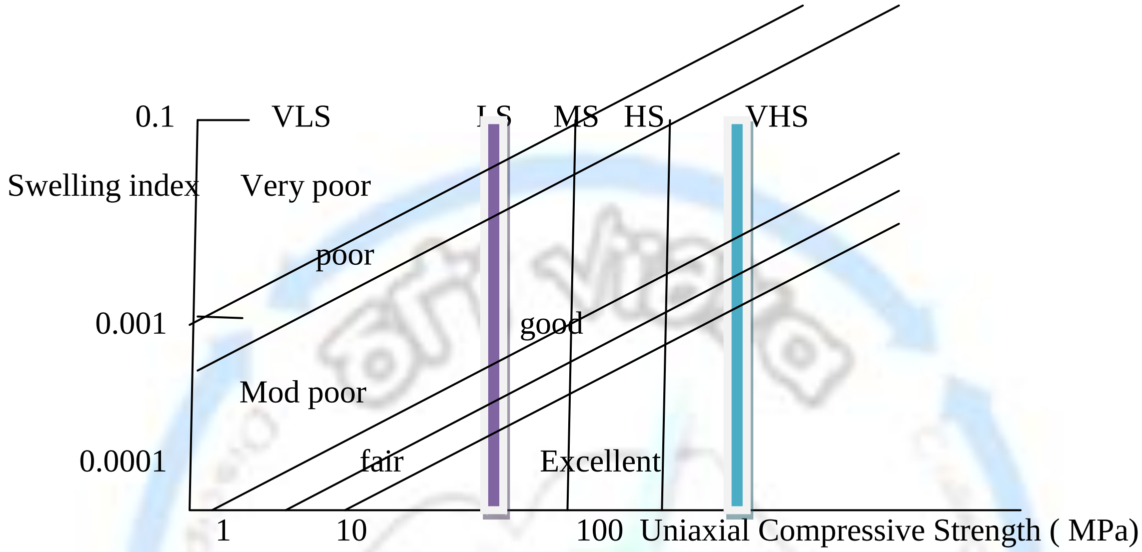
Quantitative approaches also reveals the weathering status, geodurability etc.. of rock masses.

A) Based on ultrasonic velocities, Lliev (1967) classified the weathered rock masses as : C = $(V_F - V_W / V_F)$ where C = coefficient of weathering
V_F = velocity in fresh rock & V_W = velocity in weathered rock.

Grade	Coefficient
Fresh	0
Slightly weathered	0 – 0.2
moderately weathered	0.2 – 0.4
Strongly weathered	0.4 – 0.6
Very strongly weathered	0.6 – 1.0

B. This classification was proposed by Oliver by incorporating UNIAXIAL COMPRESSIVE STRENGTH (UCS) & SWELLING INDEX (means the change in length on swelling to the original length of sample) for rock masses.

VLS=Very Low Strength; LS=Low Strength; MS=Medium strength; HS=High strength



This method is essentially meant for assessing the weathered status of the rock mass for TUNNELLING OPERATIONS.

Effect of weathering of a common rock GRANITE:

Among different rocks, Granite (an acidic rock) is one of the most abundant rock on the earth's surface. Therefore, it will be appropriate to analyse the process of weathering in granite.

Granite consists of quartz, feldspars (orthoclase, plagioclase), and accessory minerals (amphiboles, pyroxenes; biotite / muscovite, magnetite / haematite, rutile, zircon, apatite, garnet..)

During the oxidation, feldspars in granite converts into sericite and then to kaolinite thereby silica removed from the reaction by ground water.

Feldspars → sericite (mica) → kaolinite (clay)

Quartz minerals remain unchanged whereas muscovite or biotite becomes chlorite on decomposition. Pyroxenes (augite / diopside) decompose and pass into hornblende or breakdown into chlorite.

The above changes due to weathering causes failure of civil construction projects and hence the study of weathering of rocks is important for any civil project.

Finally, Geological considerations such as Topography and geomorphology of the site, impact of geological structures; Lithology of the formations ; Identification of weak zones in addition to weathering of rocks plays an important role in civil engineering constructions.

Effect of weathering on other rocks: On the other hand, the decomposition of basic rocks (basalt, gabbro) which contain ferro magnesium silicates produce soluble materials (clay); iron-oxides; less silica.

Disintegration (mechanical weathering) produce rough angular materials which may from form on the mountain top or accumulate at the foot hills. These loose accumulations are called **TALUS or SCREE.**

The finest particles are usually removed from a scree by percolating water and the fine angular fragments get cemented. So, a cemented scree is known as **BRECCIA. CHERT and FLINT** also may occur in residue when limestones undergo weathering.

GENERAL GEOLOGY

Geology in civil engineering

Ø It enables a civil engineer to understand engineering applications of certain conditions related to the area of construction, which are essentially geological in nature. It enables a geologist to understand the nature of geological information that is absolutely essential for a safe design and construction of a civil engineering project.

Branches in geology

(a) **Physical Geology**

It deals with the origin, development and ultimate fate of various surface features of the earth and also with its internal structure. The role played by internal agents and external agent on the physical features of the earth makes major areas of study in physical geology. Similarly, the disposition of rock bodies, water bodies and huge moving deposits of ice on the surface and their structures also form important subjects of physicalgeology.

