

A Course Material on
Engineering Geology



By

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QUALITY CERTIFICATE

This is to certify that the e-course material

Subject Code : **CE6301**

Subject : **Engineering Geology**

Class : II Year CIVIL

being prepared by me and it meets the knowledge requirement of the university curriculum.

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SEAL

OBJECTIVES: At the end of this course the students will be able to understand the importance of geological knowledge such as earth, earthquake, volcanism and to apply this knowledge in projects such as dams, tunnels, bridges, roads, airport and harbor as well as to choose types of foundations.

UNIT I PHYSICAL GEOLOGY 9

Geology in civil engineering – branches of geology – structure of earth and its composition – weathering of rocks – scale of weathering – soils - landforms and processes associated with river, wind, groundwater and sea – relevance to civil engineering. Plate tectonics – Earth quakes – Seismic zones in India.

UNIT II MINEROLOGY 9

Physical properties of minerals – Quartz group, Feldspar group, Pyroxene - hypersthene and augite, Amphibole – hornblende, Mica – muscovite and biotite, Calcite, Gypsum and Clay minerals.

UNIT III PETROLOGY 9

Classification of rocks, distinction between Igneous, Sedimentary and Metamorphic rocks. Engineering properties of rocks. Description, occurrence, engineering properties, distribution and uses of Granite, Dolerite, Basalt, Sandstone, Limestone, Laterite, Shale, Quartzite, Marble, Slate, Gneiss and Schist.

UNIT IV STRUCTURAL GEOLOGY AND GEOPHYSICAL METHODS 9

Geological maps – attitude of beds, study of structures – folds, faults and joints – relevance to civil engineering. Geophysical methods – Seismic and electrical methods for subsurface investigations.

UNIT V APPLICATION OF GEOLOGICAL INVESTIGATIONS 9

Remote sensing for civil engineering applications; Geological conditions necessary for design and construction of Dams, Reservoirs, Tunnels, and Road cuttings - Hydrogeological investigations and mining - Coastal protection structures. Investigation of Landslides, causes and mitigation.

TOTAL: 45 PERIODS

TEXT BOOKS: 1. Varghese, P.C., Engineering Geology for Civil Engineering Prentice Hall of India Learning Private Limited, New Delhi, 2012. 2. Venkat Reddy. D. Engineering Geology, Vikas Publishing House Pvt. Lt, 2010. 3. Gokhale KVGK, "Principles of Engineering Geology", B.S. Publications, Hyderabad 2011. 4. Chenna Kesavulu N. "Textbook of Engineering Geology", Macmillan India Ltd., 2009. 5. Parbin Singh. A "Text book of Engineering and General Geology", Katson publishing house, Ludhiana 2009.

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CHAPTER 1

PHYSICAL GEOLOGY

1.1 PRE REQUISTE DISCUSSION

Engineering geology may be defined as that of applied sciences which deals with the application of geology for a safe, stable land economical design and construction of a civil engineering project

1.2 SCOPE OF GEOLOGY IN CIVIL ENGINEERING

- It is defined as that of applied science which deal with the application of geology for a safe, stable and economic design and construction of a civil engineering project.
- Engineering geology is almost universally considered as essential as that of soil mechanics, strength of material, or theory of structures.
- The application of geological knowledge in planning, designing and construction of big civil engineering projects.
- The basic objects of a course in engineering geology are two folds.
- It enables a civil engineer to understand the engineering implications of certain condition should relate to the area of construction which is essentially geological in nature.
- It enables a geologist to understand the nature of the geological information that is absolutely essentially for a safe design and construction of a civil engineering projects.

The scope of geology can be studied is best studied with reference to major activities of the profession of a civil engineer which are

- Construction
- Water resources development
- Town and regional planning

1.3 BRANCHES OF GEOLOGY

Geology is a relatively recent subject. In addition to its core branches, advances in geology in allied fields have lead to specialized sciences like geophysics, geochemistry, seismology, oceanography and remote sensing.

Main and Allied branches of geology:

The vast subject of geology has been subjected into the following branches:

Main Branches

Physical geology
 geology Mineralogy
 geology
 Geophysics
 Geohydrology
 Geochemistry Paleontology
 Economic geology

Structural

Allied Branches

Engineering
 Mining
 Petrology
 geology
 Stratigraphy

Physical geology:

This is also variously described as dynamic geology, geomorphology etc. It deals with:

- i) Different physical features of the earth, such as mountains, plateaus, valleys, rivers, lakes, glaciers and volcanoes in terms of their origin and development.
- ii) The different changes occurring on the earth surface like marine transgression, marine regression, formation or disappearance of rivers, springs and lakes.
- iii) Geological work of wind, glaciers, rivers, oceans, and groundwater and their role in constantly moulding the earth surface features
- iv) Natural phenomena like landslides, earthquakes and weathering.

Mineralogy:

This deals with the study of minerals. Minerals are basic units with different rocks and ores of the earth are made up of.

Details of mode of formation, composition, occurrence, types, association, properties uses etc. of minerals form the subject matter of mineralogy. For example: sometimes quartzite and marble resemble one another in shine, colour and appearance while marble disintegrates and decomposes in a shorter period because of its mineral composition and properties.

Petrology:

Petrology deals with the study of rocks. The earth's crust also called lithosphere is made up of different types of rocks. Hence petrology deals with the mode of formation, structure, texture, composition, occurrence, and types of rocks. This is the most important branch of geology from the civil engineering point of view.

Structural geology:

The rocks, which from the earth's crust, undergo various deformations, dislocations and disturbances under the influence of tectonic forces. The result is the occurrence of different geological structures like folds, fault, joints and unconformities in rocks. The details of mode of formation, causes, types, classification, importance etc of these geological structures form the subject matter of structural geology.

Stratigraphy:

The climatic and geological changes including tectonic events in the geological past can also be known from these investigations. This kind of study of the earth's history through the sedimentary rock is called historical geology. It is also called stratigraphy (Strata = a set of sedimentary rocks, graphy description).

Economic geology:

Minerals can be grouped as general rock forming minerals and economic minerals. Some of the economic minerals like talc, graphite, mica, asbestos, gypsum, magnesite, diamond and gems. The details of their mode of formation, occurrence, classification. Association, varieties, concentration, properties, uses form the subject matter of economic geology. Further based on application of geological knowledge in other fields there is many other allied branches collectively called earth science.

Some of them described here are:

- Engineering geology
- Mining geology
- Geophysics
- Geohydrology
- Geochemistry

Engineering geology:

This deals with the application of geological knowledge in the field of civil engineering, for execution of safe, stable and economic constructions like dams, bridges and tunnels.

Mining geology:

This deals with the application of geological knowledge in the field of mining. A mining engineer is interested in the mode and extent of occurrence of ores, their association, properties etc. It is also necessary to know other physical parameters like depth direction inclination thickness and reserve of the bodies for efficient utilization. Such details of mineral exploration, estimation and exploration are dealt within mining geology.

Geophysics:

The study of physical properties like density and magnetism of the earth or its parts. To know its interior form the subject matter of geophysics. There are different types of geophysical investigations based on the physical property utilized gravity methods, seismic methods, magnetic methods. Engineering geophysics is a branch of exploration geophysics, which aims at solving civil engineering problems by interpreting subsurface geology of the area concerned. Electrical resistivity methods and seismic refraction methods are commonly used in solving civil engineering problems.

Geohydrology:

This may also be called hydrogeology. It deals with occurrence, movement and nature of groundwater in an area. It has applied importance because ground water has many advantages over surface water. In general geological and geophysical studies are together taken up for groundwater investigations.

Geochemistry:

This branch is relatively more recent and deals with the occurrence, distribution, abundance, mobility etc, of different elements in the earth crust. It is not important from the civil engineering point of view.

1.4 WEATHERING

Weathering is defined as a process of decay, disintegration and decomposition of rocks under the influence of certain physical and chemical agencies.

Disintegration:

It may be defined as the process of breaking up of rocks into small pieces by the mechanical agencies of physical agents.

Decomposition:

It may be defined as the process of breaking up of mineral constituents to form new components by the chemical actions of the physical agents.

Denudation:

It is a general term used when the surface of the earth is worn away by the chemical as well as mechanical actions of physical agents and the lower layers are exposed.

The process of weathering depends upon the following three factors:

- i) Nature of rocks

- ii) Length of
- time iii) Climate

Two Chief types of weathering are commonly distinguished on the basis of type of agency involved in the process and nature of the end product. They are:

- i) Physical or mechanical weathering
- ii) Chemical weathering

Physical weathering:

It is the physical breakdown of rock masses under the attack of certain atmospheric agents. A single rock block is broken gradually into smaller irregular fragments and then into particles of still smaller dimensions. It is the most active in cold, dry and higher areas of the earth surface. Temperature variations are responsible to a great extent of physical weathering.

Thermal effects:

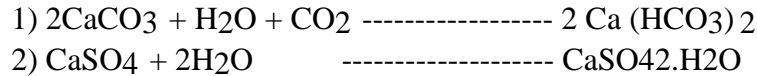
The effect of change of temperature on rocks is of considerable importance in arid and semi arid regions where difference between daytime and nighttime temperature is often very high. Such temperature fluctuations produce physical disintegration in a normally expected manner. Expansion on heating followed by contraction on cooling. When the rock mass is layered and good thickness additional disturbing stresses may be developed into by unequal expansion and contraction from surface to the lower regions. The rock sometimes is found to break off into concentric shells. This process is known as exfoliation.

When weathering occurs part of the disintegrated rock material is carried away by running water or any other transporting agent. Some of them are left on the surface of the bedrock as residual boulders. It is often seen that boulders have an onion like structure. This kind of weathering is called spheroidal weathering.

Chemical weathering:

The chemical decomposition of the rock is called chemical weathering which is nothing but chemical reaction between gases of the atmosphere and minerals of the rocks. The chemical changes invariably take place in the presence of water generally rainwater –in which are dissolved many active gases from the atmosphere like CO₂, nitrogen, Hydrogen etc. These conditions are defined primarily by chemical composition of the rocks humidity and the environmental surrounding the rock under attack.

Chemical weathering is essentially a process of chemical reactions between gases of the atmosphere and the surface rocks. For example:



Engineering importance of rock weathering:

As engineer is directly or indirectly interested in rock weathering specially when he has to select a suitable quarry for the extraction of stones for structural and decorative purposes. The process of weathering always causes a lose in the strength of the rocks or soil.

For the construction engineer it is always necessary to see that:

To what extent the area under consideration for a proposed project has been affected by weathering and
 What may be possible effects of weathering processes typical of the area on the construction materials

1.5 LANDFORM AND PROCESS ASSOCIATED WITH WIND

The earth is surrounded by an envelop of gases called the atmosphere. The movement of the atmosphere in a direction parallel to the earth surface is wind.i.e the air in motion is called wind whereas the vertical movement s of the atmosphere are termed as air currents.

Erosion by wind and developed features:

Wind erosion is generally caused by two erosion processes:

- i) Deflation ii) Abrasion.

Deflation:

Deflation is the process of simply removing the loose sand and dust sized particles from as area, by fast moving winds. Wind deflation can successfully operate in comparatively dry regions with little or no rainfall and where the mantle is unprotected due to absence of vegetation.

Such a removal of loose fine particles may at certain places leave a denuded surface consisting mostly of hard rocks or coarse materials like gravel and is called lag gravel. This gravel layer prevents further deflation.

Abrasion:

The wind loaded with such particles attains a considerable erosive power which helps a considerable er4osive power which helps in eroding the rock surfaces by rubbing and grinding actions and produce many changes. This type of wind erosion is known as abrasion.

Vertical column of rocks are thus more readily worm out towards their lower portions and a result pedestal rocks are formed which wider tops have supported on comparatively narrower bases. Such type of rock formations is called Pedestal or Mushroom rocks.

Transportation by wind:

The total sediment load carried by a wind can be divided into two parts.

- a) Bed load
- b) Suspended load

The larger and heavier particles such as sands or gravels, which are moved by the winds but not lifted more than 30 to 60 cm of the earth surface constitute the bed load. Whereas the finer clay or dust particles which are lifted by the moving winds by a distance of hundreds of meters above the earth's surface constitute the suspended load.

Deposition of sediment by wind and the developed features:

The sediments get dropped and deposited forming what are known as Aeolian deposits. There are two types of Aeolian deposits;

- a) Sand dunes
- b) Loess

Sand dunes:

Sand dunes are huge heaps of sand formed by the natural deposition of wind-blown sand sometimes of characteristic and recognizable shape. Such deposits are often found to migrate from one place to another due to change in the direction and velocity of wind.

The active dunes can be divided into three types:

- a) Barchans or Crescent shaped dunes
- b) Transverse dunes
- c) Longitudinal dunes

Barchans:

These dunes that look like a new moon in plan are of most common occurrence. They are triangular in section with the steep side facing away from the wind direction and inclined at an angle of about 30° to 33° to the horizontal.

The gently sloping side lies on the windward side, and makes an angle of about 10° to 15° with the horizontal. They may have variable sizes, with a generally maximum height of about 335 meters and horn to horn width of say 350 meters.

Transverse Dunes:

A transverse dune is similar to a barchans in section but in plan it is not curved like barchans such that its longer axis is broadly transverse to the direction of the prevailing winds.

Longitudinal dunes:

Longitudinal dunes are the elongated ridges of sand with their longer axis broadly parallel to the direction of the prevailing wind. When seen in the side view they will appear to be triangular on an average they may be 3 m height and 200 m long.

Loess:

The finest particles of dust travelling in suspension with the wind are transported to a considerable distance. When dropped down under favourable conditions these have been found to accumulate in the different constituents the form of paper-thin laminae, which have aggregated together to form a massive deposit known as Loess.

Engineering considerations:

In general no site is selected for any type of important work on the moving dunes because such dunes are always a source of trouble to an engineer. It has been experienced that sometimes the moving dunes damage certain important works. But if an engineer is compelled to select such a site, special methods should be adopted to check the motion of the moving dunes. For ex:

Either to construct windbreaks or growing vegetation on the surrounding areas.

1.6 GROUND WATER

Groundwater hydrology may be defined as the science of the occurrence, distribution and movement of water below the surface of the earth. Ground water is the underground water that occurs in the saturated one of variable thickness and depth below the earth's surface. Groundwater is an important source of water supply throughout the world. Its use in irrigation, industries, urban and rural home continues to increase.

Origin of ground water:

Almost all groundwater can be thought of as a part of hydrologic cycle, including surface and atmospheric waters. Connate water is water entrapped in the interstices of sedimentary rock at the time it was deposited. It may have been derived from the ocean or fresh water sources and typically is highly mineralized. New water of magmatic, almost all ground water can be thought

of as a part of the hydrologic cycle, including surface volcanic or cosmic origin added to the terrestrial water supply is juvenile water.

Ground water constitutes one portion of the earth water circulatory system known as the hydrologic cycle. Water bearing formations, of the earth crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations from the ground surface or from bodies of surface water

After which it travels slowly for varying distances until it returns to the surface by action of natural flow, plants or man. Ground water emerging into surface stream channels aids in sustaining stream flow when surface runoff is low or non-existent. Similarly water pumped from wells represents the sole water source in many regions during much of every year.

All ground water originates as surface water. Principal sources of natural recharge include precipitation, stream flow, lakes and reservoirs. Other contributions known as artificial recharge occur from excess irrigation, seepage from canals and water purposely applied to augment groundwater supplies. Discharge of ground water occurs when it emerges from underground. Most natural discharge occurs as flow into surface water bodies such as streams, lakes and oceans. Flow to the surface appears as spring. Groundwater near the surface may return directly to the atmosphere by evaporation from the soil and by transpiration from vegetation.

Occurrence of ground water:

Ground water occurs in permeable geologic formations known as aquifers. ie, formations having structures that permit appreciable water to move through them under ordinary field conditions. Ground water reservoir and water bearing formation are commonly used synonyms.

An aquitard is a formation, in which only seepage is possible and thus the yield is insignificant compared to an aquifer. It is partly permeable. An aquiclude is an impermeable formation which may contain water but is incapable of transmitting significant water quantities. An aquifuge is an impermeable formation neither containing nor transmitting water.

Porosity:

The portion of a rock or soil not occupied by solid mineral matter may be occupied by groundwater. These spaces are known as voids, interstices, pores or pore space. Because interstices can act as groundwater conduits they are of fundamental importance to the study of groundwater. Typically they are characterized by their size, shape, irregularity and distribution. Original interstices were created by geologic process governing the origin of the geologic formation and are found in sedimentary and igneous rocks. Secondary interstices developed after the rock was formed. Capillary interstices are sufficiently small so that surface tension forces will hold water within them. Depending upon the connection of interstices with others, they may be classed as communicating or isolated. The amount of pore space per unit volume of the aquifer material is called porosity. It is expressed as the percentage of void space to the total volume of the mass

Permeability:

As stated above the ground water is stored in the pores of rock and will hence be available in the ground rocks, only if they are sufficiently porous. The porosity of the rock, thus defining the maximum amount of water that can be stored in the rock. In fact the water can enter into a rock only if the rock permits the flow of water through it, it depends on whether the rock is permeable or not. The size of the pores is thus quite an important factor and it should be sufficiently large to make the rock permeable.

Vertical distribution of groundwater:

The subsurface occurrence of groundwater may be divided into:

- i) Zones of saturation
- ii) Zones of aeration

In the Zones of Saturation water exists within the interstices and is known as the groundwater. This is the most important zone for a groundwater hydraulic engineer, because he has to tap out this water. Water in this zone is under hydrostatic pressure. The space above the water and below the surface is known as the zone of aeration. Water exists in this zone by molecular attraction.

This zone is also divided into three classes depending upon the number of interstices present. The capillary fringe is the belt overlying the zone of saturation and it does contain some interstitial water and is thus a continuation to the zone of saturation while the depth from the surface, which is penetrated by the roots of vegetation, is known as the soil zone.

1.7 EXPLAIN THE CAUSES, CLASSIFICATION OF EARTHQUAKE

The physical forces the surfaces are rearranging rock materials by shifting magmas about altering the structures of solid rocks. The adjustment beneath the surface however involve various crystal movements, some of which because of suddenness and intensity produce tremors in the rocks and they are known as earthquake. The science dealing with the study of earthquakes in all their aspects is called seismology.

Focus and epicenter:

The exact spot underneath the earth surface at which an earthquake originates is known as its focus. These waves first reach the point at the surface, which is immediately above the focus or origin of the earthquake. This point is called epicenter. The point which is diametrically opposite to the epicenter is called anticenter.

Intensity and magnitude:

Intensity of an earthquake may be defined as the ratio of an earthquake based on

actual effects produced by the quakes on the earth.

Magnitude of a tectonic earthquake may be defined as the rating of an earthquake based on the total amount of energy released when the over strained rocks suddenly rebound, causing the earthquake.

Causes of earthquake:

The earthquake may be caused due to various reasons, depending upon its intensity. Following causes of earthquake are important:

1. Earthquakes due to superficial movements:

The feeble earthquakes are caused due to superficial movements, i.e., dynamic agencies, and operation upon surface of the earth.

The dashing waves cause vibrations along the seashore.

Water descending along high water falls, impinges the valley floor and causes vibrations along the neighbouring areas.