(b) **Geomorphology**

v Deals specifically with the study of surface features of the earth, primarily of theland surface. Detailed investigations regarding development and disposition of mountains,plains, plateaus, valleys and basins and various other landforms associated with them; fall in the domain of geomorphology. The structure and evolution of these landforms through space and time are advanced fields of study within geomorphology.

(c) **Mineralogy**

v Mineralogy is that branch of geology, which, deals with formation, occurrence,aggregation, properties, and uses of minerals. Mineralogy is sometimes itself divided into specific sub-branches such as crystallography, optical mineralogy and descriptive mineralogy, and so on.

v Crystallography is a well-established branch of mineralogy that deals exclusively with internal structure and external manifestations of minerals occurring in crystallized form in the natural process or made from synthetic processes.

(d) **Petrology**

v Minerals occurring in natural aggregated form are called rocks, These rocks form the building blocks that make up the crust of the earth. The rocks are themselves made up of minerals already defined as building units. Formation of various types of rocks, their mode of occurrence, composition,textures and structures, geological and geographical distribution on the earth are all studied under petrology. It is one of the most important subdivisions of geology and is further subdivided into three distinct branches: Igneous petrology, Sedimentary petrology and Metamorphic petrology.

(e) **Historical Geology**

v It deals with the past history of the Earth as deciphered from the study of rocks and features associated with them. Rocks may be treated as pages of the Earth' s history. They contain within them enough evidence indicative of nature and time of their formation, composition, constitution, magnetism, structural disposition and in many cases, fossils (remains of ancient life), all of which when interpreted scientifically reveal a lot about the events that have passed since their formation. Thus, fairly accurate estimates can be made from the above evidence about the climates, biological and environmental conditions prevailing just before, during and after the formation of these rocks in and around the areas of their occurrence.Paleo-geography, paleontology and stratigraphy are three distinct subdivisions of Historical Geology.

(f) **Economic Geology**

v The branch deals with the study of those minerals and rocks and other materials (fuels etc) occurring on and in the earth that can be exploited for the benefit of man. These include a wide variety of ores of all the metals and non-metals, building stones, salt deposits, fuels (coal, petroleum, natural gas and atomic minerals) and industrial minerals refractories, abrasives and insulations and for manufacture of chemicals.

EARTH STRUCTURES AND COMPOSITION

The Atmosphere

The outer gaseous part of the Earth starting from the surface and extending as far as 700 km and even beyond is termed atmosphere. It makes only about one-millionth part of the total mass of the Earth. The gaseous envelope, like the other matter, is held around the planet due to gravitational pull of the body of the Earth.

Based on thermal characters the atmosphere is divided into the following layers:

(a) The Troposphere:

It is the lowermost zone of the atmosphere rising from the surface of the earth extending, on an average to a height of 11 km. Its upper boundary called tropopause about 9km above the poles and at 18 kmabove the equator.

Ø The troposphere contains almost nine-tenths of the total mass of the atmosphere this layer of gases that is responsible for most of the weather forming or 1 processes on the earth.

Ø In the troposphere there is recorded a regular fall in tem a lapse rate of 6.3 up to tropopause resulting to as low temperatures as —4 0 C to -60 degree at those heights.

Structure of the atmosphere

(b) The stratosphere

Ø It is the second layer of the atmosphere starting from the tropopause and extending upto an average height of 50 km

Ø The temperature becomes constant for a height of 20km (above tropopause) and then starts increasing.

Ø It contains almost the entire concentration of OZONE GAS that occurs above the Earth in the form of a well-defined envelope distinguished as the Ozone layer

Ø The stratosphere itself has a layered structure and there is no significant mixing or turbulence of gases in this layer.

Ø The Ozone Layer starts at a height of 9 km above the surface and continues up to 35 km. The maximum concentration of ozone in this layer is estimated at a height

of 20-25km.
Ø The importance of ozone layer for the life on the planet Earth lies in its capacity to absorb a good proportion of the solar radiation including the entire content of most dangerous ultraviolet rays coming from the Sun.
Ø In this process, the gas gets itself heated up and hence becomes the cause of higher temperature in the upper regions of the atmosphere.
Ø The upper boundary of the stratosphere is called stratopause.
(c) The Mesosphere
Ø This is the third thermal zone of atmosphere which begins at stratopause at about 50km above the surface and continues up to a height of about 80 km.
Ø It is characterized with a steep fall in temperature that may go to as low levels as —100 °C at the upper limit of mesosphere.
(d) The Thermosphere
Ø The fourth and the last zone of the atmosphere starts at about 80 km and extends up to 500 km and beyond.
Ø In this zone, temperature starts rising once again and reaches 1000°C and above.
Ø The IONOSPHER is a special zone recognized within the atmosphere. It starts from 80 km and extends upwards to variable heights.
Ø Atmospheric gases at these heights absorb a great part of solar radiation coming to the Earth.
Ø In this process, these gases break up into ions or electrically charged particles. As a result, this part of the is made up entirely ions and hence is designated as ionosphere.
(e) The Lithosphere
Three specific layers or zones:
Ø The crust,
Ø The mantle and
Ø The core.
The term lithosphere is now understood to include only the uppermost shell of the earth, the crust and a part of the second layer, the mantle, up to which the material exists in a definite solid state.
(a) The Crust
It is the uppermost solid shell of the earth which has varying thickness in different areas as follows
(a) Under the oceans 5 - 6 km
(b) Under the continents 30 - 35 km
(c) Under the mountains : 60 - 70 km
Ø It is obvious that when compared with the radius of the Earth (6730 km. on an average), the crust makes just an insignificant part in the structure of the earth.
Ø The chemical composition of the crust
(1) Silica (Si0 is the most dominant component; its value lies above 50% by volume in the oceanic crust and above 62% in the continental crust;
(ii) Alumina (A is the next dominant component, its value varying between 13-16 per cent;
(iii) Iron Oxide (Fe Lime (CaO)-6%; Sodium Oxide-4%, Magnesium Oxide-4%, Potassium Oxide and Titanium oxide- 2% are the other components making the crust of the Earth.
Ø The solid aggregate that makes the crust of the earth is named as a rock. stone. The entire crust is made up of different types of rocks.
(b) The Mantle

Ø Materials making the earth become quite different in properties at the base of the crust.
Ø This depth below the surface of the Earth at which a striking change in the properties of the materials is observed has been named as Mohorovicic discontinuity.
Ø In geological literature, it is often referred as M-discontinuity or simply as Moho. The material below Moho forms a nearly homogeneous zone till a depth of 2900 km is reached.
Ø At that depth, another striking change is observed in the quality of the material on the basis of the seismic waves reaching there.
Ø Hence, mantle is that zone within the Earth that starts from M-discontinuity and continues up to a depth of 2900 km (Fig. 1.4) Mantle is made up of extremely basic material called aptly ultra basic, that is very rich in iron and magnesium but quite poor in silica
Ø This zone is characterized with a high density that increases with depth.
Ø The material of the mantle is believed to be variably viscous in nature so much so that the overlying crusted blocks can virtually float over it, of course at a very slow rate and in a broader sense of the term.

(c) The Core

Ø It is the third and the innermost structural shell of the earth as conclusively proved by the seismic evidence. It starts at a depth of 2900 km below the surface and extends right up to the center of the earth, at a depth of 6370 km.
Ø The core remains a mystery in many ways. Within the core, the physical nature and composition of the material is not uniform throughout its depth. Further, it has a very high density at mantle-core boundary, above lOg/cc.
Ø But despite such a high density, the outer core behaves like a liquid towards the seismic waves.
Ø The liquid like core extending from a depth of 2900 km to about 4800 km is often termed as outer core.
Ø The inner core - starting from 4800 km and extending up to 6370 km is of unknown nature but definitely of solid character and with properties resembling to a metallic body.
Ø According to a widely favored view, the core may be made up of iron and nickel, alloyed in some yet unknown manner.
Ø This view gets some support from the composition of meteorites that are often recovered from different regions of the globe. The meteorites, as already mentioned, are wandering fragments from the interiors of some other destroyed planets that enter our atmosphere as meteors from time to time.

(f) The Hydrosphere

Ø It is a collective name for all the natural water bodies occurring on or below the surface. Although hydrosphere makes only 0.03 percent of mass of the earth as a planet, its relevance to the existence of life on this planet can hardly be overstated
Ø More than 98 percent of the hydrosphere is made up of huge surface bodies of saline water called seas and oceans.
Ø Rivers and lakes spread over hundreds of thousands square kilometers are other constituents of the hydrosphere.
Ø Huge bodies of frozen water, the ice and snow, together making up the glaciers are the third major component of hydrosphere.
Ø Lastly, but not the least, water occurring in pores, cavities and cracks of the rocks of the crust of the earth, called the ground water, is another important part of the

hydrosphere.

(g) The Biosphere

Ø This term is sometimes used to express the collective life form, as it exists on the surface and under water.

Ø The biosphere depends for its existence on the other three zones of the planet already described: the lithosphere, the atmosphere and the hydrosphere.

Ø This zone has also been responsible for many geological processes that have been going on the planet since the evolution of life.

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WEATHERING

Ø Weathering, is a natural process of in-situ mechanical disintegration and/or chemical decomposition of the rocks of the crust of the Earth by certain physical and chemical agencies of the atmosphere.

Ø The most important aspect of this process is that the is a natural process of in-situ mechanical disintegration and/or chemical decomposition of the rocks of the crust of the Earth by certain physical and chemical agencies of the atmosphere.

Ø The most important aspect of this process is that the weathered product remains lying over and above or near to the parent rock unless it is removed from there by some other agency of the nature.

Ø There are several methods by which rocks undergo weathering.

Ø These may be classified and discussed under two main classes:

v mechanical (physical) weathering and

v chemical weathering.

Mechanical (Physical) Weathering

Ø It is a natural process of in-situ disintegration of rocks into smaller fragments and particles through essentially physical processes without a change in their composition.