At high altitudes the snow falling down is an avalanche, also causes vibrations along the neighbouring areas.

2. Earthquake due to volcanic eruptions:

Most of the volcanoes erupt quietly and as consequence, initiate no vibration on the adjoining area. But a few of them when erupt, cause feeble tremors in the surface of the earth. But there may be still a volcanic eruption may cause a severe vibration on the adjoining area and have really disastrous effects.

3. Earthquake due to folding or faulting:

The earthquakes are also caused due to folding of the layers of the earth's crust. If the earthquakes are caused due to folding or faulting then such earthquakes are more disastrous and are known as tectonic earthquakes and directly or indirectly change the structural features of the earth crust.

Classification of earthquakes:

Earthquakes are classified on a no. of basis. Of these the depth of focus, the cause of origin and intensity are important.

a) Depth of focus:

Three classes of earthquakes are recognized on this basis, shallow, intermediate and deep seated. In the shallow earthquakes the depth of focus lies anywhere up to 50 km below

the surface. The intermediate earthquakes originate between 50 and 300 km depth below the surface.

b) Cause of origin:

- i) Tectonic earthquakes are originated due to relative movements of crystal block on faulting, commonly, earthquakes are of this type.
- ii) Non tectonic earthquakes: that owes their origin to causes distinctly different from faulting, such as earthquakes arising due to volcanic eruptions or landslides.

C) Intensity as basis:

Initially a scale of earthquakes intensity with ten divisions was given by Rossi and Ferrel. Which was based on the sensation of the people and the damage caused. However it was modified by Mercalli and later by Wood and Neumann.

Engineering considerations:

The time and intensity of the earthquake can never be predicted. The only remedy that can be done at the best, it is provide additional factors in the design of structure to minimize the losses due to shocks of an earthquake. This can be done in the following way:

- To collect sufficient data, regarding the previous seismic activity in the area.
- To assess the losses, which are likely to take place in furniture due to earthquake shocks
- To provide factors of safety, to stop or minimize the loss due to severe earth shocks.

Following are the few precautions which make the building sufficiently earthquake proof.

- The foundation of a building should rest on a firm rock bed. Grillage foundations should preferably be provided.
- Excavation of the foundation should be done up to the same level, throughout the building.
- The concrete should be laid in rich mortar and continuously
- Masonry should be done with cement mortar of not less than 1:4 max.
- Flat R.C.C slab should be provided.
- All the parts of building should be tied firmly with each other.
- Building should be uniform height.
- Cantilevers, projections, parapets, domes etc, should be provided.
- Best materials should be used.

CHAPTER 2

MINERALOGY

2.1 PRE REQUISITE DISCUSSION

Inorganic substances which has more or less definite atomic structure and chemical composition

It has constant physical property which are used in the identification of mineral in the field

It can be divided into 2 groups

Rock forming mineral: Which are found in abundance of earth crust

Ore forming minerals: which are economic valuable minerals

MINERAL GROUPS:

MINERAL GROUP	EXAMPLES
Oxides	Quartz, magnetite, haematite, etc
Silicates	Feldspar, mica, hornblende, augite, olivine, etc
Carbonates	Calcite, dolomite, etc
Sulphides	Pyrites, galena, sphalerite, etc
Sulphates	Gypsum
Chlorite	Rock salt, etc

Over 4000 mineral exist in earth crust

All are composed of oxygen, silicon, aluminium, iron, calcium, potassium, sodium and magnesium

2.2 PHYSICAL PROPERTIES OF MINERALS

The following are the important physical properties:

- i) Color
- ii) Streak

- iii) Lustre
- iv) Structure
- v) Hardness
- vi) Specific gravity
- vii) Cleavage
- viii) Fracture
- ix) Tenacity
- x) Form

Color:

Color is not constant in most of the minerals and commonly the color is due to stain or impurities in the minerals some minerals show peculiar phenomena connected with color.

Play of colors: It is the development of a series of prismatic colors shown by some minerals or turning about in light.

Change of colors: It is similar to play of colors that rate of change of colors on rotation is rather slow.

Iridescence: Some minerals show rainbow colors either in their interior or on the surface. This is termed iridescence.

Streak:

The streak, which is the color of the mineral powder, is more nearly constant than the color. The streak is determined by marking unglazed porcelain or simply by scratching it with a knife and observing the color of the powder.

Lustre:

It is the appearance of a fresh surface of a mineral in ordinary reflected light. The following are the important terms used to denote the lustre of

- | | | |
|---------------------------|---|---------------------------------------|
| Classy or vitreous lustre | - | Lustre like a broken glass |
| Metallic lustre | - | When a mineral has lustre like metal. |
| Pearly lustre | - | Lustre like pearls |

Structure:

This is a term used to denote the shape and form of minerals. The following are the important terms used to denote the structures of minerals.

- | | | |
|--------------------|---|--|
| Columnar Structure | - | The mineral has a thick or thin column like structures |
|--------------------|---|--|

- Bladed Structure - The mineral has blade like structure.
- Radiated structure - For columnar of fibrous diverging from central Point
s.
- Lamellar structure - The mineral made of separable plates. Botroidal structure - For an aggregate like bunch of grapes. Reniform structure - For kidney shaped aggregate.

Hardness:

It is the resistance of mineral offers to abrasion or scratching and is measured relative to a standard scale of ten minerals known as Moh's scale of hardness.

Hardness mineral	Name of the
01	Talc
02	Gypsum
03	Calcite
04	Fluorite
05	Apatite
06	Orthoclase
07	Quartz

The scale comprises ten minerals arranged to order of ascending hardness; the softest is assigned a value of 1 and the hardest value of 10. Hardness of any mineral will lie in between these two limits.

Specific gravity:

It may be defined as the density of the mineral compared to the density of water and as such represents a ratio. i.e. specific gravity of a mineral is the ratio of its weight of an equal volume of water. Specific gravity of a mineral depends upon the weight and spacing of its atoms.

Cleavage:

It is defined as the tendency of a crystallized mineral to break along certain definite planes yielding more or less smooth surfaces. Cleavage is related to the internal structure of a mineral. The cleavage planes are always parallel to some faces of the crystal form typical of mineral. It is also described on the basis of perfection or the degree of easiness with which minerals can split along the cleavage planes.

Fracture:

The fractures of a mineral may be defined as the appearance of its broken surface. Common types of fractures are:

Conchoidal fracture	-	The broken surfaces shows concentric rings Or curved surface.
Even fracture flat.	-	When the broken surface is smooth and flat.
Uneven fracture	-	When the mineral breaks with an irregular Surface. It is a common fracture of many Minerals.
Splintery structure	-	When the mineral breaks with a rough.

Tenacity:

Important properties related to tenacity of the minerals are expressed by the terms like balances, flexibility, elasticity, sectility and mellability etc. when a mineral can be cut with a knife it is termed “sectile” and if the slice cut out from it can be flattened under a hammer. It is also said “mellable” “brittle” minerals. Term elastic is used if it regains its former shape as the pressure is released.

2.3 MONOCLINIC SYSTEM

The monoclinic system includes all those forms that can be referred to three crystallographic axes which are essentially unequal in length and further that can be of these is always inclined.

Axial diagram

All the three axes are unequal, they are designated by the letters a, b and c. The c axis is always vertical. The inclined axis is a- axis. It is inclined towards the observer and is also referred as clino axis.

Normal class symmetry

There are three symmetry classes placed in monoclinic system. The symmetry of the normal class is as given below:

a) Axis of Symmetry	1 axis of two fold symmetry only
b) Planes of symmetry	1 plane of symmetry only. And a centre of symmetry. The plane of symmetry is that plane which contains the crystallographic axes a and c

Forms

The common forms of this system are

1) Pinacoid

it is an open form of two faces, each face being parallel to the two axes and cutting the third at a unit length. Three pinacoids are distinguished in the monoclinic system.

2. Domes

A dome is also form of two faces, each face meeting the vertical axis and one of the other two axes. It is a parallel to the third axis. Two types of domes are recognized:

- i) Orthodome
- ii) Clinodome

3. Prisms

There are three types of prisms is there;

- i) Unit prism
- ii) Orthoprism
- iii) Clinoprism

4. Pyramid

These are closed forms and in these each face meets all the three axes.

- i) Unit pyramid
- ii) Orthopyramid
- iii) Clinopyramid

Form:

The internal atomic arrangement of a mineral is manifested outwardly by development of geometrical shapes or crystal characters. The forms may be following three types:

- i crystallized – When the mineral occurs in the form of well defined crystals.
- ii Amorphous - When it shows absolutely no signs or evidence of crystallization.
- iii Crystalline - when well-defined crystals are absent but a marked tendency Towards crystallization.

Miscellaneous:

Some of the special properties are mentioned below:

Magnetism:

Some minerals are highly magnetic, e.g. magnetite, whereas few others may be feebly magnetic like spinels and tourmaline.

Electricity:

Some minerals an electric charge may be developed by heating in some others same effect results by applying pressure.

Fluorescence:

This term express property of some minerals to emit light when exposed to radiation.

Phosphorescence:

It is similar to fluorescence in essential character but in this case light is emitted not during the act of exposure to radiation but after the substance is transferred rapidly to dark place.

2.4 QUARTZ GROUP

It is an important rock forming mineral next to feldspar

It is a non-metallic refractory mineral

It is a silicate group

PHYSICAL PROPERTIES OF QUARTZ:

CRYSTAL SYSTEM: Hexagonal **HABIT:** Crystalline or amorphous

FRACTURE: Conchoidal

HARDNESS: 7

SPECIFIC GRAVITY: 2.65-2.66 (LOW)

STREAK: No

TRANSPARENCY: Transparent/semi-transparent/opaque

POLYMORPHISM TRANSFORMATION:

Quartz, tridymite, cristobalite, melt

COLOURED VARIETIES:

Pure quartz is always colourless and transparent

Presence of impurities the mineral showing colour they

Amethyst: purple or violet

Smoky quartz: shades of grey

Milky quartz: light brown, pure white, opaque

Rose quartz: rose

2.5 FELSPAR GROUP

It is most abundant of all minerals

It is used for making more than 50% by weight crust of earth

It is non-metallic and silicate minerals

CHEMICAL COMPOSITION:

Potash feldspar $KAlSi_3O_8$

Soda-lime feldspar $NaAlSi_3O_8$ (OR) $CaAl_2Si_2O_8$

VARIETIES OF POTASH

FELSPAR: Orthoclase

Sanidine

Microcline

SODA LIME FELSPAR:

Albite

Oligoclase

Andesine

Amarthite

Labrodorie

GENERAL PHYSICAL:

CRYSTAL SYSTEM: monoclinic, triclinic

HABIT: Tabular (crystalline)

CLEAVAGE: Perfect (2- directional)

2.6 PYROXENES GROUP

It is important group of rock forming minerals

They are commonly occur in dark colours, igneous and metamorphic rocks

They are rich in calcium, magnesium, iron, silicates

It show single chain structure of silicate

It is classified into orthopyroxene and clinopyroxene. It is based on internal atomic structure

ORTHOPYROX

ENE: Enstatite

(MgSiO₃)

Hyperthene [(Mg,Fe)SiO₃]

CLINOPYROXENE:

Augite [(Ca, Na) (Mg, Fe, Al) (Al, Si)₂O₆] **Diopside** [CaMgSi₂O₆]

Hedenbergite [CaFeSi₂O₆]

AUGITE:

CRYSTAL SYSTEM: Monoclinic

HABIT: Crystalline

CLEAVAGE: Good (primastic cleavage)

FRACTURE: Conchoidal

COLOUR: shades of greyish green and black

LUSTRE: vitreous

HARDNESS: 5-6

SPECIFIC GRAVITY: medium

STREAK: white

OCCURRENCE: ferro magnesium mineral of igneous rock (dolerite)

USES: rock forming mineral

COMPOSITION: $[(Ca, Na)(Mg, Fe, Al)(Al, Si)_2O_6]$

TRANSPARENCY: Translucent/opaque

2.7 AMPHIBOLE GROUP

These are closely related to pyroxene group

It shows double chain silicate structure

Rich in calcium, magnesium, iron oxide and Mn, Na, K and H

CLASSIFICATION:

1. Orthorhombic
2. Monoclinic
 - a. Hornblende
 - b. Tremolite
 - c. Actinolite

2.8 HORNBLLENDE: (COMPOUND-COMPLEX SILICATE)

CRYSTAL SYSTEM: Monoclinic

HABIT: crystalline

CLEAVAGE:

good (prismatic)

FRACTURE: conchoidal

COLOUR: dark green, dark brown black

LUSTRE: vitreous

HARDNESS: 5 to 6

SPECIFIC GRAVITY: 3 to 3.5 (medium)

STREAK: colourless or white

COMPOSITION: hydrous silicates of Ca, Na,

Mg, Al **TRANSPARENCY:** translucent/opaque

OCCURRENCE: found in igneous rocks

USES: road material

2.9 MICA GROUP

Form sheet like structure

Can be split into very thin sheets along one direction

Aluminium and magnesium are rich

Occupy 4% of earth crust

CHAPTER 3

PETROLOGY

3.1 PRE REQUISTE DISCUSSION

Formation of various type of rock, their mode of occurrence, composition ,textures and structure,geological and geographical distribution on the earth are all studied under petrology.

3.2 IGNEOUS ROCKS

- Ø Rocks that have formed from an originally hot molten material through the process of cooling and crystallization may be defined as igneous rocks.

Important Conditions For The Original Material

- Ø very high temperature and
- Ø a molten state

COMPOSITION

Magma

- 1 The hot molten material occurring naturally below the surface of the Earth is called magma.
- 2 It is called lava when erupted through volcanoes.
- 3 Igneous rocks are formed both from magma and lava.
- 4 It maybe mentioned here that magma is actually a hypothetical melt.
- 5 Lava is a thoroughly studied material that has poured out occasionally from volcanoes in many regions of the world again and again.
- 6 Magma or lava from which igneous rocks are formed may not be entirely a pure melt: it may have a crystalline or solid fraction and also a gaseous fraction thoroughly mixed with it.
- 7 The solid and gaseous fractions, however, form only a small part of the magma or lava, which are predominantly made up of liquid material igneous rock.

Igneous rocks are divided into following three sub-groups

Volcanic rocks

- Ø These are the igneous rocks formed on the surface of the Earth by cooling and crystallisation of lava erupted from volcanoes.
- Ø Since the lava cools down at very fast rate (compared to magma), the grain size of the crystals formed in these rocks is very fine, often microscopic.
- Ø Further, cooling of lava may take place on the surface or even under waters of seas and oceans, the latter process being more common.

Plutonic Rocks

- ∅ These are igneous rocks formed at considerable depths-generally between 7-10 km below the surface of the earth.
- ∅ Because of a very slow rate of cooling at these depths, the rocks resulting from magma are coarse grained.
- ∅ These rocks get exposed on the surface of the earth as a consequence of erosion of the overlying strata.
- ∅ Granites, Syenites, and Gabbros are a few **examples** of Plutonic rocks.

Hypabyssal Rocks

- ∅ These igneous rocks are formed at intermediate depths, generally up to 2 kms below the surface of the earth and exhibit mixed characteristics of volcanic and plutonic rocks.
- ∅ Porphyries of various compositions are **examples** of hypabyssal rocks.

COMPOSITION

Mineralogical composition

- ∅ Igneous rocks like other rock groups are characterised by the abundance of only a few, minerals.

<i>S.No</i>	<i>Mineral</i>	(%)	<i>S.No</i>	<i>Mineral</i>	(%)
(i)	Felspars	59.5	(v)	Titanium	1.5
(ii)	Pyroxenes & Amphiboles	16.8	(vi)	Apatite	0.6
(iii)	Quartz	12.0	(vii)	Accessory Minerals	5.8
(iv)	Biotite	3.8)		

3.2.1 TEXTURES OF IGNEOUS ROCKS

- ∅ The term texture is defined as the mutual relationship of different mineralogical constituents in a rock. It is determined by the size, shape and arrangement of these constituents within the body of the rock.

Factors Explaining Texture

The following three factors will primarily define the type of texture in a given igneous rock:

Degree of Crystallization

Ø In an igneous rock, all the constituent minerals may be present in distinctly crystallized forms and easily recognized by unaided eye, or, they may be poorly crystallized or be even glassy or non-crystallized form.

Ø The resulting rock textures are then described as:

(i) **Holocrystalline**: When all the constituent minerals are distinctly crystallized;

(ii) **Holohyaline**: When all the constituents are very fine in size and glassy or non-crystalline in nature.

Ø The term **merocrystalline** is commonly used to express the intermediate type, *i.e.* when some minerals are crystallized and others are of glassy character in the same rock.

Ø Rocks with **holocrystalline** texture are also termed as phaneric and the holohyaline rocks are referred as aphanitic. The term microcrystalline is used for the textures in which the minerals are perceptibly crystallized but in extremely fine grain.

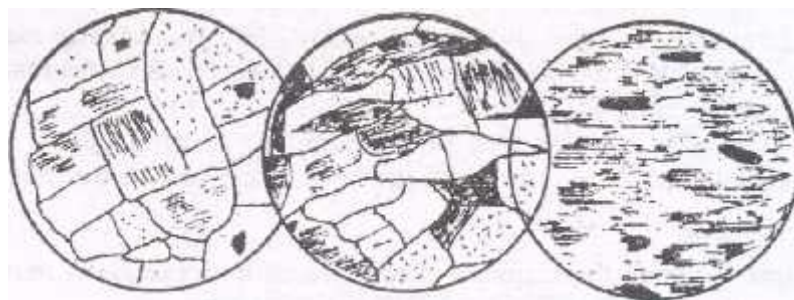
Granularity

Ø The grain size of the various components of a rock are the average dimensions of different constituent minerals which are taken into account to describe the grain size of the rock as a whole. Thus the rock texture is described as :

(i) **Coarse-grained**. When the average grain size is above 5 mm; the constituent minerals

are then easily identified with naked eye.

(ii) **Medium-grained**. When the average grain size lies between 5 mm and 1 mm. Use of magnifying lens often becomes necessary for identifying all the constituent mineral components.



(iii) **Fine-grained.** When the average grain size is less than 1 mm. In such rocks, identification of the constituent mineral grains is possible only with the help of microscope for which very thin rock sections have to be prepared for microscopic studies

Fabric

- ∅ This is a composite term expressing the relative grain size of different mineral constituents in a rock as well as the degree of perfection in the form of the crystals of the individual minerals.
- ∅ The texture is termed as equigranular when all the component minerals are of approximately equal dimensions and as inequigranular when some minerals in the rock are exceptionally larger or smaller than the other.
- ∅ Similarly, the shape or form of the crystals, which is best seen only in thin sections under microscope, may be described as perfect, semi perfect or totally irregular. The textural terms to describe these shapes are, respectively, euhedral, subhedral and anhedral.
- ∅ An igneous rock may contain crystals of anyone type in a predominating proportion; hence its fabric will be defined by one of the following three terms related to fabric:
 - (i) **Panidiomrphi:** when majority of the components are in fully developed shapes;
 - (ii) **Hypidiomorphic:** the rock contains crystals of all the categories: euhedral, subhedral or anhedral;
 - (iii) **Allotriomorphic:** when most of the crystals are of anhedral or irregular shapes

Types of Textures

These can be broadly divided into five categories:

- . Equigranular textures
- . Inequigranular textures
- . Directive textures
- . Intergrowth textures and
- . Intergranular textures.