Ø A single rock block on a hill slope or a plain, for instance, may be disintegrated gradually into numerous small irregular fragments through frost action that in turn may break up naturally into fragments and particles of still smaller dimensions.

Ø These loose fragments and particles may rest temporarily on the surface if it is a plain.

Ø On slopes, however, the end product fragments and particles may roll down under the influence of gravity and get accumulated at the base as heaps of unsorted debris.

Ø All these fragments and particles, however, have the same chemical composition as the parent rock.

Ø Mechanical weathering is one of the very common geological processes of slow natural rock disintegration in all parts of the world.

Ø Temperature variations and organic activity are two important factors that bring about this change under specific conditions.

(a) Frost Action

Ø As is known, water on freezing undergoes an increase in its volume by about ten per cent. This expansion is accompanied by exertion of pressure at the rate of 140 kg/cm (2000 lbs/in on the walls of the vessel containing the freezing water.

Ø In areas of intensive cold and humid climates, temperatures often fall below the freezing point of water repeatedly during winter months.

Ø In such areas freezing of water in pots and pools, water pipes and taps and in cavities and cracks in concreted roads causing their bursting and disintegration in many cases is a matter of common observation.

Ø This process of freezing of water when happening within the pores, cracks, fractures and cavities of rocks affects them considerably.
Ø The original openings are widened at the first stage of attack and thereby accommodate more and more water to come and freeze in subsequent cycles.
(b) Thermal Effects (Insolation)
Ø In arid, desert and semi-arid regions where summer and winter temperatures differ considerably, rocks undergo physical disintegration by another phenomenon related to temperature.
Ø As we know, rocks, like many other solids, expand on heating and contract on cooling. They (rocks) are, of course classed as bad conductors of heat but even then prolonged exposure to direct heating by the Sun does induce appreciable volumetric changes in them.
Ø Such repeated variations in temperature experienced by a body of rock gradually break it into smaller pieces, especially in the top layers, by development of tensile stresses developing from alternate expansion and contraction.
Exfoliation
Ø In a thick rock body or where the rock is layered, these are the upper layers that get affected most due to the temperature variations.
Ø As a result, the upper layers may virtually peal off from the underlying rock mass. In many cases such a change is also accompanied by chemical weathering, especially at margins and boundaries of the separated layers, developing curved surfaces.
Ø This phenomenon of pealing off of curved shells from rocks under the influence of thermal effects in association with chemical weathering is often termed as exfoliation.
(c) Unloading
Ø This is another process of mechanical weathering where large-scale development of fracturing in confined rock masses is attributed to removal of the overlying rock cover due to prolonged erosional work of other agencies.
Ø These rock masses remain confined from sides but due to relief of pressure from above, they expand upwards; consequently joints develop in them parallel to the uncovered surface dividing them into sheets.
Ø This rupturing or jointing in itself is a mechanical breakdown of rocks and makes them available for further weathering or decay along the joint planes.
Chemical Weathering
Ø It is a process of alteration of rocks of the crust by chemical decomposition brought about by atmospheric gases and moisture.
Ø The chemical change in the nature of the rock takes place in the presence of moisture containing many active gases from the atmosphere such as carbon dioxide, nitrogen, hydrogen and oxygen.
Ø As we know, rocks are made up of minerals all of which are not in chemical equilibrium with the atmosphere around them.
Ø Chemical weathering is, essentially a process of chemical reactions between the surfaces of rocks and the atmospheric gases in the direction of establishing a chemical equilibrium.
Ø The end product of chemical weathering has a different chemical composition and poorer physical constitution as compared to the parent rock.
Ø Chemical weathering eats up the rocks in a number of ways depending upon their mineralogical composition and the nature of chemical environment surrounding them.

(a) Solution
Ø Some rocks contain one or more minerals that are soluble in water to some extent. Rock salt, gypsum and calcite are few common examples.
Ø It is also well known that though pure water is not a good solvent of minerals in most cases, but when it (the water) is carbonated, its solvent action for many common minerals is enhanced.
Ø Thus, limestone is not easily soluble in pure water but carbonated water dissolves the rock effectively. Limestone gets pitted and porous due to chemical weathering.
(b) Hydration and Hydrolysis
Ø These two processes indicate the direct attack of atmospheric moisture on the individual minerals of a rock that ultimately affect its structural make up.
Ø It is believed that though the interior of many minerals is in electric equilibrium, the surfaces of many crystals are not; they may have partially unsatisfied valences.
Ø When polarized water molecules come in contact with such crystals, it may cause any one of the following two reactions:
The ions tend to hold the polarized side of the water molecule and form a hydrate. This process of addition of the water molecule is termed as hydration.
Examples are provided by hydration of iron oxides and **calcium sulphate crystals.**
In some minerals with ferrous iron, the **Fe++** ion holds the water molecule and forms water-iron complex or a hydroxide.
Similarly, Ca50 or anhydrite gets slowly converted to gypsum by hydration:
Ø Ions may be exchanged whereby some ions from water may enter into the crystal lattice of the mineral.
Ø This process of exchange of ions is called hydrolysis.
Ø It is a very common process of weathering of silicate minerals (which are quite abundant in rocks) and is best explained with reference to weathering of mineral Orthoclase, a feispar.
(c) Oxidation and Reduction
Ø Iron is a chief constituent of many minerals and rocks.
Ø The iron bearing minerals (and hence rocks) are especially prone to chemical weathering through the process of oxidation and reduction.
Oxidation. Ferrous iron (Fe++) of the minerals is oxidized to ferric iron (Fe+++) on exposure to air rich in moisture. Ferric iron is not stable and is further oxidized to a stable ferric hydroxide:
Reduction. In specific types of environment, such as where soil is rich in decaying vegetation (swamps), minerals and rocks containing iron oxide may undergo a reduction o the oxides to elemental iron. In this case the decaying vegetation supplies the carbonaceous content causing reduction.
(d) Carbonation
Ø It is the process of weathering of rocks under the combined action of atmospheric carbor dioxide and moisture, which on combination form a mildly reacting carbonic acid.
Ø The acic so formed exerts an especially corrosive action over a number of silicate bearing rocks.
Ø ThE silicates of potassium, sodium and calcium are particularly vulnerable to decay undez conditions of carbonation.
Ø A typical example is that of feispar orthoclase, a very common and important constituent of many igneous, sedimentary and metamorphic rocks, which