(1) Equigranular Textures

- ∅ All those textures in which majority of constituent crystals of a rock are broadly equal in size are described as equigranular textures.
- ∅ In igneous rocks, these textures are shown by granites and felsites and hence are also often named as granitic and felsitic textures
- ∅ In the granitic texture, the constituents are either all coarse grained or all medium grained and the crystals show euhedral to subhedral outlines.
- ∅ In the felsitic texture, the rock is micro granular, the grains being mostly microscopic crystals but these invariably show perfect outlines.
- ∅ Thus felsitic textures may be described as equigranular and panidiomrphic.
- ∅ Orthophyric texture is another type of equigranular texture, which is in between

the granitic and felsitic textures. The individual grains are fine in size but not microgranular.

(2) Inequigranular Texture

- Ø Igneous textures in which the majority of constituent minerals show marked difference in their relative grain size are grouped as inequigranular texture.
- Ø Porphyritic and Poikilitic textures are important examples of such textures.
- Ø Porphyritic Texture is characterised by the presence of a few conspicuously large sized crystals (the phenocrysts) which are embedded in a fine-grained ground mass or matrix.
- Ø The texture is sometimes further distinguished into mega-porphyritic and microporphyritic depending upon the size of the phenocrysts.

Difference in molecular concentration

- Ø When the magma is rich in molecules of particular mineral, the latter has better chance to grow into big crystals which may get embedded in the fine-grained mass resulting from the deficient components.

Change in physico-chemical conditions.

- Ø Every magma is surrounded by a set of physico-chemical conditions like temperature, pressure and chemical composition, which influence the trend of crystallisation greatly.
- Ø Abrupt and discontinuous changes in these textures may result in the formation of the crystals of unequal dimensions.
- Ø Thus, magma crystallizing at great depths may produce well-defined, large sized crystals.
- Ø When the same magma (carrying with it these large crystals) moves upward, the pressure and temperature acting on it are greatly reduced.
- Ø Crystallisation in the upper levels of magma becomes very rapid resulting in a fine-grained matrix that contains the big sized crystals formed earlier.

Relative insolubility

- Ø During the process of crystallisation, their crystal grains get enlarged whereas crystals of other soluble constituents get mixed up again with the magma; thus, the relatively insoluble constituents form the phenocrysts
- Ø And the soluble constituents make up the ground mass crystallizing towards the end.

(3) Directive Textures

- Ø The textures that indicate the result of flow of magma during the formation of rocks

are known as directive textures.

- ∅ These exhibit perfect or semi perfect parallelism of crystals or crystallites in the direction of the flow of magma.
- ∅ Trachytic and Trachytoid textures are common examples.
- ∅ The former is characteristic of certain felspathic lavas and is recognised by a parallel arrangement of feldspar crystals; the latter is found in some syenites.

(4) Intergrowth Textures

- ∅ During the formation of the igneous rocks, sometimes two or more minerals may crystallize out simultaneously in a limited space so that the resulting crystals are mixed up or intergrown.
- ∅ This type of mutual arrangement is expressed by the term intergrowth texture.
- ∅ Graphic and granophyric textures are examples of the intergrowth textures.
- ∅ In graphic texture, the intergrowth is most conspicuous and regular between quartz and feldspar crystals. In granophyric textures the intergrowth is rather irregular.

(5) Intergranular Textures

- ∅ In certain igneous rocks crystals formed at earlier stages may get so arranged that polygonal or trigonal spaces are left in between them.
- ∅ These spaces get filled subsequently during the process of rock formation by crystalline or glassy

masses of other minerals.

- ∅ The texture so produced is called an intergranular texture. Sometimes the texture is specifically termed intersertal if the material filling the spaces is glassy in nature.

3.2.2 FORMS OF IGNEOUS ROCKS

An igneous mass will acquire on cooling depends on a number of factors such as

- (a) the structural disposition of the host rock (also called the country rock)
- (b) the viscosity of the magma or lava
- (c) the composition of the magma or lava
- (d) the environment in which injection of magma or eruption of lava takes place.

It is possible to divide the various forms of igneous intrusions into two broad classes:

All those intrusions in which the magma has been injected and cooled along or parallel to the structural planes of the host rocks are grouped as concordant bodies.

Forms of concordant bodies

Sills

- ∅ The igneous intrusions that have been injected along or between the bedding planes or sedimentary sequence are known as sills.
- ∅ It is typical of sills that their thickness is much small than their width and length. Moreover, this body commonly thins out or tapers along its outer margins.
- ∅ The upper and lower margins of sills commonly show a comparatively finer

grain size than their interior portions. This is explained by relatively faster cooling of magmatic injection at these positions

Ø In length, sills may vary from a few centimeters to hundreds of meters

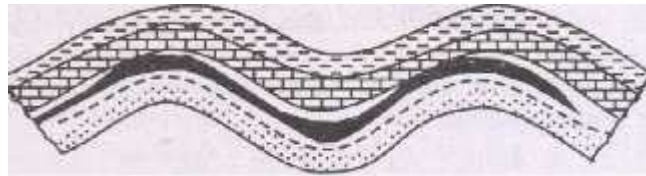
Sills are commonly subdivided into following types:

- (a) **Simple Sills:** formed of a single intrusion of magma;
- (b) **Multiple Sills:** which consist of two or more injections, which are essentially of the same kind of magma;
- (c) **Composite Sills:** which result from two or more injections of different types of magma;
- (d) **Differentiated Sills:** these are exceptionally large, sheet-like injections of magma in which there has been segregation of minerals formed at various stages of crystallisation into separate layers or zones.
- (e) **Interformational Sheets:** the sheet of magma injected along or in between the planes of unconformity in a sequence are specially termed as interformational sheets. These resemble the sills in all other general details.

Ø These are concordant, small sized intrusive that occupy positions in the troughs and crests of bends called folds. In outline, these bodies are doubly convex and appear crescents or half-moon shaped in cross-section.

Ø As regards their origin, it is thought that when magma is injected into a folded sequence of rocks, it passes to the crests and troughs almost passively *i.e.* without exerting much pressure.

Phacoliths



Laccoliths

- Ø These are concordant intrusions due to which the invaded strata have been arched up or deformed into a dome.
- Ø The igneous mass itself has a flat or concave base and a dome shaped top.
- Ø Laccoliths are formed when the magma being injected is considerably viscous so that it is unable to flow and spread for greater distances.
- Ø Instead, it gets collected in the form of a heap about the orifice of eruption. As the magma is injected with sufficient pressure, it makes room for itself by arching up the

overlying strata.

- Ø Extreme types of laccoliths are called bysmaliths and in these the overlying strata get ultimately fractured at the top of the dome because of continuous injections from below.

Lopoliths

- Ø Those igneous intrusions, which are associated with structural basins, that are sedimentary beds inclined towards a common centre, are termed as lopoliths.
- Ø It is believed that in the origin of the lopoliths, the formation of structural basin and the injection of magma are "contemporaneous", that is, broadly simultaneous.

DISCORDANT BODIES

- Ø All those intrusive bodies that have been injected into the strata without being influenced by their structural disposition (dip and strike) and thus traverse across or oblique to the bedding planes etc. are grouped as discordant bodies.
- Ø Important types of discordant intrusions are dykes, volcanic necks and batholiths.
- Ø These may be defined as columnar bodies of igneous rocks that cut across the bedding plane or unconformities or cleavage planes and similar structures.
- Ø Dykes are formed by the intrusion of magma into pre-existing fractures.
- Ø It depends on the nature of magma and the character of the invaded rock whether the walls of the fracture are pushed apart, that is, it is widened or not.
- Ø Dykes show great variations in their thickness, length, texture and composition.
- Ø They may be only few centimeters or many hundreds of metres thick.
- Ø In composition, dykes are generally made up of hypabyssal rocks like dolerites, porphyries and lamprophyres, showing all textures between glassy and phaneritic types.
- Ø **Cone sheets and Ring Dykes** may be considered as the special types of dykes.
- Ø The cone sheets are defined as assemblages of dyke-like injections, which are generally inclined towards common centres.
- Ø Their outcrops are arcuate in outline and their inclination is generally between 30° - 40°.
- Ø The outer sheets tend to dip more gently as compared to the inner ones
- Ø **Ring Dykes** are characterised by typically arcuate, closed and ring shaped outcrops.
- Ø These may be arranged in concentric series, each separated from the other by a screen of country rock.
- Ø They show a great variation in their diameter; their average diameter is around 7

kilometers. Few ring dykes with diameters ranging up to 25 kms are also known.

- Ø **Origin of dykes** It has been already mentioned that dykes are intrusions of magma into pre-existing fractures present in the rocks of the crust.
- Ø These original fractures are generally caused due to tension.
- Ø Their original width might have been much less than the present thickness of the dykes.
- Ø This indicates widening of the cracks under the hydrostatic pressure of magmatic injection.

Volcanic Necks

- Ø In some cases vents of quiet volcanoes have become sealed with the intrusions.
- Ø Such congealed intrusions are termed volcanic necks or volcanic plugs.
- Ø In outline these masses may be circular, semicircular, or irregular and show considerable variation in their diameter. The country rock generally shows an inwardly dipping contact.

Batholiths

- Ø These are huge bodies of igneous masses that s

how both concordant and discordant relations with the country rock.

- Ø Their dimensions vary considerably but it is generally agreed that to qualify as a batholith the igneous mass should be greater than 100 square kilometers in area and its depth should not be traceable. This is typical of batholiths: they show extensive downward enlargement
- Ø In composition, batholiths may be made of any type of igneous rock.
- Ø They also exhibit many types of textures and structures. But as, a matter of observation, majority of batholiths shows predominantly granitic composition, texture and structure.

3.3 IMPORTANT IGNEOUS ROCKS

Granites

- Ø Definition Granites may be defined as plutonic light coloured igneous rocks.
- Ø These are among the most common igneous rocks.
- Ø Composition. Two most common and essential mineral constituents of granite are: Quartz and Felspar.
- Ø Quartz is always recognized by its glassy lustre, high hardness ($H = 7$), and cleavage less transparent white appearance.
- Ø Felspars making granites may be of two varieties: the potash felspars, commonly orthoclase and the soda-bearing felspars like albite and oligoclase.

- Ø Felspar microcline may also be present in some granites.
- Ø Among the accessory minerals in granites, micas deserve first mention. Both varieties (muscovite or white mica and biotite or black mica) are present in small proportions in most apatite, garnet and tourmaline.

Granites are generally coarse to medium grained, holocrystalline (phaneric) and equigranular rocks. Granitic, graphic, porphyritic and intergrowth textures are the most common types of textures met with in granites of different varieties.

- Ø As regards structures, granites occur in large massive bodies, often as batholiths, stocks and bosses beside in usual intrusive bodies like sills and dykes.
- Ø Many types of granites are distinguished on the basis of relative abundance in them of some particular accessory mineral.
- Ø For instance, when white mica, muscovite is present as a prominent accessory mineral, the granite may be distinguished as muscovite granite.
- Ø Similarly, when it is the black mica or biotite, which is a prominent accessory mineral, the granite may be called a biotite-granite. When both the biotite and muscovite are present

Types

- Ø Many types of granites are distinguished on the basis of relative abundance in them of some particular accessory mineral.
- Ø For instance, when white mica, muscovite is present as a prominent accessory mineral, the granite may be distinguished as muscovite granite.
- Ø Similarly, when it is the black mica or biotite, which is a prominent accessory mineral, the granite may be called a biotite-granite. When both the biotite and muscovite are present

Occurrence

- Ø Granites are the most widely distributed igneous rocks in the crust of the earth.
- Ø They occur chiefly as deep-seated intrusive bodies like sills, bosses, stocks and batholiths.
- Ø Their occurrence on the surface of the earth is attributed to prolonged weathering and erosion of the overlying strata through historical times running over millions of years.

Megasacopic Identification. Granites may be identified in hand specimens by their:

- (i) Light-coloured (leucocratic) appearance, such as grey, pink, brownish and yellowish. Some of the shades may take brilliant polish to make it eminently suitable as a decorative building stone.
- (ii) Coarse to medium-grained texture; fine-grained granites are rare specimens.
- (iii) Abundance of quartz and felspar orthoclase as essential minerals.

Use

- Ø Granites find extensive use in architectural and massive construction where they are found in abundance.
- Ø These rocks have been used extensively in monuments and memorials, as columns and steps and as flooring in buildings.

Origin

- Ø Many minor granitic bodies occurring as sills and similar masses are clearly of igneous plutonic origin.
 - Ø Their formation from parent magma through the normal process of cooling and crystallisation is easily accepted.
 - Ø But exceptionally large bodies like batholiths and stocks and bosses running over hundreds of square kilometers close to or on the surface are not accepted by many as simple igneous intrusions mainly because of their extensive dimensions.
 - Ø These large granitic masses are believed by many to have been formed from pre-existing rocks through the process of granitization.

Variations

Following variations appear in the composition of these rocks:

- Ø the relative proportion of quartz (SiO_2) falls gradually so that in diorites it is reduced to a subordinate
- Ø felspar orthoclase, which is a dominant mineral in granites, is reduced in relative amount and replaced by felspar plagioclase in granodiorites.
- Ø In diorites, it is felspar plagioclase that makes the bulk of felspar constituent. A number of rock types get distinguished on the basis of this variation.
- Ø For example, adamellite is a variety of granodiorites that contains felspar orthoclase and plagioclase in equal proportion.

Diorite

Definition.

Ø It is an intermediate type of igneous rock of plutonic origin with silica percentage generally lying between 52-66 per cent.

Composition.

- Ø Diorites are typically rich in felspar plagioclase of sodic group (e.g. Albite).
- Ø Besides plagioclase and alkali feldspars, diorites also contain accessory minerals like hornblende, biotite and some pyroxenes.
- Ø Quartz is not common but may be present in some varieties that are then specially named as quartz-diorites.

Texture.

Ø In texture, diorites show quite close resemblance to granites and other plutonic, rocks. They are coarse to medium grained and holocrystalline.

Occurrence

- Ø Diorites commonly occur as small intrusive bodies like dikes, sills, stocks and other irregular intrusive masses.
- Ø They also get formed at the margins of bigger igneous masses.

Andesite

Definition.

- ∅ These are volcanic rocks in which plagioclase feldspars (sodic and sub-calcic varieties like albite, andesine and labradorite) are the predominant constituents making the potash feldspar only a subordinate member.

Composition.

- ∅ Besides plagioclase and potash feldspars, andesites may contain small amount of quartz as well as biotite, hornblende, augite, olivine and hypersthene from the dark minerals giving them an overall grayish or darker appearance.

Occurrence

- ∅ Andesites are known to be quite abundant volcanic rocks, next only to basalts and may occur as crystallized lava flows of extensive dimensions.
- ∅ Petrologists are sharply divided over the origin of andesites. Some believe them to be the products of normal crystallisation from a mafic magma whereas others think that some andesites may be the products from mixed magmas or magmas enriched with fragments from the wall rocks.
- ∅ The second view is supported by the presence of some foreign materials in andesites.

Syenites**Definition**

- ∅ Syenites are defined as igneous, plutonic, even-grained rocks in which alkali feldspars (including orthoclase and albite) are the chief constituent minerals.
- ∅ They may contain, besides these essential constituents, dark minerals- like biotite, hornblende, augite and some accessories

Composition.

- ∅ The most common feldspars of syenites are orthoclase and albite; microcline, oligoclase and anorthite are also present in them in subordinate amounts.
- ∅ In some syenites, the feldspathoids (nepheline, leucite) also make appearance.
- ∅ Common accessory minerals occurring in syenites are apatite, zircon, and sphene.
- ∅ Quartz so common in granites is altogether absent or is only a minor accessory in syenites.

Texture

- ∅ Syenites show textures broadly similar to those of granites, that is, they are coarse to medium- grained, holocrystalline in nature and exhibiting graphic, inter- grown or porphyritic relationship among its constituents.

Dolerites

Definition.

- Ø These are igneous rocks of typically hypabyssal origin having formed as shallow sills and dykes
- Ø They may be regarded as equivalents of gabbros of plutonic origin and basalts of volcanic origin.

Composition.

- Ø Dolerites are predominantly made up of calcic plagioclase (e.g. anorthite and labradorite).
- Ø Dark minerals like augite, olivine and iron oxide etc. are also present in good proportion in dolerites along with the plagioclase minerals.
- Ø Dolerites are mostly medium to fine grained rocks.
- Ø Ophitic and porphyritic textures are quite common in many dolerites.

Occurrence.

- Ø Sills and dykes of doleritic composition have been recorded at many places associated with magmatic activity.
- Ø In the Singhbhum region of south Bihar, India, many doleritic dykes traverse the Singhbhum granites.

Basalts

Definition

- Ø Basalts are volcanic igneous rocks formed by rapid cooling from lava flows from volcanoes either over the surface or under water on oceanic floors. They are basic in character. .

Composition.

- Ø Basalts are commonly made up of calcic plagioclase feldspars (anorthite and labradorite) and a number of ferro-magnesian minerals like augite, hornblende, hypersthene, olivine, biotite and iron oxides etc.
- Ø In fact many types of basalts are distinguished on the basis of the type and proportion of ferro- magnesian minerals in them.
- Ø Thus, for instance, Basanite is an olivine-rich basalt and Tepherite is an olivine-free type basalt.
The olivine free basalts, that are quite abundant in occurrence, are sometimes named collectively as Tholeiites.

Occurrence.

- Ø Basaltic rocks form extensive lava flows on the continents and also on the oceanic floors in almost all the regions of the world.
- Ø In India, the Deccan Traps, which are of basaltic and related rocks, are spread over more than four hundred thousand square kilometers in Maharashtra,

Gujarat, Madhya Pradesh and adjoining parts of Indian Peninsula.

Pegmatites

- Ø These are exceptionally coarse-grained igneous rocks formed from hydrothermal solutions emanating from magmas that get cooled and crystallized in cavities and cracks around magmatic intrusions.
- Ø These rocks are searched for their containing big sized crystals of minerals. Some of these crystals may be gems and other precious minerals.

Composition

- Ø Pegmatites exhibit great variation in their mineral composition.
- Ø The granite pegmatites contain alkali feldspars and quartz as the dominant minerals. Crystals of some minerals in exceptionally big sizes have been found from pegmatites at many places.

Texture and Structure

- Ø Pegmatites do not show any special textures and structures except that they are invariably coarse grained and mostly inequigranular.
- Ø In many pegmatites, the so-called complex pegmatites, a zonal structure is commonly observed. In such cases, different minerals of pegmatite occur in different zones starting from the periphery and proceeding towards the centre.
- Ø In a five-zoned pegmatite, for instance, the outermost zone is made up of muscovite and feldspar, the second zone is of quartz and feldspar, third zone of microcline and fourth of quartz. The central zone is polymineralic containing albite and spodumene besides quartz and mica.

Origin.

- Ø Petrologically, pegmatites of complex composition are known to occur.
- Ø **First.** Pegmatites have been formed from magmatic melts towards the end of the process of crystallisation, The hydrothermal fractions left behind at this stage are capable of taking in solution all metallic and non-metallic components by virtue of their temperature, pressure and chemical reactivity.
- Ø Most of the granite- and syenite -pegmatites are believed to have been formed through this mode.
- Ø **Second.** Pegmatites have formed due to replacement reactions between the hydrothermal solutions and the country rock through which these liquids happen to pass.