decomposes according to following reaction:
(e) Colloid Formation
Ø The processes of hydration, hydrolysis, oxidation and reduction operating on the rocks and minerals under different atmospheric conditions may not always end in the formation of stable end products.
Ø Often they result in splitting of particles into smaller particles- the colloidscharacterized by atoms with only partially satisfied electrical charges.
Formation of colloidal particles is especially common in the weathering of clay minerals, silica and iron oxides.
Spheroidal Weathering
Ø It is a complex type of weathering observed in jointed rocks and characterized with the breaking of original rock mass into spheroidal blocks.
Ø Both mechanical and chemical weathering is believed to actively cooperate in causing spheroidal weathering.
Ø The original solid rock mass is split into small blocks by development of parallel joints due to thermal effects (insolation).
Ø Simultaneously, the chemical weathering processes corrode the borders and surfaces of the blocks causing their shapes roughly into spheroidal contours.
Factors Affecting Weathering
(i) Nature of the Rock
v Rocks vary in chemical composition and physical constitution.
v Some rocks are easily affected by weathering processes in a particular environment whereas others may get only slightly affected and still others may remain totally unaffected under the same conditions.
v Thus of granite and sandstones exposed to atmosphere simultaneously in the same or adjoining areas having hot and humid climate, the sandstone will resist weathering to a great extent because they are made up mainly of quartz (Si0 which is highly weathering resistant mineral.
(ii) Climate
Ø The process of weathering is intimately related to the climatic conditions prevailing in an area.
Ø Same types of rocks exposed in three or more types of climates may show entirely different trends of weathering.
Ø Thus cold and humid conditions favour both chemical and mechanical types of weathering, whereas in totally dry and cold climates, neither chemical nor mechanical weathering may be quite conspicuous (due to absence of moisture).
(iii) Physical Environment
Ø The topography of the area where rocks are directly exposed to the atmosphere also affects the rate of weathering to a good extent.
Ø Rock forming bare cliffs, mountain slopes devoid of vegetation and valley sides is more prone to weathering than same rocks exposed in level lands in similar climates and/or under vegetable cover.
GEOLOGICAL WORK OF WIND
Ø Atmosphere is composed mainly of gases that are collectively known as air. Air in motion is called wind.
Ø In general it may be said that winds are born mainly due to non-uniform heating of the surface of the earth at different places causing differences in atmospheric pressure.
Ø The pressure difference so created makes the atmospheric gases (the air) to move from areas of high pressure to areas of low pressure in the form of winds.

Ø During such a movement, wind may create temporary or semi permanent changes on the land surface.
Ø These changes manifest themselves in the form of some surface features, their exact nature depending on wind volume, wind velocity, nature of the surface over which the wind blows, duration of time for which it blows and so on.
Ø Thus, strong winds blowing over loose ground, dry soils or deserts may create many temporary new features within short span of time whereas very strong wind blowing over vast areas covered with dense vegetation may not affect the original topography at all for any length of time.
Ø Wind acts as agent of erosion, as a carrier for transporting particles and grains so eroded from one place and also for depositing huge quantities of such wind blown material at different places.

Wind Erosion

Wind performs work of erosion by at least three different methods: deflation, abrasion and attrition.

(a) Deflation

Ø By itself, wind possesses not much erosive power over rocks or over the ground covered with vegetation.
Ø But when moving with sufficient velocity over dry and loose sands or bare ground over dust, it can remove or sweep away huge quantity of the loose material from the surface.
Ø This process of removal of particles of dust and sand by strong winds is called deflation. It is the main process of wind erosion in desert regions.
Ø In fact, in some deserts, deflation may cause the removal of sand from a particular location to such an extent that a big enough depression is created, sometimes with its base touching the water table at quite a depth.
Ø Such depressions are variously called blowouts when developed on a small scale and of shallower depth.
Ø Much deeper and extensive depression where the water table is intersected and it gets partially filled up with water is called an OASIS.
Ø Oases are the most sought after locations in deserts for more than one reason: it is only around them that some vegetation may grow and also they sustain temporary or semi permanent shelters.
v **Slack** is another term used for such depressions created by deflation.
The Quattara depression of western Egypt is one of the biggest slacks. It is 300 km long and 150 km wide; its base is 130 m below sea level.
v Another feature produced due to deflation is called a **Hamada**.
v It is a bare rock surface in a desert from over which thin cover of sand has been blown away by strong winds.
v It is also called a desert pavement and may extend for considerable distance in a desert region.