- Ø Hydrothermal liquids at elevated temperatures are considered quite effective in replacing original minerals by new minerals.

Occurrence.

- Ø Pegmatites occur in a variety of forms as dykes, veins, lenses and patches of irregular masses.

Use

- Ø Pegmatites are the source of many precious stones, gems, ores of rare-earths and heavy metals besides the industry grade muscovite mica.

Aplites

- Ø These are igneous rocks of plutonic origin but characterized with a fine-grained, essentially equigranular, allotriomorphic texture.
- Ø Essential minerals of the aplites are the same as that of granites, that is, feldspars and quartz.
- Ø They commonly occur as dykes and are formed from magmas that have different gaseous content compared to magmas from which granites are formed.

Lamprophyre

Texture.

- Ø Panidiomorphic (in which most of crystals show perfect outline), fine grained and holocrystalline.

Composition

- Ø Lamprophyres show a great variation in their mineralogical composition.
- Ø Mostly they are rich in ferro-magnesian silicates. Important minerals forming lamprophyres are:
biotite, augite and other pyroxenes, hornblende and other amphiboles, feldspars and olivine.

Types.

- Ø Many types of lamprophyres are distinguished on the basis of the type of feldspar and the dark minerals occurring in them.
- Ø Thus, Minette is, a lamprophyre containing feldspar orthoclase and the black mica, biotite; Vogesite is another variety having feldspar orthoclase and augite or hornblende.

Peridotites

Definition

- Ø The term peridotite is commonly used to express the ultra-mafic igneous rocks that are highly rich in a ferro-magnesian mineral OLIVINE, which has a composition of $(Mg,Fe)SiO_4$.

The chief characteristics of peridotites are:

- Low silica index;** such rocks invariably contain less than 45% silica.
- High colour index;** rich as they are in dark minerals, the colour index of peridotites is always above 70, generally in the range of 90-100.

Texture. Peridotites are generally massive and coarse grained in texture.

Varieties. A number of types of peridotites are distinguished on the basis of the accessory minerals, *e.g.* hornblende-peridotite, pyroxene-peridotite etc. Kimberlite is a peridotite in which olivine is altered to serpentine.

Occurrence. Peridotites generally form sills and dykes of moderate size.

Origin

- Ø A number of modes of origin have been suggested for peridotites.
- Ø Hess believes them to be the products of primary peridotitic magma, a view that is very strongly objected by many others.
- Ø Another view holds them having been formed from a primary basic (basaltic) magma from which olivine and other mafic minerals were separated by some process.
- Ø A third possibility suggested regards the development of peridotite bodies simply as a result of hydrothermal (pneumatolytic) transport of their material and its subsequent reaction with rocks of appropriate composition.

ENGINEERING IMPORTANCE

- Ø Many of igneous rocks, where available in abundance, are extensively used as materials for construction.
- Ø Granites, syenites and dolerites are characterized by very high crushing strengths and hence can be easily trusted in most of construction works.
- Ø Basalts and other dark coloured igneous rocks, though equally strong, may not be used in residential building but find much use as foundation and road stones.
- Ø The igneous rocks are typically impervious, hard and strong and form very strong foundations for most of civil engineering projects such as dams and reservoirs.
- Ø They can be trusted as wall and roof rocks in tunnels of all types unless traversed by joints. At the same time, because of their low porosity, they cannot be expected to hold oil or groundwater reserves.
- Ø Some igneous rocks like peridotites and pegmatites are valuable as they may contain many valuable minerals of much economic worth.

3.4 BRIEFLY EXPLAIN ABOUT SEDIMENTARY ROCKS

- Ø Sedimentary rocks are also called secondary rocks.
- Ø This group includes a wide variety of rocks formed by accumulation, compaction and consolidation of sediments.
- Ø The sediments may be defined as particles produced from the decay and weathering of pre-existing rocks or may be derived from remains of dead sea or land animals in suitable environments.

- Ø The accumulation and compaction of these sediments commonly takes place under water or at least in the presence of water.

. FORMATION

- Ø The process of formation of sedimentary rocks is ever prevailing.
- Ø The sediments so produced are transported to the settling basins such as sea floors where they are deposited, get compacted and consolidated and finally transformed into a cohesive solid mass.
That is a sedimentary rock.
- Ø Some chemical processes especially evaporation and precipitation regularly operate on surface of water bodies containing dissolved salts and produce solids that settle down in those bodies.
- Ø Sedimentary rocks are broadly grouped into three classes on the basis of their mode of formation: Mechanically formed or Clastic Rocks; Organically formed Rocks and Chemically formed Rocks
- Ø The last two groups are considered as a single class and named as Non-Clastic Rocks.
Clastic (Mechanically Formed) Rocks
- Ø A series of well-defined steps are involved in the formation of clastic rocks.

Decay and Disintegration

- Ø Rocks existing on the surface of the earth are exposed to decay and disintegration by the action of natural agencies like atmosphere, water and ice on them
- Ø The original hard and coherent rock bodies are gradually broken down into smaller and still smaller fragments, grains and particles.
- Ø The disintegrated, loosened material so formed and accumulated near the source is called detritus.
Hence, clastic rocks are often also called as detrital rocks

Transport of Sediments

- Ø The detritus produced from the decay and disintegration of the pre-existing rocks forms the source of the sedimentary rocks but it has to be transported to a suitable place for transformation again into a rock mass.
- Ø The wind, running water and ice in the form of glaciers are the very strong and common agents of transport for carrying millions of tonnes of sediments and particles from one place to another including seas and oceans.
- Ø The winds transport the sediments from ploughed fields, the deserts and dry lands in series of jumps (saltation) and in suspension modes.
- Ø These loads of sediments are dropped down wherever intercepted by rains.

- Ø The mightiest agents of transport of sediments are, of course, streams and rivers, all terminating into lakes or seas.
- Ø The running water bodies transport the sediment load as bed-load, suspended-load and dissolved load, all dumped at the settling basins.
- Ø Ice in the form of huge moving bodies called glaciers also breaks the rocks along their bases and sides (in valley glaciers) and dumps the same at snow lines thereby making large volumes of the clastic load available for further transport by other agencies. It is easy to imagine that millions of tonnes of land mass as scratched by these surface agencies is transported to seas and oceans every year and deposited there.

Dradual deposition

- Ø The sediments as produced through weathering and erosion are transported to settling basins.
These basins may be located in different environments such as on the continents, along the seashores or in deep-sea environments.
- Ø As such sedimentary rocks formed in different environments will show different inherent characters.
- Ø In the continental environments may be included the glacial deposits, the fluvial deposits, the glacio-fluvial deposits and the eolian deposits, each type giving rise to a definite type of sediment accumulation.
- Ø In the marine deposits, some sediments may be dropped just along the sea-shore, or at some shallow depth within the sea or miles away in the deep-sea environment.

Diagenesis

- Ø The process of transformation of loose sediments deposited in the settlement basins to solid cohesive rock masses either under pressure or because of cementation is collectively known as diagenesis.
- Ø It may be achieved by either of the two methods: **welding or cementation**.
- Ø **Welding** is the process of compaction of the sediments accumulated in lower layers of a basin due to the pressure exerted by the load of the overlying sediments.
- Ø This results in squeezing out all or most of the water from in between the sediments, thus bringing them closer and closer and consolidating them virtually in a solid rock mass.
- Ø In fact the degree of packing of sediments in a sedimentary rock is broadly directly proportional to the load of the overlying sediments.
- Ø **Cementation** is the process by which loose grains or sediments in a settlement basin get held together by a binding material.
- Ø The binding material may be derived from within the accumulated particles or

the fluids that percolate through them and also evaporate or precipitate around those particles thus binding them in a rock like mass.

. Chemically Formed (Non-clastic) Rocks

- Ø Water from rains, springs, streams, rivers, lakes and underground water bodies dissolves many compounds from the rocks with which it comes into contact.
- Ø In most cases all these dissolved salts are carried by the running water to its ultimate destination the sea.
- Ø Hence the brackish or saltish taste of the sea water.
- Ø In many other cases also, the local water-bodies may get saturated with one or other dissolved salt.
- Ø In all cases, a stage maybe reached when the dissolved salts get crystallized out either through evaporation or through precipitation.
- Ø Thus, limestone may be formed by precipitation from carbonated water due to loss of carbon dioxide.
- Ø Rock salt may be formed from sodium-chloride rich seawater merely by the process of continued evaporation in bays and lagoons.
- Ø Chemically formed rocks may be thus of two types: precipitates and evaporites. Examples are lime stones, rock salt, gypsum, and anhydrite.

Organically Formed (Non-clastic) Rocks

- Ø These extensive water bodies sustain a great variety of animal and plant life.
- Ø The hard parts of many sea organisms are constituted chiefly of calcium and/or magnesium, carbonates.
- Ø Death and decay of these organisms within the water bodies gradually results into huge accumulations of carbonate materials, which get compacted and consolidated in the same manner as the normal sediments.
- Ø Lime stones are the best examples of organically formed sedimentary rocks

TEXTURES

(i) Origin of Grains

- Ø A sedimentary rock may be partially or wholly composed of clastic (or allogenic) grains, or of chemically formed or organically contributed parts.
- Ø Thus the rock may show a clastic texture or a non-clastic texture.

(ii) Size of Grains

- Ø The grain size in the sedimentary rocks varies within wide limits.
- Ø Individual grains of less than 0.002 mm and more than 250 mm may form a part or whole of these rocks.

Three textures recognized on the basis of grain size are:

Coarse -grained rocks;	average grain size > 5 mm
Medium grained rocks;	average grain size between 5 and 1 mm.
Fine-grained rocks;	average grain size < 1 mm

(iii) Shape of Grains

- ∅ The sediments making the rocks may be of various shapes: rounded, sub rounded, angular and sub angular.
- ∅ They may show sphericity to various degrees.
- ∅ Roundness and sphericity are the indications of varying degree of transport and abrasion suffered during that process.
- ∅ Thus, Breccias are made up mostly of rough and angular fragments indicating least transport and abrasion.
- ∅ Conglomerates are full of rounded and smooth-surfaced pebbles and gravels indicating lot of transport and rubbing action during their transport before getting deposited and consolidated into a rock mass.

(iv) Packing of Grains.

- ∅ Sedimentary rocks may be open-packed or porous in textures or densely packed depending upon their environment of formation.
- ∅ The degree of packing is generally related to the load of the overlying sediments during the process of deposition.

(v) Fabric of Grains

- ∅ A given sedimentary rock may contain many elongate particles.
- ∅ Their orientation is studied and described in terms of orientation of their longer axes.
- ∅ If all or most of the elongated particles are arranged in such a way that their longer axes lie in the same general direction, the rock is said to show a high degree of preferred orientation. This direction is generally indicative of the direction of flow of the current during the period of deposition.

(vi) Crystallisation Trend

- ∅ In sedimentary rocks of chemical origin, the texture is generally defined by the degree and nature of crystallized grains.
- ∅ Rocks may show perfectly interlocking grains giving rise to crystalline granular texture or they may be made up of non-crystalline, colloidal particles when they are termed as amorphous.

3.5 IMPORTANT SEDIMENTARY ROCKS**1. Breccia**

- ∅ It is a mechanically formed sedimentary rock classed as Rudite.
- ∅ It consists of angular fragments of heterogeneous composition embedded in a fine matrix of clayey material.
- ∅ The fragments making breccia are greater than 2mm average diameter but some times these may be quite big in dimensions.
- ∅ The angularity of the fragments indicates that these have suffered very little or even no transport after their disintegration from the parent rocks. On the basis of

their source, following types of breccia are commonly recognized:

✓ **Basal Breccia**

This rock is formed by the sea waters advancing over a coastal region covered with fragments of chert and other similar rocks. The advancing waters supply the fine mud, which is spread over the rock fragments and acts as a binding material. Once the seawater retreats, the loose chert fragments get cemented together as breccia rocks.

✓ **Fault Breccia**

This rock is also called crush-breccia. Such rocks are so named because they are made up of angular fragments that have been produced during the process of faulting. The fragments so produced due to crushing effect of the block movements subsequently get embedded in clay and other fine material (often also derived during the faulting process and called gouge) and ultimately form a cemented rock the crush-breccia.

✓ **Agglomeratic Breccia**

It is a specific type of breccia containing angular and sub angular fragments derived from volcanic eruptions.

It may also contain some fused material that has been cemented together with the solid material broken and thrown out of the craters.

2. Conglomerates

Definition

- Ø These are sedimentary rocks of clastic nature and also belong to rudaceous group.
- Ø They consist mostly of rounded fragments of various sizes but generally above 2mm. cemented together in clayey or ferruginous or mixed matrix.
- Ø The roundness of gravels making the rock is a useful characteristic to differentiate it from breccia in which the fragments are essentially angular.
- Ø The roundness indicates that the constituent gravels have been transported to considerable distances before their deposition and transformation into conglomerate rock.

Types

On the basis of the dominant grade of the constituent gravels in following three types:
 Boulder-Conglomerates Cobble-Conglomerate Pebble-Conglomerate (gravels > 256mm) (gravels: 64-256 mm) (gravels: 2-64 mm)

On the basis of *source* of the gravels, as

- (i) **Basal-conglomerates** Having gravels derived from advancing sea-waves over subsiding land masses;

(ii) **Glacial-conglomerates** In which gravel making the conglomerates are distinctly of glacial origin;

(iii) **Volcanic-conglomerates** In which gravels are of distinct volcanic origin but have subsequently been subjected to lot of transport resulting in their smoothening and polishing by river transport before their deposition and compaction or cementation.

On litho
logical basis

(a) **Oligomictic** Simple in composition, these gravels are made up of quartz, chert and calcite;

(b) **Polymictic**. In these conglomerates the constituent gravels are derived from rocks of all sorts: igneous, sedimentary and metamorphic, all cemented together. The so-called Fanglomerates are conglomerates formed and found at the base of alluvial fans and cones.

3. Sandstones

Ø Sandstones are mechanically formed sedimentary rocks of Arenaceous Group.

Ø These are mostly composed of sand grade particles that have been compacted and consolidated

together in the form of beds in basins of sedimentation.

Ø The component grains of sandstones generally range in size between 2mm and 1/16 mm. Silica in the form of very resistant mineral QUARTZ is the dominant mineral constituent of most sandstones.

Composition.

Ø Quartz (SiO₂) is the most common mineral making the sandstones. In fact some varieties of sandstone are made up entirely of quartz.

Ø Besides quartz, minerals like feldspars, micas, garnet and magnetite may also be found in small proportions in many sand stones composition.

Texture.

Ø Sandstones are, in general, medium to fine-grained in texture.

Ø The component grains show a great variation in their size, shape and arrangement in different varieties.

Thus, when the texture is determined on the basis of the grade of the component grains, three types are recognized:

Type:	Coarse-grain	Medium-grain	Fine -grain
Size-range:	2 mm-1/2 mm	1/2 mm-1/4 mm	1/4 mm-1/16 mm

Colour

- Ø Sandstones naturally occur in a variety of colours: red, brown, grey and white being the most common colours.
- Ø The colour of sandstone depends on its composition, especially nature of the cementing material.
For example, presence of iron oxide is responsible for the red, brown and yellow shades;
presence of glauconite gives a greenish shade to the sandstones.

Types

On the basis of their composition and the nature of the cementing material.

Siliceous Sandstones

- Ø Silica (SiO_2) is the cementing material in these sandstones.
- Ø Sometimes the quality of the siliceous cement is so dense and uniform that a massive compact and homogeneous rock is formed.
- Ø This is named QUARTZITE. This type of sedimentary quartzite, when subjected to loading fractures across the grains showing clearly very dense nature and homogeneity of the cementing silica with the main constituent silica of the rock.

Calcareous Sandstones. are those varieties of sandstones in which carbonates of calcium and magnesium are the cementing materials.

Argillaceous Sandstones These are among the soft varieties of sandstone because the cementing material is clay that has not much inherent strength.

Ferruginous Sandstones As the name indicates, the cementing material is an iron oxide compound. On the basis of mineralogical composition

Arkose.

- Ø This is a variety of sandstone that is exceptionally rich in felspar minerals besides the main constituent quartz.
- Ø It is believed that these rocks are formed due to relatively quick deposition of detritus derived from weathering and disintegration of crystalline igneous and metamorphic rocks like granites and gneisses respectively.
- Ø Arkose rock generally occurs in horizons that can be genetically related to some crystalline massifs occurring in close neighbourhood.

Greywacke.

- Ø These are broadly defined as grey coloured sandstones having a complex mineralogical composition.
- Ø They contain a fine-grained matrix. In this matrix, grains of quartz and some felspars are found embedded side by side with fragments of rocks like felsites, granites, shales etc.

∅ The exact composition of the matrix is so complex that it may not be easily determined in most cases.

Flagstone

∅ It is a variety of sandstone that is exceptionally rich in mica dispersed in parallel or sub parallel layers.

∅ The abundance as well as arrangement of mica, typically muscovite, renders the stone weak and easily splitting. Hence its use in load bearing situations is not recommended.

Freestone.

∅ It is a massive variety of sandstone that is rich in quartz and does not contain bedding planes or any mica. It is compact, dense, massive and a strong rock suitable for construction demanding high crushing strength.

∅ Ganister. It is another type of sandstone consisting of angular and sub angular quartz grains and cement of secondary quartz with some kaolin.

Uses

∅ Sandstones of hard, massive and compact character are very useful natural resources.

∅ They are most commonly used as materials of construction: building stones, pavement stones, road stones and also as a source material for concrete.

∅ The Red Fort of India is made up of red sandstones.

Distribution.

∅ Next to shales, sandstones are the most abundant sedimentary rocks found in the upper 15 km of the crust and make an estimated 15 percent of total sedimentary rocks of the earth.

4. Shale

∅ Shale is a fine-grained sedimentary rock of argillaceous (clayey) composition.

∅ Shales are generally characterized with a distinct fissility (parting) parallel to the bedding planes and are made up of very fine particles of silt grade and to some extent of clay.

∅ Besides fissility, some shales show the laminated structure.

Composition

∅ The exact mineralogical composition of shales is often difficult to ascertain because of the very fine size of the constituents.

∅ shales are very intimate mixtures of quartz, clay minerals and accessory minerals like oxides of iron, carbonates, and organic matter.

∅ Silica and clay minerals together make more than seventy percent of shales in most cases.

∅ Chemically speaking, shales exhibit still greater variation.

Average Chemical Composition of Shales

S.N	Oxide	% age	S.No	Oxide	%age
1	-	58%	5	Ca	3%
2	SiO ₂	15%	6	O	3%
3	Al ₂ O ₃	6%	7	K ₂ O	1%
4		2%	8	Na ₂ O	5%

Types

Ø Shales have been classified variously. Three Classes On The Basis Of Their Origin: .

Residual Shales:

These are formed from decay and decomposition of pre-existing rocks followed by compaction and consolidation of the particles in adjoining basins without much mixing:.

Transported Shales:

These are deposits of clastic materials of finer dimensions transported over wide distances before final settlement in basins of deposition.

Hybrid Shales

In such shales, materials derived both from clastic sources and non clastics especially those from organic sources make up the rock.

on the basis of their mineralogical composition:

Quartz shales: rich in free quartz content.

Felspathic shales: in which feldspars and clay minerals predominate; silica becomes a secondary constituent. **Chloritic shales:** in these shales, minerals of chlorite group and clay-group make the bulk of the shales. **Micaceous shales:** these are rich in muscovite mica and other flaky and clay minerals.

3.6 LIMESTONES

Definition

Ø These are the most common sedimentary rocks from the non-clastic-group and are composed chiefly of carbonate of calcium with subordinate proportions of carbonate of magnesium.

Ø They are formed both bio-chemically and mechanically.

Composition

Ø Pure limestone is invariably made up of mineral calcite (CaCO₃).

Ø In terms of chemical composition, limestone's are chiefly made up of CaO and CO₂, Magnesium Oxide is a common impurity in most limestone's; in some its percentage may exceed 2 percent, the rock is then called magnesian limestone.

Ø Other oxides that may be present in limestone are: silicon dioxide, ferrous and ferric oxides (or carbonates); and aluminium oxide. Strontium oxide is also present in some limestone's as a

trace element.

Texture.

- Ø The most important textural feature of limestone's is their fossiliferous nature.
- Ø Fossils in all stages of preservation may be found occurring in limestone's.
- Ø Other varieties of limestone's show dense and compact texture; some may be loosely packed and highly porous; others may be compact and homogeneous.
- Ø Concretionary texture is also common in limestone's.

Types.

- Ø Many varieties of limestone's are known.
- Ø Broadly speaking these can be divided into two groups: autochthonous and allochthonous.
- Ø Autochthonous includes those varieties which have been formed by biogenic precipitation from seawaters.
- Ø Allochthonous types are formed from the precipitated calcareous sediments that have been transported from one place to another where they were finally deposited.

Following are common types of limestones.

Chalk.

- Ø It is the purest form of limestone characterised by fine-grained earthy texture. Common colour of chalk is white. Some chalks may be exceptionally rich in the remains of very small sea organisms called foraminifera.

Shelly Limestone.

- Ø Also called fossiliferous limestone, it has a rich assemblage of fossils that are fully or partly preserved. When the limestone is made up entirely of fossils, it is termed coquina.

Argillaceous Limestone

- Ø These limestones contain clay as a significant constituent and are clearly of allochthonous origin.
- When the clay and carbonate fractions are present in almost equal proportions, the rock is termed marl.

Lithographic Limestones

- Ø These are compact massive homogeneous varieties of pure limestones that find extensive use in litho- printing.

Kankar

- Ø It is a common nodular or concretionary form of carbonate material formed by evaporation of subsoil water rich in calcium carbonate just near the soil surface.
- Ø It is non-marine in origin.

Calc-Sinter.

- Ø It is a carbonate deposit formed by precipitation from carbonate rich spring waters.

Ø These deposits are also known as travertine or calc-tuffa and commonly occur around margins of Hot Springs.

DOLomite

Definition.

- Ø It is a carbonate rock of sedimentary origin and is made up chiefly more than 50 percent - of the mineral dolomite which is a double carbonate of calcium and magnesium with a formula of $\text{CaMg}(\text{CO}_3)_2$.
- Ø Ferrous iron is present in small proportions in some varieties.
- Ø Gypsum also makes appearance in some dolomites.
- Ø But the chief associated carbonate is that of calcium, in the form of calcite.

Texture

- Ø Dolomite shows textures mostly similar to limestones to which it is very often genetically related.
- Ø In other varieties, dolomites may be coarsely crystalline, finely crystalline or showing interlocking crystals.

Formation.

- Ø Dolomites are formed in most cases from limestones by a simple process of replacement of Ca^{++} ions by Mg^{++} ions through the action of Mg^{++} ion rich waters.
- Ø This ionic replacement process is often termed dolomitization
- Ø The replacement may have started shortly after the deposition of limestone or quite subsequent to their compaction.
- Ø **Direct precipitation** of dolomites from magnesium rich waters is also possible.
- Ø Such directly precipitated deposits of magnesium carbonate occur in association with gypsum, anhydrite and calcite.
- Ø It is believed that in such cases, it is the calcite, which is precipitated first, depleting the seawater of CaCO_3 and enriching it with MgCO_3 .
- Ø The $\text{CaMg}(\text{CO}_3)_2$ precipitates at a later stage.
- Ø Dolomitization by replacement method, however, is believed to be the most common method of formation of dolomites.

Occurrence

- Ø Dolomite is a widespread sedimentary rock and is found commonly associated with limestones.
- Ø It forms intervening layers between limestone formations spread over wide areas.
- Ø Also, it may occur at the extended boundaries of many limestone deposits.
- Ø These indicate locations where 'magnesium rich ground waters could have an easy access for the replacement process to take place in an original limestone" rock.
- Ø Dolomite is so closely related to limestone in composition, texture, structure and physical properties that it may not always be easily possible to differentiate between the two rocks in hand specimens.

7. Coals

Definition.

- Ø These may broadly be defined as metamorphosed sedimentary rocks of carbonaceous character in which the raw material has mostly been supplied by plants of various groups.
- Ø The original raw material passes through many biomechanical and biochemical processes before it becomes a coal in technical terms;

Formation.

- Ø In most cases coals represent carbonized wood.
- Ø The process of coal formation involves a series of stages similar to formation of sedimentary rocks such as wastage of forests and transport of the wood material through different natural agencies to places of deposition, accumulation of the material in huge formations.
- Ø Its burial under clays and other matter and its compaction and consolidation under superimposed load.
- Ø Biochemical transformation of the organic matter so accumulated starts and is completed under the influence of aerobic and anaerobic bacteria available at the place of deposition.
- Ø The degree of carbonification depends to a great extent on the time and type of environment in which the above processes have operated on the source material giving rise to different varieties of coal.

Types

Peat.

- Ø It is the lowest grade coal that consists of only slightly altered vegetable matter. It may not be even considered as a coal. It has very low calorific value, high percentage of moisture and is rich in volatile matter.

Lignite.

- Ø It is also known as brown coal and forms the poorest grade of coal with calorific value ranging between 6300-8300 B.th.V.
- Ø It is compact and massive in structure with an upper specific gravity of 1.5 and hardness of 2.5 on Mohs' Scale of Hardness.
- Ø Some varieties of lignite may still show to a good extent the traces of original vegetable structure.

Bituminous Coals

- Ø These form a broad group of common coals having essential properties varying within wide limits.
- Ø The fixed carbon ranges between 69-78 per cent and the calorific value between 9,500 B.th.V to 14,000 B.th.V.
- Ø Their common character is that they contain enough volatile matter, which makes them quite soft on heating, and they start agglomerating.
- Ø Some of bituminous coals may contain volatile matter to such a high extent as 30 per

cent of their bulk.

Anthracite

- Ø It is considered the highest-grade coal with fixed carbon ranging between 92-98 per cent.
- Ø It has highest calorific value in coals and burns almost without any smoke, as the volatile matter is negligible.

Occurrence

- Ø Coals of different varieties are found to occur almost in all countries of the world, though in varying proportions.
- Ø Coals form all-purpose fuels, some varieties being more suitable for specific industrial uses.

8. Iron Ores of Sedimentary Origin

- Ø The iron ores form beds or layers of variable thickness that occur interstratified with other sedimentary rocks.
- Ø Sedimentary iron deposits are regarded having formed chiefly as chemical precipitates in the form of oxides, carbonates and silicates from marine waters rich in corresponding salts.
- Ø Metasomatic replacement has also been suggested as another important process for formation of many iron ore deposits.
- Ø It is also suggested that certain type of bacteria play considerable role in the precipitation of iron.

9. Gypsum

- Ø It is a sedimentary rock composed of the mineral of the same name-gypsum, which has a composition of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.
- Ø Its common colour is white but it may also occur in other shades such as yellow, red or dark grey due to impurities present in the rock.
- Ø Gypsum is formed in nature as a result of evaporation from sea-waters rich in sulphate salts.

ANHYDRITE is a granular aggregate of mineral anhydrite, CaSO_4 and is genetically related to the mineral gypsum: hydration of anhydrite results in gypsum.

These rocks are commonly associated in occurrence

Uses: Gypsum finds extensive uses in many industries, e.g.

- (i) as a raw material in the manufacture of fertilizers;
- (ii) as an essential ingredient in the manufacture of Cement;
- (iii) in the manufacture of Plaster of Paris.
- (iv) as fire proofing component of gypsum boards.

10. Rock Salt

- Ø It is also a sedimentary rock composed of mineral halite (NaCl).
- Ø The texture of rock salt varies from coarse-grained crystalline to fine-grained massive.
- Ø The purest rock salt is white in colour but it may occur in various other shades as

grayish and reddish due to presence of impurities

- Ø Rock salt occurs in many parts of the world interbedded with other sedimentary formations.
- Ø It is commonly associated with other evaporites.
- Ø Subsidence of the basin of deposition during the process of evaporation has been suggested by some as a possible explanation.

11. Flint and Chert

- Ø Flint is a dark coloured sedimentary rock of siliceous composition consisting chiefly of halcedony and extremely fine-grained quartz.
- Ø It occurs commonly as concretions or nodules in chalk (limestone) deposits.
- Ø Chert is also a sedimentary rock composed of cryptocrystalline silica showing great variety of colours.
- Ø It is more common in occurrence compared to flint and occurs in the form of beds or layers within limestones and other deposits.

Their origin may be due to any of following two causes:

(a) Primary Precipitation.

- Ø It is believed that under special environments chert gets precipitated inorganically from seawater rich in amorphous silica.
- Ø The theory is yet considered inadequate because modern seawaters are generally quite under saturated with amorphous silica.

(b) Replacement.

- Ø Waters containing amorphous silica from siliceous skeletal sources are thought to have replaced lime stones forming concretions and nodules of flint by the process of replacement.

12. Tillite

- Ø It is a sedimentary rock of glacial origin.
- Ø It is characterised by a structure less matrix that has fragments of various sizes, shapes and composition embedded in it.
- Ø Most of these embedded fragments bear striations and other evidence of their transport by glaciers before their deposition and compaction.
- Ø The name is derived from the fact the rock is merely a compacted and consolidated form of the glacial debris called till.
- Ø The matrix or ground mass of the till is generally of grey to greenish appearance whereas the embedded fragments are of extremely heterogeneous character.

ENGINEERING IMPORTANCE

- Ø Sedimentary rocks cover a great part of the crust of the earth; they make up more than 75 percent of the surface area of the land mass.
- Ø It is with these types of rocks that an engineer has to deal with in majority of cases.
- Ø It is, therefore, essential for a civil engineer to know as much as is possible about the salient features of these rocks.
- Ø He has to see, for instance, if such rocks would withstand loads under heavy

construction and also, if they could be trusted in cuts and tunnels in highway construction and also as reservoirs.

- Ø They are the most important rocks to act as natural reservoirs of oil and ground water supplies.

3.7 METAMORPHIC ROCKS

METAMORPHISM

METAMORPHISM is the term used to express the process responsible for all the changes that take place in an original rock under the influence of changes in the surrounding conditions of temperature, pressure and chemically active fluids.

METAMORPHIC ROCKS

Definition

- Ø Metamorphic rocks are defined as those rocks which have formed through the operation of

Stress Minerals

various types of metamorphic processes on the pre-existing igneous and sedimentary rocks involving changes in textures, structures and mineralogical compositions.

- Ø The direction of change depends upon the type of the original rock and the type of metamorphic process that operates on the rock.
- Ø Heat, pressure and chemically active fluids are the main agents involved in metamorphic processes.
- Ø Plastic deformation, recrystallisation of mineral constituents and development of parallel orientation are typical characters of metamorphic rocks.

MINERALOGICAL COMPOSITION

Metamorphic rocks exhibit a great variation in their mineralogical composition that depends in most cases on

- (i) the composition of the parent rock;
- (ii) the type and degree of metamorphism undergone by the rock.

Two broad groups of minerals formed during metamorphism are:

- ✓ Stress minerals and
- ✓ Anti-stress minerals

Stress minerals

- Ø The minerals, which are produced in the metamorphic rocks chiefly under the stress factor, are known as stress minerals.
- Ø They are characterised by flaky, platy, lamellar, flattened and elongated forms. **Examples:**

kyanite, staurolite, muscovite, chlorite and some amphiboles.

Anti-Stress Minerals

- ∅ These are metamorphic minerals produced primarily under the influence of temperature factor.
- ∅ Such minerals are generally of a regular equidimensional outline. **Examples:** sillimanite, olivine, cordierite and many pyroxenes

Textures of Metamorphic Rocks

These can be broadly grouped under two headings:

(a) Crystalloblastic

- ∅ Textures which include all those textures that have been newly imposed upon the rock during the process of metamorphism and are, therefore, essentially the product of metamorphism.

(b) Palimpsest (Relict)

- ∅ Textures that include textures which were present in the parent rock and have been retained by the rock despite metamorphic changes in other aspects.
- ∅ Among the crystalloblastic textures, Porphyroblastic and Granoblastic types are most common. outlines) of stronger minerals.
- ∅ In the granoblastic texture, the rock is made of equidimensional recrystallised minerals without there being any fine grained ground mass.
- ∅ Palimpsest textures are similar in essential details as in the parent rock with little or no modifications taking place during metamorphism.
- ∅ These are described by using the term *blasto* as a prefix to the name of the original texture retained by the rock.

3.7.1 CLASSIFICATION OF METAMORPHIC ROCKS

- ∅ Metamorphic rocks have been variously classified on the basis of texture and structure, degree of metamorphism, mineralogical composition and mode of origin etc.
- ∅ A very general two-fold classification based on the presence or absence of layered structure or

FOLIATION as defined above is as follows:

(a) Foliated Rocks

- ∅ All metamorphic rocks showing development of conspicuous parallelism in their mineralogical and structural constitution falling under the general term foliation are grouped together as foliated rocks.
- ∅ The parallelism indicating features include slaty cleavage, schistosity and gneissose structures
- ∅ Typical rocks included in this group are slates, phyllites, schists and gneisses of great variety.

(b) Non-Foliated Rocks

- ∅ Included in this group are all those metamorphic rocks characterised with total or nearly total absence of foliation or parallelism of mineralogical constituents.

- Ø Typical examples of non-foliated rocks are quartzites, hornfels, marbles, amphibolites and soapstone etc.

IMPORTANT METAMORPHIC ROCKS

Definition

- Ø Slate is an extremely fine-grained metamorphic rock characterized by a slate cleavage by virtue of which it can be readily split into thin sheets having parallel smooth surfaces.
- Ø The slaty cleavage is due to parallel arrangement of platy and flaky minerals of the slate under the dominant stresses operating during the process of metamorphism.

Composition

- Ø Mineralogically, slate is made up of very fine flakes of mica, chlorite and microscopic grains of quartz, feldspar, oxides of iron and many other minerals, all of which cannot be easily identified even under microscope because of their fine grain size.

Origin.

- Ø Slate is a product of low-grad regional metamorphism of argillaceous rock: like clays and shales.
- Ø When slate is subjected to further action of dynamothermal metamorphism, recrystallisation leads to the development in number and size of some minerals, especially micas.
- Ø Such metamorphic rocks with conspicuous micaceous constituents and general slaty appearance are termed **PHYLLITES**.

Uses.

- Ø Slate is used locally (where available) for construction purpose as a roofing and paving material only.

Schists:

Schists are megascopically crystalline foliated metamorphic rocks characterised by a typical schistose structure.

The constituent flaky and platy minerals are mostly arranged in parallel or sub parallel layers or bands.

Texture and Structure

- Ø Most varieties are coarsely crystalline in texture and exhibit a typical schistose structure.
- Ø Quite a few types show lineation and porphyroblastic fabric.

Composition

- Ø Platy and rod-like acicular minerals form the bulk of most of the schists.
- Ø Micas (both muscovite and biotite), chlorite, hornblende, tremolite, actinolite and kyanite are quite common constituents of most of the schists
- Ø Quartz and feldspars are comparatively rare but not altogether absent.

- Ø Porphyroblasts of granular minerals like staurolite, garnet and andalucite make their appearance in many schists.

Varieties

- Ø Specific names are given to different types of schists on the basis of predominance of anyone or more minerals.
- Ø Thus some commonly found schists are: muscovite schists, biotite schists, sericite- schist, tourmaline- schist etc.
- Ø Sometimes schists are grouped into two categories on the basis of degree of metamorphism as indicated by the presence of index minerals:

a) Low-grade schists

- Ø Formed under conditions of regional metamorphism at low temperature.
- Ø These are rich in minerals like albite, muscovite and chlorite that are unstable at high temperature.
- Ø **Examples** Mica-schist, chlorite-schist and talc-schist are a few from this group.

b) High-grade schists

- Ø These are formed under conditions of regional metamorphism and are rich in minerals that are stable at high temperatures such as andalusite, cordierite, gamet, staurolite and sillimanite etc.
- Ø Gamet-schists, cordierite-schists and stal'rolite-schists are common examples.

Origin

- Ø Slates and Schists are generally the product of dynamothermal metamorphism of argillaceous sedimentary rocks like clays and shales.
- Ø These indicate the final and stable stage in the metamorphism of shales through the intervening stages of slates and phyllites.

GNEISS Definition

- Ø A gneiss is a megascopically crystalline foliated metamorphic rock characterised by segregation of constituent minerals into layers or bands of contrasting colour, texture and composition.
- Ø A typical gneiss will show bands of micaceous minerals alternating with bands of equidimensional minerals like feldspars, quartz and garnet etc.

Composition

- Ø Gneisses are generally rich in the minerals of parent rocks that are simply recrystallised during the process of metamorphism.
- Ø Feldspar and quartz are more common in gneisses than in schists.
- Ø Dark minerals of pyroxene and amphibole groups are also common, as are the typical metamorphic minerals like staurolite, sillimanite, gamet, kyanite and epidote etc.

Texture and Structure

- Ø Gneisses show a variety of textures and structures, the most common being coarsely crystalline texture and the gneissose structure.
- Ø Augen-gneisses show a typical cataclastic structure in which the hard minerals are flattened and elongated.

Varieties

Important types are:

- Ø **Orthogneiss** formed as a result of metamorphism of granites and other igneous rocks.
 - Ø **Paragneiss** these are formed from the metamorphism of sedimentary rocks like sandstones;
 - Ø **Banded gneiss** typical gneiss in which the tabular and flaky minerals are segregated in very conspicuous bands of alternating dark and light colours.
- Ø Gneisses of all varieties are generally the result of advanced stages of metamorphism of a variety of parent rocks such as sandstones, conglomerates, granites and rhyolites etc.
- Ø There is difference of opinion on the origin of the granitic gneisses; their mineralogical composition is close to granites but in structure they appear more metamorphic.

Uses

- Ø Compact, dense and massive varieties of gneisses find applications as road stones and in some cases as building stones.

QUARTZITE

Definition

- Ø Quartzites are granular metamorphic rocks composed chiefly of inter sutured grains of quartz.
- Ø The name Orthoquartzite is used for a sedimentary rock of similar composition but having a different (sedimentary) origin, in which quartz grains are cemented together by siliceous cement.