(b) Wind Abrasion

Ø Wind becomes a powerful agent for rubbing and abrading the rock surfaces when naturally loaded with sand and dust particles.
Ø This load is acquired by the strong winds quite easily when blowing over sand dunes in deserts and over the dry ploughed fields.
Ø This type of erosion involving rubbing, grinding, abrading and polishing the rock surfaces by any natural agent (wind, water or ice) with the help of its load while passing over the rocks is termed as abrasion.
Ø **Yardangs**. These are elongated, low-lying ridges forming overhangs

above local depressions.
Ø Yardangs are formed in areas where rocks of alternate hard and soft character are laying one above another with a general gentle slope.

GEOLOGICAL WORK OF STREAMS AND RIVERS

METHODS OF RIVER EROSION

v By erosion is meant disintegration and decomposition of the rocks and soil material by a natural agent through mechanical, chemical and other physicochemical processes accompanied by removal of the disintegrated or decomposed product to far off places by the same agent.

(a) **Hydraulic Action**

Ø It is the mechanical loosening and removal of the material from the rocks due to pressure exerted by the running water.
Ø The higher- the velocity, the greater is the pressure of the running water and hence greater is its capacity to bodily move out parts of the rock or grains of soil from the parent body occurring along its base or sides.
Ø Occurrence of planes of weakness in the rocks such as joints, fissures, cavities and cracks are especially helpful to the running water in carrying out hydraulic action.
Ø The river water flowing with sufficient velocity often develops force strong enough to disintegrate a loose rock, displace the fragments so created and lift them up and move forward as part of bed load.
Ø At places, where some of the out from the bedrock the river bed may develop potholes.

(b) **Cavitations**

Ø It is a distinct and rare type of hydraulic action performed by running water.
Ø It is particularly observed where river water suddenly acquires exceptionally high velocity such as at the location of a waterfall.
Ø It is known that where stream velocity exceeds 12m/sec, the water pressure developed at the impinging points equals vapour pressure.

(c) **Abrasion**

Ø It is the principal method of stream erosion and involves wearing away of the bedrocks and rocks along the banks of a stream or river by the running water with the help of sand grains, pebbles and gravels and all such particles that are being carried by it as load.
Ø These particles, grains and rock fragments moving along with river water are collectively known as tools of erosion.
Ø Abrasion is, in fact, a sort of impact and scour method involving loosening, disintegrating, rubbing, grinding and polishing action of tools on the rocks of the channel.

(d) **Attrition**

Ø Term is used for wear and tear of the load sediments being transported by a moving natural agency through the process of mutual impacts and collusions which they suffer during their transport.
Ø Every part of the sediment in load in suspension or being moved along the bed of the stream receives repeated impacts from other particles.
Ø Due to these mutual collusions, the irregularities and angularities of the particles are worn out. These become spherical in outline and rounded and polished at the surface.

(e) **Corrosion**

Ø The slow but steady chemical (especially solvent) action of the stream water on

the rocks is expressed by the term corrosion.
Ø The extent of corrosion depends much on the composition of rocks and also on the composition of flowing water.
Ø Limestones, gypsum and rock salt bodies are soluble in water to varying degrees. The stream may hardly corrode sandstones, quartzites, granites and gneisses
FEATURES OF STREAM EROSION
1. **Potholes**
Ø These are variously shaped depressions of different dimensions that are developed in the riverbed by excessive localized erosion by the streams.
Ø The potholes are generally cylindrical or bowl shaped in outline and range from a few centimeters to many meters in diameter as well as in depth.
Ø The formation process for a pothole may be initiated by a simple plucking out of a protruding or outstanding rock projection at the riverbed by hydraulic action.
Ø This produces a small depression only at the place of plucking in the otherwise normal bedrock.
Ø Some of the depressions so initiated may eventually become the spots where pebbles and gravels of the stronger rocks are caught in eddies and thrown into a swirling or churning motion.
2. **River Valleys**
Ø A valley may be defined as a low land surrounded on sides by inclined hill slopes and mountains.
Ø Every major river is associated with a valley of its own. In fact, rivers are responsible for the origin, development and modification of their valleys through well- understood processes of river erosion.
Ø For instance, origin and deepening, lengthening and widening of river valleys are often explained as follows.
(a) **Origin**.
Ø A river valley may have a modest origin when traced backwards in the geological history of the area.
Ø On a gently sloping land surface, rain-water gets collected along lower level and flows as small streamlets or rivulets.
Ø In a short time, small gullies are produced where rainwater gets naturally collected from the adjoining slopes. The gullies are, therefore, incipient valleys
Ø Further erosion deepens and widens an original gully that can accommodate bigger volumes of water and thus suffer greater erosion.
Ø In this way a small-scale gully may, with the passage of geological time, eventually grow into a large- scale feature of the same character and may be called a valley.
(b) **Valley deepening**.
Ø It is achieved by cooperative action of all the processes involved in erosion: hydraulic action, abrasion and chemical action or corrosion.
Ø Deepening is obviously caused due to cutting down of the riverbed, which depends to a great extent on the velocity of stream and all the factors controlling the velocity.
(c) **Lengthening of River Valley**.
Ø A peculiar type of is generally held responsible for lengthening of river valleys.
Ø In this process, the streams or rivers are more actively eroding in the higher up regions, close to their points of origin.
Ø Here each stream or river receives a number of tributaries having their origin in the areas away from the point of origin of the main stream.

River Capture (Piracy)
Ø A peculiar phenomenon of capture of drainage basin of one river by another river fast eroding its channel in headward direction has been seen at many places.
Ø In this case the divide between the two rivers say A and B gets eroded at a certain point to such an extent that finally part or whole of water of river B gets diverted to river A through a gap created at the divide by the river A.
Ø The process of river piracy is of considerable significance in the drainage basins of both the rivers in their geological work after the capture.
(d) **Streams achieve valley widening**
Ø The streams cut down their channels and also remove away the loose soil and rocks from the banks thereby widening the valley directly.
Ø This process cannot be expected to have widened their valleys to many times the width of the stream.
Ø As is known, once a small valley is created, the slopes of the valley are always exposed to the secondary processes such as weathering of all types, rain-wash, soil creep and landslides etc.
Ø The combined action of these secondary processes loosens the material from the slopes. This material is passed on to the river flowing down at the base of the valley that carries it away sooner or later.
Ø Thus, rivers contribute to valley widening by actively transporting whatever material is supplied to them from the valley slopes produced there through the processes of mass wasting.
Gorges and Canyons
Ø The process of valley deepening often gives rise to magnificent surface features known as gorges and canyons.
Ø Gorges are very deep and narrow valleys with very steep and high walls on either side. Their length varies considerably, from a few meters to several kilometers at a stretch.
Ø A canyon is a specific type of gorge where the layers cut down by a river are essentially stratified and horizontal in attitude
Valley Profile
Ø Rivers exhibit certain peculiarities about development of their valleys that are best understood with respect to their transverse and longitudinal profiles.
Transverse Profile.
Ø In the mountainous and hilly tracts where a stream flows with very high veloeity ind where flow is often of turbulent character, the valley cross-sections at different places closely resemble to a V-shape .
Ø This may be attributed to down cutting of the river bed at a much faster rate compared to widening of the valley that is achieved mostly by secondary processes of mass wasting which operate comparatively at a slow rate.
Ø Theoretically this deepening process could continue till the base level of that river is achieved. Practically, however, most streams become sluggish much earlier due to reduction in slope channel.
Ø The V-shape of the river valley developed in the initial stages is subject to modification with the passage of time, especially on account of operation of valley widening processes.
Ø A mature river valley, therefore, may show good departure from the original Vshape. It may have a much wider base with very gentle slopes.
Ø Even this mature shape of the river valley may ultimately get worn-out after ages of geological work in the area to almost flat-banks in the old age of the river.

Longitudinal Profile
Ø It may be defined as a curve depicting the course of a stream from its head (place of origin) to its mouth (place of emptying into lake or sea).
Ø For a major river originating from back in the mountains and emptying into a sea, the longitudinal profile is a curve with a steep slope in the hills that gets reduced gradually to flattening lines for the plain region.
Ø For every stream, the main tendency is to achieve a straight longitudinal profile, as near as possible, to the base level of erosion.
(e) **Escarpments**
Ø These are erosional features produced by rivers in regions composed of alternating beds of hard and soft rocks.
Ø The river easily and quickly erodes the soft layers whereas the hard layers resist the erosion and stand projecting as ledges on the sides.
Ø These ledges are gradually undercut by continued stream erosion. A time comes when a given ledge is no longer able to support itself any further and hence falls down in the river giving rise to a steep slope in its place.
Ø It is this steep slope caused by falling of undercut ledge of hard rocks that is referred to as an Escarpment.
Dip Slope
Ø In some cases a stream may succeed in completely eroding the overlying softer rock, thereby fully exposing the underlying hard layer all along its dip (i.e. the angle of inclination of the layer with the horizontal).
Ø The resulting slope is the same as the dip of the layer and becomes in itself a typical erosional feature. It is called a dip slope.
CUESTA
Ø It is the term given to a combined set of escarpment and dip slope occurring adjacently in an area of escarpment topography.
Ø Obviously it results due to prolonged erosion of rocks forming the channel of a river and having been made of alternating hard and soft layers of rocks.
Hogback
Ø It is an erosional feature made by streams and is carved out from very steeply inclined rocks that have proved resistant to erosion.
Ø The hogback is a typically outstanding outcrop of hard rock having erosional slopes on either side.
Mesa and Butte
Ø These are erosional features made up essentially of horizontally layered rocks, having a cap of hard and resistant rocks that have escaped erosion.
Ø Large sized caps are called mesa whereas comparatively small sized and isolated patches are called butte or kopjees.
Ø These features (Mesa and Butte) result in areas of alternating hard and soft layers exposed to river erosion.
Waterfalls
Ø These are defined as magnificent jumps made by stream or river water at certain specific parts of their course where there is a sudden and considerable drop in the gradient of the channel.
Ø In a waterfall, the stream literally falls (instead of flowing) from a considerable height before acquiring normal flow again at a lower level.
Ø Obviously, the velocity of water at the point of fall increases tremendously.
Ø Successive falls of smaller heights are sometimes referred as rapids and cascades.
Ø Many falls are easily attributed to unequal erosion of the channel rocks within a