Composition

- Ø Besides quartz, the rock generally contains subordinate amounts of micas, feldspars, garnets and some amphiboles which result from the recrystallisation of some impurities of the original sandstone during the process of metamorphism.

Origin

- Ø Metamorphic quartzites result from the recrystallisation of rather pure sandstones under the influence of contact and dynamic metamorphism.

Uses

- Ø The rock is generally very hard, strong, dense and uniformly grained.
- Ø It finds extensive use in building and road construction.

MARBLE

Definition

- Ø Marble is essentially a granular metamorphic rock composed chiefly of recrystallised limestone (made of mineral calcite).
- Ø It is characterized by a granular texture but the grain size shows considerable variation in different varieties;
- Ø It varies from finely spheruloidal to highly coarse grained. Marbles often show a banded structure also; coarse varieties may exhibit a variety of structures.

Composition

- ∅ Small amounts of many other granular minerals like olivine, serpentine, garnet and some amphiboles are also present in many varieties, which are derived from the impurities present in the original limestone during the process of metamorphic recrystallisation.

Varieties

- ∅ Various types of marble are distinguished on the basis of their colour, composition and structure.
White marble, pink marble and black marble are known on the basis of their colours, which is basically due to fine dispersion of some impurity.
- ∅ Dolomitic marble is a variety distinguished on the basis of composition; it may show slightly schistose structure.

Origin

- ∅ Marble is formed from contact metamorphism of carbonate group of sedimentary rocks: pure white marble results from pure limestone; coloured marbles from those limestones that have some impurities and dolomitic marbles from magnesian limestones.

Uses

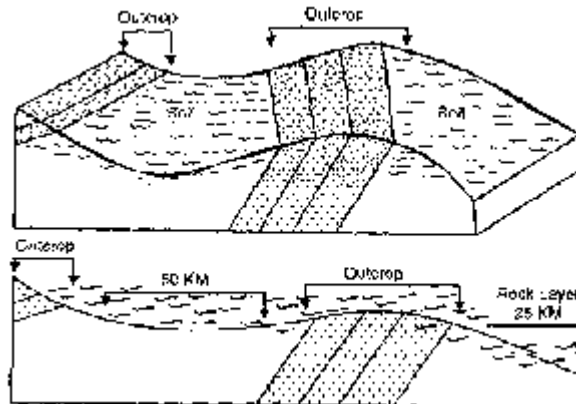
- ∅ Marble is commonly used in the construction of palatial and monumental buildings in the form of blocks, slabs, arches and in the crushed form as chips for flooring.
- ∅ Because of its restricted occurrence and transport costs, it is mostly used as ornamental stone in costly construction.

CHAPTER 4 STRUCTURAL GEOLOGY AND GEOPHYSICAL METHODS

4.1 OUTCROP

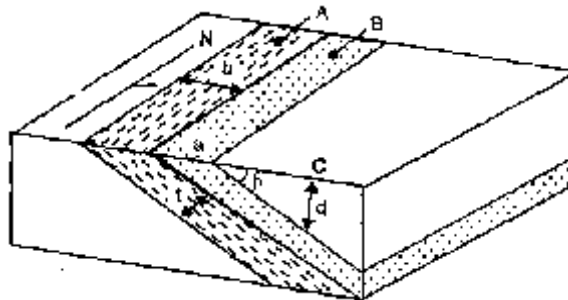
In the mountainous and sub-mountainous tracts and also in shallow plains, exposures of rocks may be easily seen forming sides of valleys or caps of hills or even uplands and slopes in level fields.

An **outcrop** is simply defined as an exposure of a solid rock on the surface of the earth.



Outcrop Dimensions

- ∅ The **width or breadth** of the outcrop of a particular bed is given by the distance between the top and bottom edges of the bed as measured on the surface of the ground in a direction perpendicular to the strike of that particular bed
- ∅ Many variations are induced in the breadth of an outcrop of a rock by the topography of the area.
- ∅ The **thickness** of a particular layer or bed is the perpendicular distance between the top and bottom surface of the same layer as seen in a vertical section at right angles to the strike of the layer



- ∅ The **depth** to a particular layer or bed at any place from the surface, if

believed to be present on the basis of general geology and dip of the formation, is given by the perpendicular distance between the ground surface and the top surface of that particular layer.

- Ø When the ground surface is horizontal, depth d to the bedrock of known dip may be obtained by the relationship

$$d = AC \times \tan \beta$$

- Ø where β is the angle of true dip of the bed exposed at a place, say at B and C is the distance from that exposure to the place C where it is desired to find out depth to that bedrock.

4.2 FOLDS

Definition

- Ø FOLDS may be defined as undulations or bends or curvatures developed in the rocks of the crust as a result of stresses to which these rocks have been subjected from time to time in the past history of the Earth.

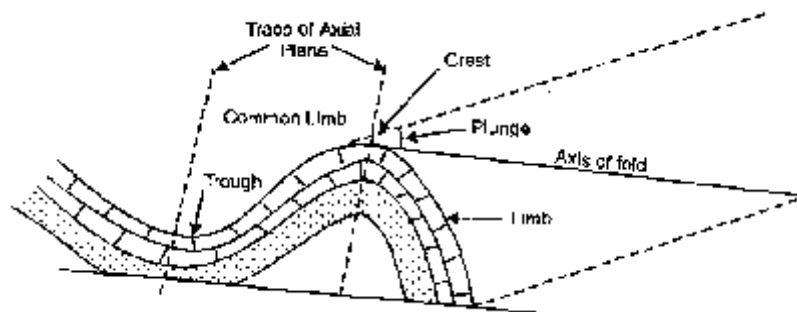
Development of folds

- Ø The folds may develop in any type of rock and may be of any shape and geometry ranging from simple up arched bends or downward curvatures to completely overturned flexures.
- Ø The ultimate shape and extent of a fold depends upon a number of factors like the nature, magnitude and the direction of and duration for which these forces act upon the rocks and also the nature of the rocks being effected.
- Ø The process of development of folds in the rocks is called **Folding**.
- Ø It is a very slow geological process and indicates an effort of the rocks in a particular environment to adjust themselves to the changing force fields operating on, within or around them.
- Ø Folding is a ductile type of deformation experienced by the rocks compared to the brittle deformation where the rocks actually get broken and displaced when stressed.

4.2.1 PARTS OF A FOLD

Limbs

- Ø These are the sides or flanks of a fold. An individual fold will have a minimum of two limbs but when the folds occur in groups, as they very often do, a middle limb will be common to two adjacent folds.



Hinge

- ∅ In a folded layer, a point can be found where curvature is maximum and one limb ends and the other limb starts from that point. This is the **hinge point**.
- ∅ When rocks occur in a sequence and their all hinge points are joined together, they make a line, called the **hinge line**.

Axial surface

- ∅ When the hinge line is traced throughout the depth of a folded sequence a surface is obtained which may be planar or non-planar. It is referred to as axial surface

Axial plane

- ∅ Axial plane is the imaginary plane that passes through all the points of maximum curvature inclined or horizontal in nature.
- ∅ A fold surface is planar in nature; otherwise it is in a folded sequence.
- ∅ It may be vertical, is sometimes called a planar fold if the axial is a non-planar fold.

Axis of a fold

- ∅ It is simply defined as a line drawn parallel to the hinge line of a fold.
- ∅ A more precise definition of an axis of a fold would be the line representing the intersection of the axial plane of a fold with any bed of the fold.

Plunge of a fold

- ∅ The angle of inclination of the fold axis with the horizontal as measured in a vertical plane is termed the plunge of the fold.

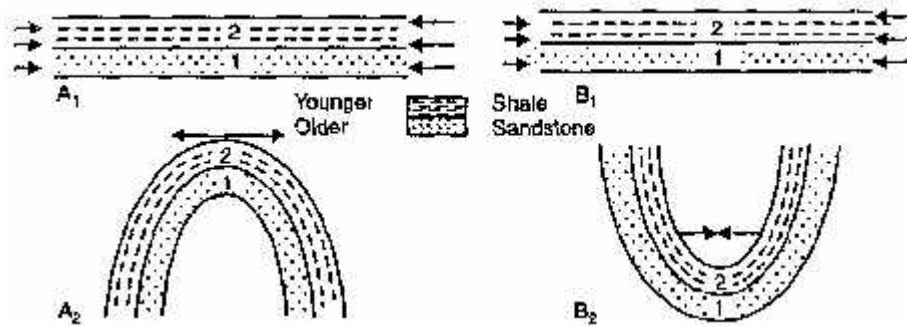
Crest and Trough.

- ∅ Most folds are variations of two general forms; uparched and downarched bends. The line running through the highest points in an uparched fold defines its crest.
- ∅ A corresponding line running through the lowest point in a downarched fold makes its trough. The crest and trough may or may not coincide with the axis of the fold.

4.2.2 CLASSIFICATION OF FOLDS

Anticlines are defined as those folds in which

- 🚩 the strata are uparched, that is, these become CONVEX UPWARDS;
- 🚩 the geologically older rocks occupy a position in the interior of the fold, oldest being positioned at the core of the fold and the youngest forming the outermost flank,
- 🚩 the limbs dip away from each other at the crest in the simplest cases.



Synclines

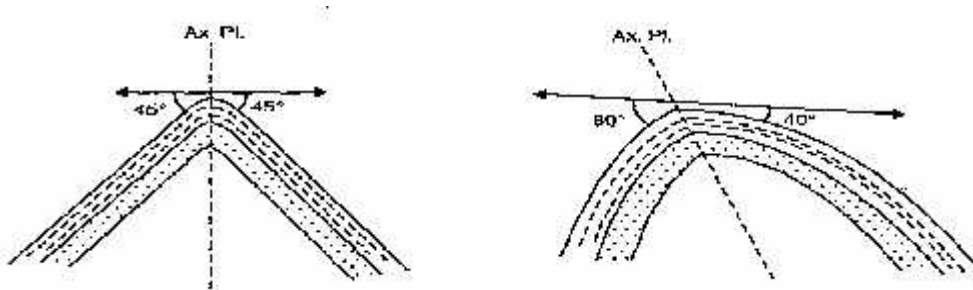
- the strata are downarched, that is, these become CONVEX DOWNWARDS;
- the geologically younger rocks occupy a position in the core of the fold and the older rocks form the outer flanks, provided the normal order of superposition is not disturbed,
- in the simplest cases in synclines, the limbs dip towards a common center.

Position of Axial Plane

Depending upon the nature and direction of the stresses the axial plane in a resulting fold may acquire any position in space, that is, it may be vertical, inclined or even horizontal. Following main types are recognized on the basis of position of the axial plane in the resulting fold:

Symmetrical Folds

- Ø These are also called normal or upright folds. In such a fold, the axial plane is essentially vertical.
- Ø The limbs are equal in length and dip equally in opposite directions.
- Ø it may be an anticline or syncline and when classified, may be described as symmetrical anticline/ syncline as the case may be.

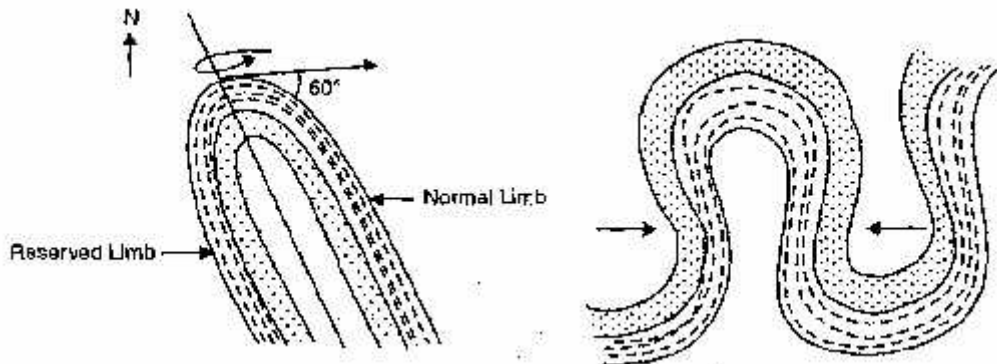


Asymmetrical Folds

- Ø All those folds, anticlines or synclines, in which the limbs are unequal in length and these dip unequally on either side from the hinge line are termed as asymmetrical folds.

Overturned folds

- Ø These are folds with inclined axial planes in which both the limbs are dipping essentially in the same general direction.
- Ø The amount of dip of the two limbs may or may not be the same.
- Ø Overfolding indicates very severe degree of folding.
- Ø One of the two limbs (the reversed limb) comes to occupy the present position after having suffered a rotation through more than 90 degrees.
- Ø The other limb is known as the normal limb.

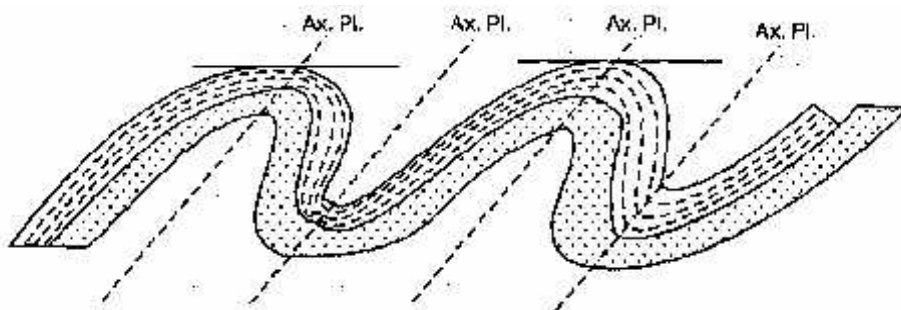


Ø In certain cases, both the limbs of a fold may get overturned because of very high lateral compression.

- Ø It may be originally either an anticline or a syncline but the extreme compression from opposite sides results in bringing the limbs so close to each other that the usual dip conditions may get reversed —anticlinal limbs dip towards each other and the synclinal limbs dip away from each other.
- Ø Such a type of fold is commonly referred to as a fan fold
- Ø In such folds, the anticlinal tops are said to have opened up into a broad, fan-shaped outline due to intense compression in the lower region.

Isoclinal Folds

- Ø These are group of folds in which all the axial planes are essentially parallel, meaning that all the component limbs are dipping at equal amounts.
- Ø They may be made up of series of anticlines and synclines



Recumbent Folds

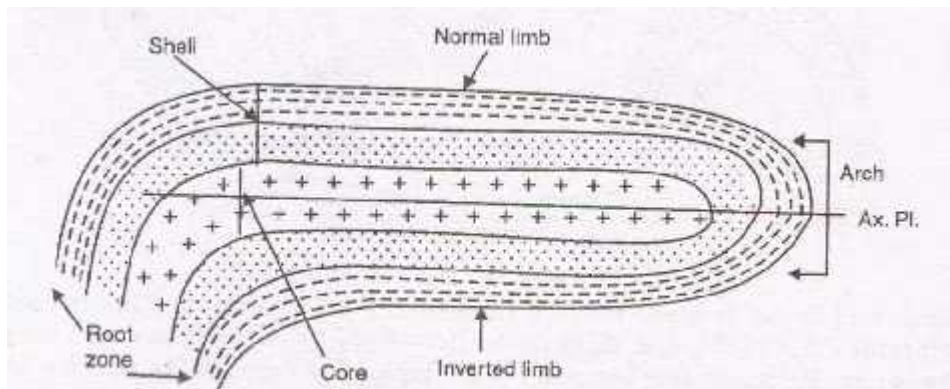
- Ø These may be described as extreme types of overturned folds in which the axial plane acquires an almost horizontal attitude.
- Ø In such folds, one limb comes to lie exactly under the other limb so that a drill hole dug at the surface in the upper limb passes through the lower limb also.
- Ø The lower limb is often called the inverted limb or the reversed limb.
- Ø Other parts of a recumbent fold are sometimes named as follows:

the arch, which is zone of curvature corresponding to crest and trough in the upright folds;

the shell, which is the outer zone made up mostly of sedimentary formations;

the core, which is the innermost part of the fold and maybe made mostly of crystalline igneous or metamorphic rocks;

the root or the root zone, which is the basal part of the fold and may or may not be easily traceable; once traced it can throw light whether the fold was originally an anticline or syncline that has suffered further inversion.

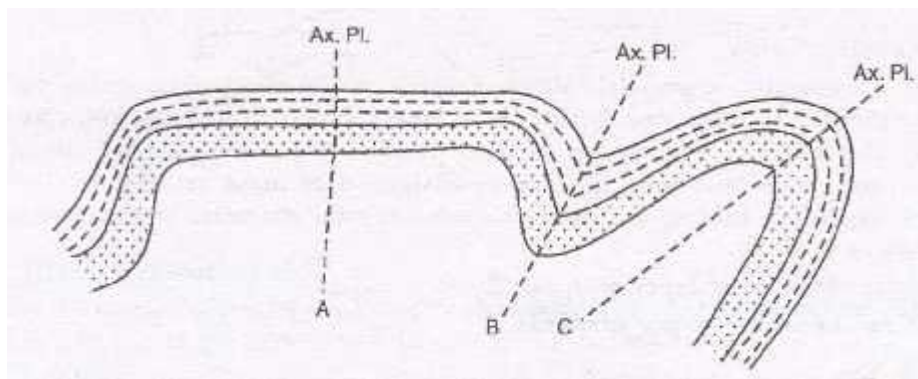


Conjugate Folds

In certain cases a pair of folds that are apparently related to each other may have mutually inclined axial planes.

Such folds are described as conjugate folds.

The individual folds themselves may be anticlinal or synclinal or their modifications.



Box Fold

It may be described as a special type of fold with exceptionally flattened top and steeply inclined limbs almost forming three sides of a rectangle.

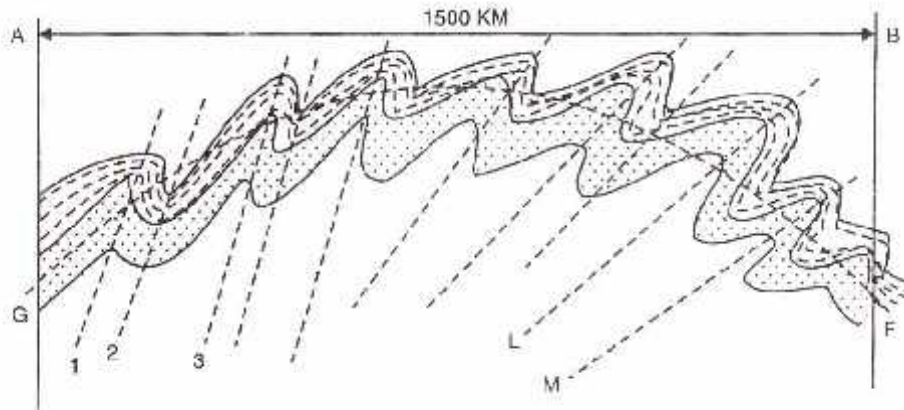


Fig. 6.23. A-B Anticlinorium

- Ø In both the anticlinorium and synclinorium, presence of large number of secondary folds, faults and fracture systems is a characteristic feature.
- Ø Similar folding but signifying still larger bending and uplifting of strata on sub-continental scales is expressed by the terms GEANTICLINES AND GEOSYNCLINES respectively.
- Ø Great importance is attached to the major depressions, the geosynclines, in the process of mountain building discussed elsewhere.
- Ø The geosynclines are believed to serve as depositional fields or basins of sedimentation to which sediments derived by the erosion of the adjoining gentilities get accumulated and compacted.
- Ø This material is then compressed and uplifted in the second stage of orogeny, to gradually take the shape of mountain systems.