short distance due to the inherent nature of the rocks.
Ø Thus, as and where the river channel is made up of a width of rock of softer character intervening a rock of sound and strong character, the weaker rock will be eroded much faster, creating a depression just ahead of the resistant ledge.
Ø The water falling from the ledge gains in velocity thereby increasing the erosion of the softer bed below to still higher rates.

Stream Terraces

Ø These are bench like ledges or flat surfaces that occur on the sides of many river valleys. From a distance, they may appear as succession of several steps of a big natural staircase rising up from the riverbank.
Ø They may be made up of hard rock or of soft rock, but the essential thing is that they look like steps.
Ø Some of them are clearly features of river erosion indicating that the stream has cut down its own channel not continuously but in a series of stages.

SEDIMENT TRANSPORT BY RIVERS

Types of Load

The load, as all the material being transported in running water of a stream or river, may thus be distinguished into following three distinct categories:

The Suspended Load

Ø It is made up of fine sand, silt and clay sediments that are light enough to be transported in the stream water in a state of suspension.
Ø This load normally remains lifted up in th stream water and not allowed to touch the base of the channel, due to eddies caused b turbulence in the flow

The Bed Load

Ø This fraction of the river load comprises the heavier particles of sand, pebbles, gravels and cobbles and all the other type of materials, which are moved along the bed of a river in different ways.
Ø In this process, the current lifts up some of the load sediment or material resting on the riverbed temporarily as and when it gains some velocity (e.g. during rams) and carries the same to some distance before it again falls to a rest position.
Ø At the place of its fall, it (the sediment) may succeed in imparting an impact to another resting particle that may be in turn lifted up by the current for some distance.

The Dissolved Load

Ø This fraction includes particles of materials soluble in water, which the river may gain due to its solvent action on the rocks of the channel and some of which may be brought to it by numerous tributaries entering the stream at different places during its seaward journey.

DEPOSITION BY RIVERS

The Process

Ø The entire load of a stream or a river will normally remain in transport unless there is a change in one or other factor responsible for its transport.
Ø Thus, as, when and where there is a decrease in the load carrying capacity of stream due to whatsoever reason, a part or whole of the load may have to be dropped down.
Ø The process of dropping down of its load by any moving natural agent is technically called deposition.
Ø Winds, rivers, glaciers and marine water are important natural agents that make typical deposits on the surface of the earth called aeolian deposits, fluvial deposits, glacial deposits and the marine deposits, respectively.

Types of Fluvial Deposits
Following are some of the typical deposits mentioned only in outline.
Alluvial Fans and Cones.
Ø These are cone shaped accumulations of stream deposits that are commonly found at places where small intermittent streamlets coming down from bill slopes enter the low lands.
Ø Alluvial fans and cones show contrasting patterns in distribution of fragments and particles of various sizes at their apices, peripheries and in the main body.
Ø Further, repeated accumulations over an initial fan or cone contribute to its considerable growth upwards as well as laterally.
Ø Very often, the rivulet may cut out fresh channels within the existing cone or fan and deposit further load ahead of the previous deposit.
Ø This way the deposits grow considerably with time. Quite often some of these deposits stabilize and become locations of villages and cultivable areas.
Flood Plains
Ø Floodwaters are invariably heavily loaded with sediments of all types.
Ø When these waters overflow the river banks and spread as enormous sheets of water in the surrounding areas, their velocity soon gets checked everywhere due to inequalities of the ground, absence of a well defined channel and many other obstructions.
Ø As a consequence, they deposit most of the load as a thick layer of mud, so commonly seen after every major flood.
Ø Since such a process may get repeated after intervals, the low lying areas surrounding major rivers are actually made up of varying thickness of flood deposits.
Ø These are generally level or plain in nature and extensive in area; hence they are aptly called Flood Plains
Two major types of flood plains are recognized:
(a) **Convex Flood Plains**.
Ø The surrounding areas are located at rather lower levels Compared with the river channel and hence give a convex shape to the deposit in a vertical cross section.
Ø The banks of the rivers are generally raised by natural levees and also have swamps in the immediate vicinity.
(b) Flat Flood Plains.
Ø These flood plains appear mostly flat in cross section and are made up mostly of sand and silt sediments.
Deltas
Ø Deltas are defined as alluvial deposits of roughly triangular shape that are deposited by major rivers at their mouths, i.e. where they enter a sea.
Ø Deltas are quite complex in their structure because of operation of a number of factors during their formation, evolution and modification with passage of time.