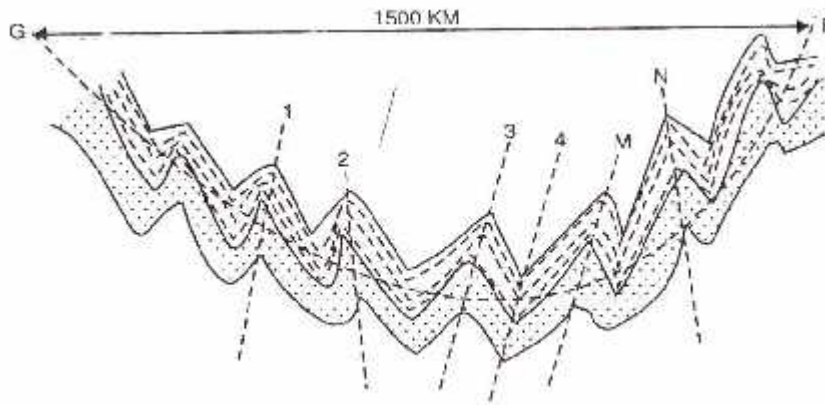


Fig. 6.23. G-F Synclinorium

4.2.3 CAUSES OF FOLDING

The Tectonic Folding may be due to any one or more of the following mechanisms:

Folding Due to Tangential Compression

Lateral Compression is believed to be the main cause for throwing the rocks of the crust into different types of folds depending upon the types of rocks involved in the process and also the direction and magnitude of the compression effecting those rocks.

In general, this primary force is believed to act at right angles to the trend of folds. under the influence of the tangential stresses, folding may develop in either of the three ways: flexural folding, flowage folding and shear folding.

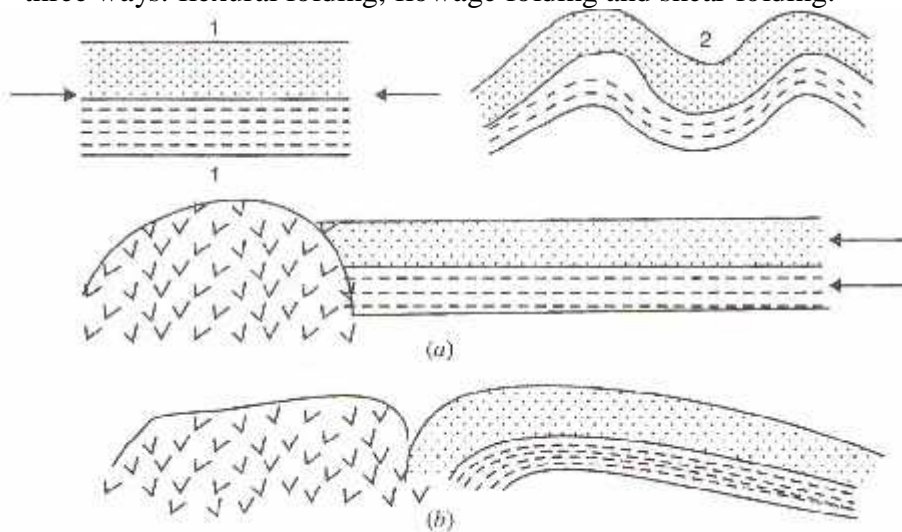


Fig. 6.29. Flexural folding

Flexural Folding.

It is that process of folding in which the competent or stronger rocks are thrown into folds due to their sliding against each other under the influence of lateral compression.

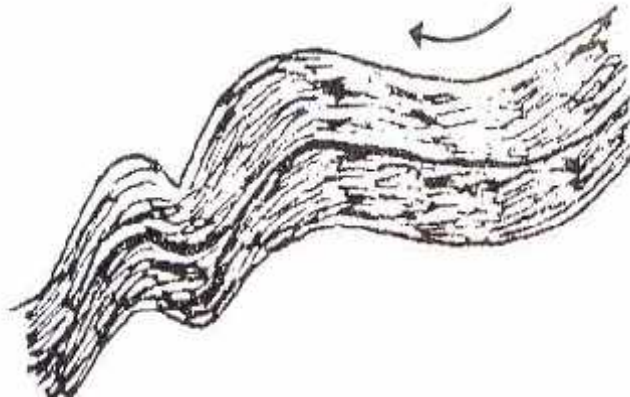
This is also distinguished as flexural-slip-folding in which the slip or movement of the strata involved takes place parallel to the bedding planes of the layers.

It has been established that in flexural folding, the amount of slip (and hence the ultimate type of fold) depends on a number of factors such as:

- ✚ thickness of the layers and nature of the contact; thicker the layers, greater is the slip; further, cohesionless contacts favour easy and greater slips;
- ✚ distance from the hinge point; greater the distance from the hinge points, larger is the
- ✚ displacement, so much so that it may be negligible at the hinge point;
- ✚ type of the rocks involved; siltstones, sandstones and limestones are more prone to flexure slip folding compared to soft clays and shales.

Flowage Folding

- ∅ It is the principal process of folding in incompetent or weaker, plastic type of rocks such as clays, shales, gypsum and rock salt etc.
- ∅ During the compression, the material of the involved layers behaves almost as a viscous or plastic mass and gets buckled up and deformed at varying rates suffering unequal distortion.
- ∅ In such cases the thickness of the resulting fold does not remain uniform.



Shear Folding.

- ∅ In many cases, folding is attributed to shearing stresses rather than simple compression.
- ∅ It is assumed that in such a process, numerous closely spaced fractures develop in the rock at the first stage of the process.
- ∅ This is followed by displacement of the blocks so developed by different amounts so that ultimately the rocks take up folded or bent configuration.
- ∅ The folded outline becomes more conspicuous when the minor fractures get sealed up due to subsequent recrystallisation.

Folding Due to Intrusions

- ∅ Intrusion of magma or even rock salt bodies from beneath has been found to be the cause of uparching of the overlying strata.
- ∅ In magmatic intrusions, highly viscous magma may be forced up very gradually and with considerable force so that the overlying sedimentary host rocks are bodily lifted up to provide space for the rising magma.
- ∅ In extreme cases, the magma may even rupture the overlying strata to flow out as lava



Fig. 6.31. A. Folding due to Intrusion; B. Folding due to Salt Plug

Folding Due to Differential Compression

- ∅ Strata that are being compacted under load in a basin of sedimentation develop, with passage of time, downward bending especially in the zones of maximum loading.
- ∅ If the strata in question is not homogeneous, the bending may not be uniform in character and results in warping or folding of different types.
- ∅ Such folds are, however, totally dependent on the load from above and are attributed to superficial causes.
- ∅ These are, therefore, non- tectonic folds.

ENGINEERING CONSIDERATIONS

- ∅ Folds developed in the areas of work are important for a civil engineer in that these make his work more complicated.
- ∅ If these structures are not thoroughly investigated and properly interpreted, any civil engineering project standing on or driven through the folded rocks may prove not only uneconomical in the ultimate analysis but also, unsafe as well.
- ∅ Due consideration is, therefore, always to be given to the presence of folds in deciding about the designing and construction of such structures as driving of traffic and hydropower tunnels, selection of sites for dams and reservoirs and in fixing the alignments of roads, bridges and highways.

Change in Attitude

- 1 Folding of any type would cause a change in the attitude (dip and strike) of the

same strata in the aerial extent and also in depth.

- 2 Hence same layers may be repeated along an alignment or one or more different layers may be unexpectedly encountered.
- 3 If it happens so and the unexpectedly repeated or encountered layers are of undesirable nature, the project costs may be effected as also the time schedule and safety of the project.

Shattering of Rocks.

- 1 The stresses are often strong enough to break or shatter the rocks, especially in the axial zones, which are the places of maximum concentration of these forces.
- 2 hence, in folded rocks, axial regions are likely to be the areas containing fractured zones.
- 3 This effect is of utmost importance because shattered rocks become:
 - weak in strength parameters of all types;
 - porous and pervious in character;

Axial regions in the folded rocks should be thoroughly studied and if possible, should be avoided for other better alignments or sites as the case may be.

If it is not possible to avoid them, these areas must be subjected to suitable processes of rock treatment for developing in them desired qualities of strength and imperviousness.

Strained Nature.

- 1 All the stresses that have acted on the rocks during their folding are generally absorbed by these rocks by undergoing strain.
- 2 In essence, the folded rocks are considerably strained, the magnitude of strain varying from point to point in the folded sequence.
- 3 Now, as and when there is an effort by nature or by the engineer to disturb this adjustment of the rocks to the stresses, the rock may respond by release of some strain energy.
- 4 Enough stored strain energy is released as soon as (or soon after) the excavations are made and huge blocks of rocks start caving in or falling with great force called the rock bursts.
- 5 This often involves fatal accidents besides causing considerable delay in the progress of the work.
- 6 A proper planning of the work in folded areas is, therefore, of utmost importance to avoid these possible hazards in construction work.

4.3 FAULT & FAULTING

- Ø Those fractures along which there has been relative movement of the blocks past each are termed as **FAULTS**.
- Ø The entire process of development of fractures and displacement the blocks against each other is termed as

FAULTING CLASSIFICATION OF FAULTS

Following factors are more commonly considered important in classification of faults:

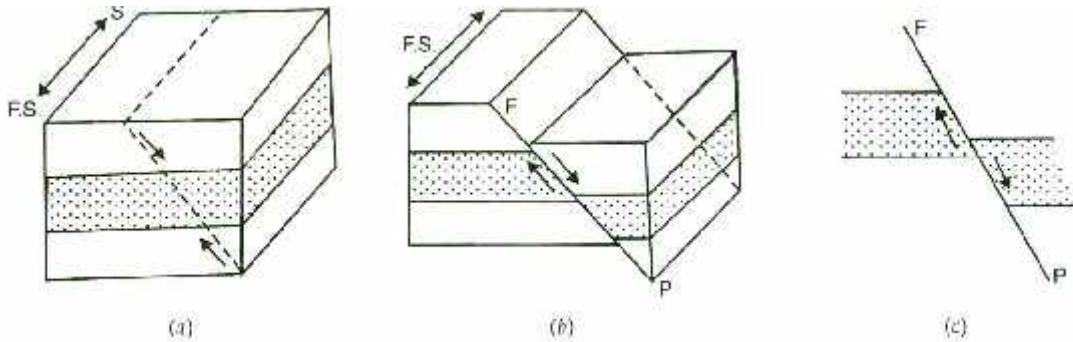
- The apparent movement of the disrupted blocks along the fault plane;
- The direction of slip;
- The relation of fault attitude with the attitude of the displaced beds;
- The amount of dip of the fault;

Mode of Occurrence.

Three fundamental types of faults are commonly distinguished on the basis of apparent movement: normal faults, reverse faults and strike slip faults.

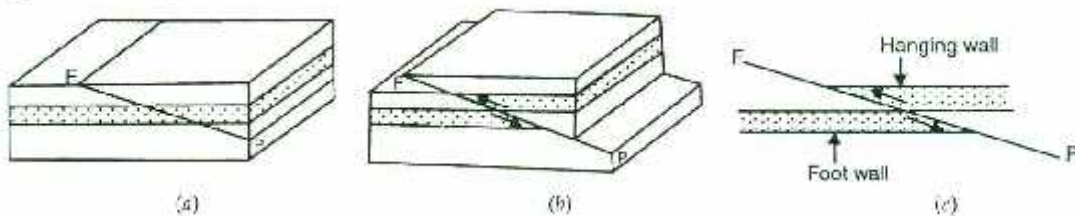
Normal Faults

- Ø Such a fault in which hanging wall has apparently moved down with respect to footwall is classified as a Normal Fault.
- Ø In this definition it is clearly implied that nothing can be said with certainty whether it was the hanging wall which moved down or the foot wall which moved up or both the walls moved down, the hanging wall moving more than the foot wall and hence the appearance.
- Ø when the fault satisfies the definition of hanging wall standing at a lower position with respect to the footwall it may be classed as a normal fault.
- Ø In normal faults, the fault plane may be inclined at any angle between horizontal and vertical, but most commonly, the fault angles are between 45 and vertical.
- Ø further, due to the inclined nature of the fault plane and downward displacement of a part of the strata, normal faults cause an extension in the crust wherever they occur.



Reverse Faults

- Ø It is such a type of fault in which the hanging wall appears to have moved up with respect to the footwall.
- Ø In reverse faults, the fault plane is generally inclined between horizontal and 45 degrees although reverse faults with steeply inclined fault surface have been also encountered.
- Ø By virtue of their inclination and direction of movement, reverse faulting involves shortening of the crust of the Earth (compare with normal faults).

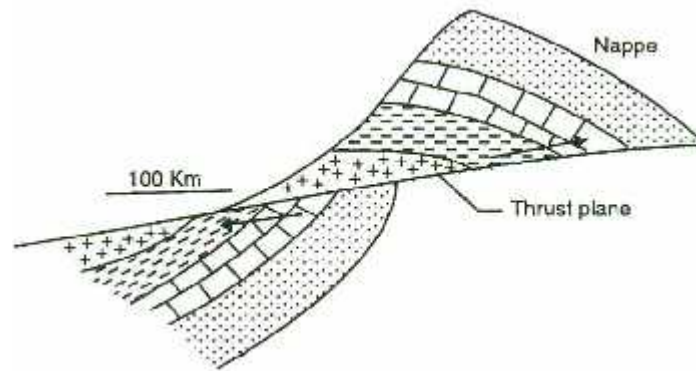


Thrust Faults

- ∅ These are, broadly speaking, such varieties of reverse faults in which the hanging wall has moved up relative to the footwall and the faults dip at angles below 45 degrees.
- ∅ The thrust faults or simply thrusts are of very common occurrence in folded mountains and seem to have originated as a further step in the process of adjustment of rocks to the imposed stresses.
- ∅ Thrusts are sometimes further distinguished into two sub-types: the over thrusts and the under thrusts.

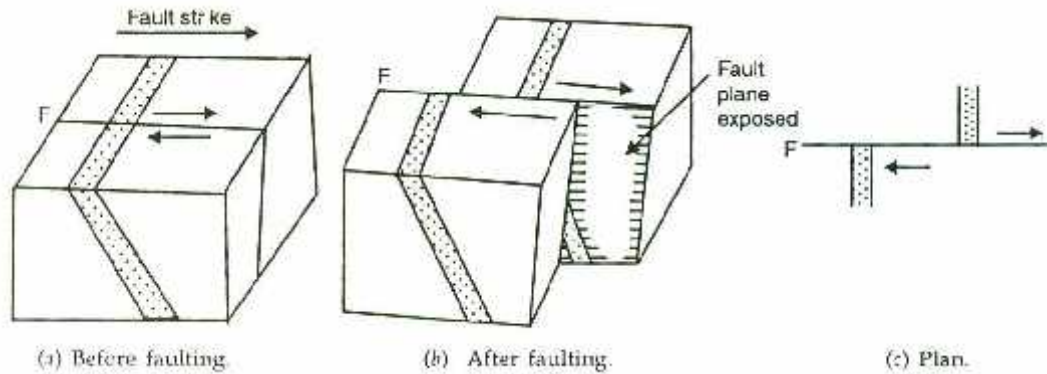
Nappes

- ∅ This term is used for extensive blocks of rocks that have been translated to great distances, often ranging to several hundred kilometers, along a thrust plane.
- ∅ The large-scale movement maybe attributed to a major over thrusting or a recumbent folding followed by thrust faulting.
- ∅ When a series of thrust faults occur in close proximity, thrust blocks are piled up one above another and all fault surfaces dip in the same direction, the resulting interesting structure is known as an imbricate Structure.



Strike-Slip Faults

- ∅ These may be defined as faults in which faulted blocks have been moved against each other in an essentially horizontal direction.
- ∅ The fault plane is almost vertical and the net slip may be measured in great distances.
- ∅ There are some other terms used for strike slip faults such as lateral faults, transverse faults, wrench faults and transform faults.
- ∅ Of these, the transform faults are very common and denote strike slip faults specially developed in oceanic ridges.



ENGINEERING CONSIDERATIONS

- Ø The safety of a civil engineering structure built on or near a faulted rock can be ascertained only in a general way.
- Ø The tectonic history of the area under consideration must be known (or studied if not known) thoroughly.
- Ø Faults of any significance are always associated with earthquakes.
- Ø So, such a study would virtually mean obtaining information about frequency of the earthquakes as also their magnitude and effects that they have left from time to time on the rocks of the region.
- Ø The exact position of the area of construction with respect to the seismic zoning of the country must be thoroughly established.
- Ø Even if the evidence collected from the study of the tectonic history of the area leads to the conclusion that no movement may be expected in the rocks of the area during the projected life span of the structure raised on them, some factor of safety must be introduced into the design of the structure, especially in the big projects in faulted areas, so that if the unexpected happens, there is minimum loss to the project.
- Ø In all big countries, maps of seismic classification are available.
- Ø In most cases recommendations of the statutory authorities are available about introducing suitable factor of safety in major civil engineering projects of any public importance that are proposed to be constructed in areas of known seismic zones.

4.4 JOINTS AND JOINTING

Terminology

- Ø Joints are defined as divisional planes or fractures along which there has been no relative displacement.
- Ø These fractures divide the rocks into parts or blocks and unlike the faults, the parts have not suffered any movement along the fracture plane.
- Ø There may be or may not be an opening up of blocks perpendicular to the joint planes.
- Ø Nature. Joints may be **open or closed** in nature.
- Ø **Open joints** are those in which the blocks have been separated or opened up

for small distances in a direction at right angles to the fracture surface.

- ∅ These may be gradually enlarged by weathering processes and develop into fissure in the rocks.
- ∅ In **closed joints**, there is no such separation.
- ∅ Even then, these joints may be capable of allowing fluids (gases and water) to pass through the rock
- ∅ Similarly, the joints may be smooth or rough on the surface and the surface may be straight or curved in outline the joints may be small in their extension

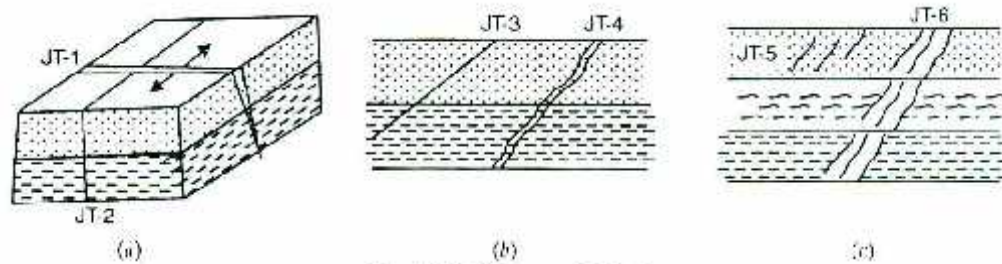


Fig. 7.26 Nature of Joints

JT-1, Open joint JT-2, Closed joint,
 JT-3, Smooth joint JT-4, Rough joint,
 JT-5, Small joint JT-6, Master joints

Attitude

- ∅ Joints are fracture planes or surfaces and their occurrence often takes place in such a way that their position in space or attitude (dip and strike) may be described conveniently either independently or with respect to the attitude of the rocks in which they occur.

CLASSIFICATION

- ∅ Joints have been classified on the basis of spatial relationships, geometry and genesis.

A. Spatial Relationship

All joints are divided into two main groups on the basis of presence or otherwise of some regularity in their occurrence:

1. Systematic joints (regular joints).

- ∅ These show a distinct regularity in their occurrence which can be measured and mapped easily.
- ∅ Such joints occur in parallel or sub-parallel joint sets that are repeated in the rocks at regular intervals.
- ∅ The columnar joints and the mural joints described below are examples of regular or systematic jointing.

2. Nonsystematic (or irregular) joints.

- ∅ As the name implies, these joints do not possess any regularity in their occurrence and distribution.
- ∅ They appear at random in the rocks and may have incompletely defined surfaces. In many cases these are related to the systematic joints in that these occur between them.

- ∅ At other times, the non- systematic joints may show no relationship with the systematic joints and their curved and rough surfaces may even cut across the former.

B. Geometry

In stratified rocks, joints are generally classified on the basis of relationship of their attitude with that of the rocks in which they occur.

Three types recognized on this basis are :

Strike joints in which the joint sets strike parallel to the strike of the rocks.

Dip joints in which the joint sets strike parallel to the dip direction of the rocks;

Oblique joints are those joints where the strike of the joints is at any angle between the dip and the strike of the layers. These are also called diagonal joints when they occur midway between the dip and strike of the layers.

C. Genesis (Origin)

In such cases, joints are classified into one of the following genetic types:

Tension joints are those, which have developed due to the tensile forces acting on the rocks. The most common location of such joints in folded sequence is on the outer margins of crests and troughs. They are also produced in igneous rocks during their cooling. Joints produced in many rocks during the weathering of overlying strata and subsequent release of stresses by expansion are also thought to be due to the tensile forces (Fig. 7.31).

Shear joints. These are commonly observed in the vicinity of fault planes and shear zones where the relationship with shearing forces is clearly established (Fig. 7.32). In folded rocks, these are located in axial regions.

Compression joints. Rocks may be compressed to crushing and numerous joints may result due to the compressive forces in this case. In the core regions of folds where compressive forces are dominant, joints may be related to the compressive forces.

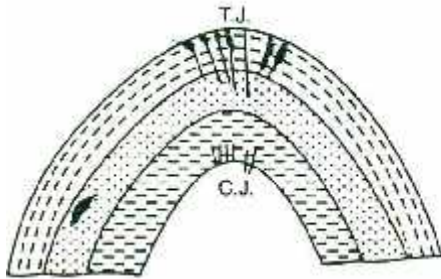


Fig. 7.31 Tension Joints (T.J).

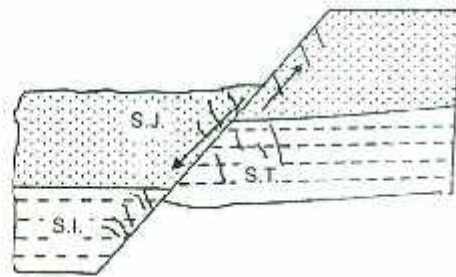


Fig. 7.32 Shear joints (S.J) and Compression Joints (C.J).

4.5 GEOPHYSICAL INVESTIGATIONS

A. Electrical Methods

Principle.

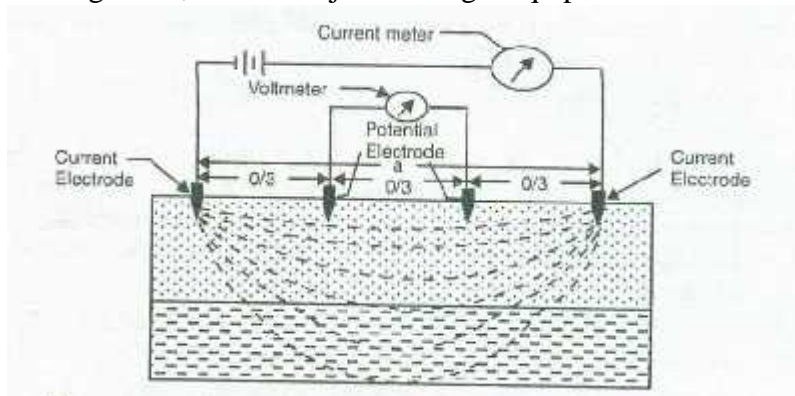
- ∅ All electrical method are based on the fundamental fact that different materials of earth's crust possess widely different electrical properties.
- ∅ Resistivity, electrochemical activity and dielectrical constant are some of these properties that are generally studied through these methods
- ∅ potential-drop methods: the natural potential may be due to electrochemical reactions between the solutions and the surrounding - subsurface rocks.
- ∅ These reactions are not always of the same order throughout the dimensions of the

rock masses thereby creating a potential difference and conditions for flow of current from one end to the other end.

- ∅ Elongated ore bodies of magnetite and pyrite etc. are easily delineated by this method.
- ∅ Natural electrical potential is measured with the help of nonpolarising electrodes along definite directions and results are plotted in terms of potential gradient along horizontal distances which are then interpreted.

Potential Drop Methods.

- ∅ These include a variety of methods in which electrical current is artificially introduced from an external source at certain points and then its flow through subsurface materials recorded at different distances.
- ∅ In the Equipotential Method two primary electrodes are inserted into the ground, 6-7 meters apart from each other, across which current is introduced.
- ∅ The position of these primary electrodes remains fixed in the subsequent investigations.
- ∅ Potential between these primary electrodes is determined with the help of two search electrodes and points of equal potential found out along the entire region under investigations, which are jointed to get equipotential lines.



- ∅ Under normal conditions, that is, when the material below is of uniform nature, electrically equipotential lines would be regular in character.
- ∅ But in cases when the material is not of uniform character (that is, it contains patches of high or low conductivity), equipotential lines would show clear distortions or irregularities which would include probable location of rock masses of different characteristics.
- ∅ The Resistivity Method is similar to equipotential method but in this case it is the resistivity of the material of the subsurface which is determined and from which important interpretations are made
- ∅ Here also, a known current is introduced through two electrodes- current electrodes, which are inserted at some distances apart from each other.,

$$\rho = 2\pi \frac{d \cdot V}{I}$$

Investigation.

- ∅ The depth of penetration of electrical current in these investigations is broadly equal to although there are many conditions attached to this generalization.
- ∅ The resistivity method envisages interpretation of the qualitative as well as quantitative characters of the subsurface materials which are governed by two basic principles
 - (i) If material below is of uniform nature, the resistivity values would be of regular character.
 - (ii) If the material is non-uniform, that is, it consists of layers or masses of different character, then these would be indicated by irregularities or anomalies in the resistivity values.
 - (iii) The depths at which these anomalies occur can be calculated and also the nature of the subsurface material broadly understood.

Applications:

(a) In Prospecting: The electrical methods have been successfully employed in delineation of ore bodies occurring at shallower depths. For such surveys at great depths, these are not of much help.

In table 1, some typical value-ranges of resistivity are given. As may be seen, rocks exhibit a great variation ranging from as high resistivity as > 10 ohm-meters in igneous rocks to as low as less than 1 ohm-m for clayey sands.

In Civil Engineering: Resistivity methods have been widely used in engineering investigation for determination of

Depth to the bed rock —as for instance, in important projects like dams, buildings and bridge foundations, where it would be desirable that the structure should rest on sound hard rocks rather than on overburden or soil

Location of geological structures —like folds, buried valleys, crushed and fractured zones due to shearing and faulting.

Location of Aquifers —and other water bearing zones which could be easily interpreted on the basis of known resistivity values of moisture rich rocks and dry rocks.

4.6 SEISMIC METHODS**Principle.**

Shocks or explosions within the earth's crust are always accompanied by generation of elastic waves, which travel in all directions from the point or place of shock, the focus.

Velocity of these shock waves is related to the nature of the medium through which they travel. In nature these waves are produced during earthquakes. The

seismic waves reveal a great deal of information about the internal constitution of the earth.

Although different types of waves are generated when a shock occurs, these are the P waves (longitudinal waves), which are the fastest and strongest. Their velocity, V_p , is related broadly to the medium (rocks) through the following equation:

$$V_p = \left[E \cdot \frac{(1 - \nu)}{e(1 + \nu)(1 - 2\nu)} \right]^{1/2}$$

where E is Modulus of elasticity, e is density and ν is the Poisson's Ratio of the medium.

The controlling factor is, obviously, the modulus of elasticity which itself is dependent upon nature of rock, its chemical and mineralogical composition, degree of freedom from structural discontinuities and degree of saturation with water and other fluids.

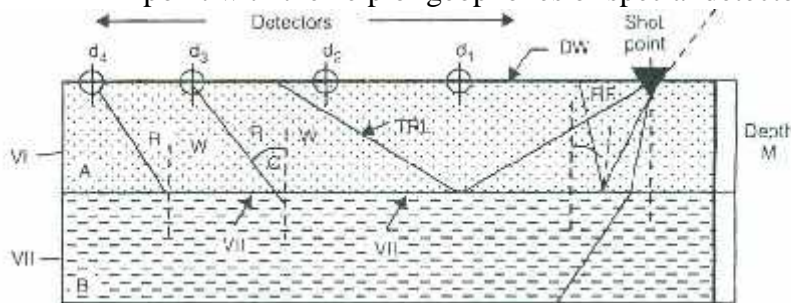
From experimental investigations, characteristic velocity values for P waves have been broadly established for different rock types.

As such, if the velocity of seismic waves travelling through a section of the ground is known, nature of the ground can be fairly assessed.

This is the underlying principle of all the seismic methods.

Method.

- ∅ The fundamental procedure in all seismic investigations for subsurface explorations is the same: a shock is created at a chosen point or location either by exploding a charge, or dynamite;
- ∅ the waves so produced are recorded at different distances from the shot point with the help of geophones or special detectors.



- ∅ The instant of shot, that is the shot time and the first arrival are recorded very carefully from which time — distance plots are prepared in a selected manner.
- ∅ A proper interpretation of these time-distance plots may reveal presence of unusually high or low velocity media at certain depths.
- ∅ Reflection methods have been found especially useful for subsurface studies under! bodies of water (e.g. lakes, rivers, and estuaries) because in such surveys signals from surface and shear waves are obliterated by water and arrival times of only longitudinal waves are recorded clearly

and easily.

- ∅ It may be pointed out that for correct inferences, it is imperative that reflection and refraction records are properly distinguished from each other as well as from records of other associated events.
- ∅ These demand considerable skill and expertise.

4.7 GRAVITATIONAL METHODS

Principle Gravity or the force by which the earth attracts other objects towards itself is a well-known principle in Physics. It can be theoretically calculated for any part of the earth from the relationship:

$$g = 978.049 (1 + 0.0052884 \sin^2 \theta - 0.00059 \sin^2 \theta)$$

where g is the normal gravity value at sea level and θ is the latitude of the place under consideration.

- ∅ In these calculations it is assumed that the earth is ideally homogenous in nature. Actually, however, the earth is far from homogenous.
- ∅ Thus, we have another means to locate the materials which are 'less' or 'more' dense than the ideal material of the earth.
- ∅ Procedure is simple: for any given area, we would know its latitude and thus calculate the value of normal gravity (the theoretical value).
- ∅ Then observations are made with sensitive instruments to determine the actual value of gravity at that place.
- ∅ This is called observed value. Under ideal conditions the two values should be identical but when there is considerable difference, a gravity anomaly is believed to exist and that would be a pointer towards existence of some unusual rock mass below the place of gravity anomaly.
- ∅ The unit for gravity is gal, which is acceleration of 1 cm/sec/ sec and that of gravity anomaly a milligal (which is a thousandth part of a gal).

Methods.

- ∅ A number of methods and instruments are available to determine the value of gravity.
- ∅ The earlier used pendulum method and the torsion balance method are almost obsolete now.
- ∅ The gravimetric method is most commonly used at present. In this method, the value of gravity is measured directly by instruments known as gravimeters.
- ∅ Two important versions of these instruments are: the stable gravimeter and the unstable gravimeter.

In the stable gravimeter,

- ✓ the spring in the gravimeter remains unchanged in its position if the gravity pull is same.
- ✓ when there is a change in the value of gravity at a place, there is a change in the length of the spring: it increases or decreases compared to original length.
- ✓ With the help of an external element, the spring can be made to acquire the original position and thereby indicate the amount of change.

In the unstable type

- ✓ the spring once disturbed due to change in gravity at the place of measurement is not brought back to the balanced state there and then.
- ✓ instead its deflections are recorded directly on a suitable magnified scale, which give a measure of gravity anomaly.
- ✓ Isogams or lines passing through points of same gravity anomaly are drawn as a result of gravimetric observations which could be then interpreted to reveal important conclusions.

4.8 MAGNETIC METHODS**Principle.**

These include some of the oldest geophysical methods of exploration and take into account the fact the earth is a gigantic magnet with definite magnetic field, the intensity of which can be calculated for any part of the earth.

But, as the earth is not ideally homogenous, the theoretical values of magnetic intensity may be quite different (higher or lower) than the values observed at given locations.

The difference between these two values is a magnetic anomaly (compare gravity anomaly) and forms the basis for interpreting bodies of magnetic ores and also such structures that can cause magnetic “highs” or “lows”.

Method.

- ∅ The magnetic intensity of rocks of earth at a given location is measured directly by very sensitive instruments called magnetometers.
- ∅ specially designed magnetometers are used for measuring horizontal intensity or vertical intensity.
- ∅ These observations are repeated in different directions over the selected area, and from the values so obtained, the magnetic anomalies are calculated.
- ∅ Lines are then drawn through the points of similar anomalies.
- ∅ This gives the isoanomalies map.
- ∅ From such maps the location and extension of materials of highly magnetic or less magnetic bodies can be determined.
- ∅ Another instrument for measuring the magnetic intensity over wider areas in the shortest possible time is Airborne Magnetometer.
- ∅ It consists of a highly sensitive detector element that is made to hang down from a plane or helicopter.
- ∅ This helps in recording total magnetic intensity along the line of flight
- ∅ The lines of flight, the height of flight and speed of the plane are controlling parameters which require very careful planning and execution of the aerial magnetic surveys.

Interpretation

- ∅ In the simplest cases, an unusually high magnetic intensity as shown by the isoanomaly map can be taken as indicative of a magnetic ore body in that area.

- Ø In actual practice, however, a number of factors have to be considered and corrections applied for arriving at reliable results. Of these, corrections due to magnetic storms are quite important.

Applications. The magnetic methods have been successfully used in prospecting for magnetic ore bodies and for oil exploration.

ACOUSTIC METHODS

- Ø This method has been specially useful in locating weathered zones, caves and major and minor cavities in rocks of susceptible compositions in the foundations.
- Ø In this method these are the sound waves which are transmitted in a controlled manner from the boreholes through the bodies of rocks and their transmission velocities recorded.
- Ø The acoustic wave velocity sketches are prepared for the site from which the size and position of caves can be interpreted.
- Ø The acoustic surveys are reliable when the site is made up of broadly homogenous rocks and the wave transmission velocities are recorded very carefully.

CHAPTER 5

APPLICATION OF GEOLOGICAL INVESTIGATIONS

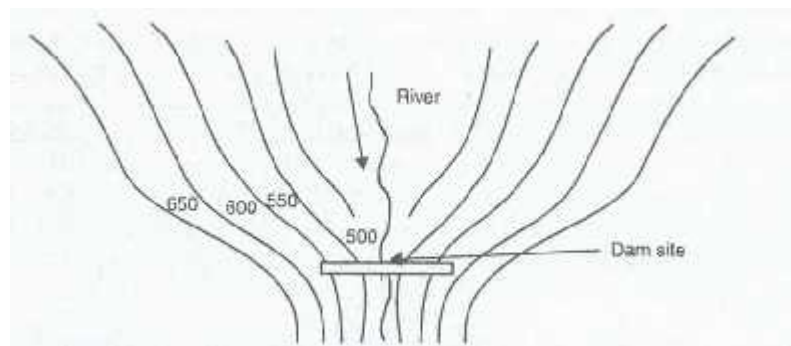
5.1 GEOLOGICAL CONDITIONS NECESSRY FOR CONSTRUCTION OF DAMS DEFINITION

- Ø A DAM may be defined as a solid barrier constructed at a suitable location across a river valley with a view of impounding water flowing through that river. (1) generation of hydropower energy;

5.1.1. SELECTION OF SITES

Topographically

- Ø It would be a narrow gorge or a small valley with enough catchments area available behind so that when a dam is placed there it would easily store a calculated volume of water in the reservoir created upstream.
- Ø This should be possible without involving significant uprooting of population, loss of cultivable land due to submergence or loss of existing construction.



Technically

- Ø The site should be as sound as possible: strong, impermeable and stable.
- Ø Strong rocks at the site make the job of the designer much easy: he can evolve best deigns.
- Ø Impermeable sites ensure better storage inventories.
- Ø Stability with reference to seismic shocks and slope failures around the dam, especially upstream, are a great relief to the public in general and the engineer in particular.
- Ø The slips, slides, and slope failures around and under the dam and susceptibility to shocks during an earthquake could prove highly hazardous.

Constructionally

- Ø The site should not be far off from deposits of materials which would be required for its construction.
- Ø All types of major dams require millions of cubic meters of natural materials — earth, sand, gravel and rock —for their construction.

Economically

- ∅ The benefits arising out of a dam placed at a particular site should be realistic and justified in terms of land irrigated or power generated or floods averted or water stored.
- ∅ Dams are invariably costly structures and cannot be placed anywhere and everywhere without proper analysis of cost-benefit aspects.

Environmentally

- ∅ The site where a dam is proposed to be placed and a reservoir created, should not involve ecological disorder, especially in the life cycles of animals and vegetation and man.
- ∅ The fish culture in the stream is the first sector to suffer a major shock due to construction of a dam. Its destruction may cause indirect effects on the population.
- ∅ These effects require as thorough analysis as for other objects. The dam and the associated reservoir should become an acceptable element of the ecological set up of the area.

5.2 GEOLOGICAL CHARACTERS FOR INVESTIGATION**Geology of the Area**

Preliminary geological surveys of the entire catchments area followed by detailed geological mapping of the reservoir area have to be conducted. These should reveal main topographic features, natural drainage patterns, general characters and structures of rock formations such as their stratification, folding and faulting and igneous intrusions, and the trend and rate of weathering and erosion in the area.

Geology of the site**Lithology.**

- ∅ The single most important feature that must be known thoroughly at the site and all around and below the valley up to a reasonable depth is the Lithology, i.e. types of the rocks that make the area.
- ∅ Surface and subsurface studies using the conventional and latest techniques of geological and geophysical investigations are carried out.
- ∅ Such studies would reveal the type, the composition and textures of the rocks exposed along the valley floor, in the walls and up to the required depth at the base.
- ∅ Rocks are inherently anisotropic materials, showing variation in properties in different directions.
- ∅ Complex lithology definitely poses challenging design problems.

Structures

- ∅ This involves detailed mapping of planes of weakness like bedding planes, schistosity, foliation, cleavage, joints, shear zones, faults and fault zones, folding and the associated features.

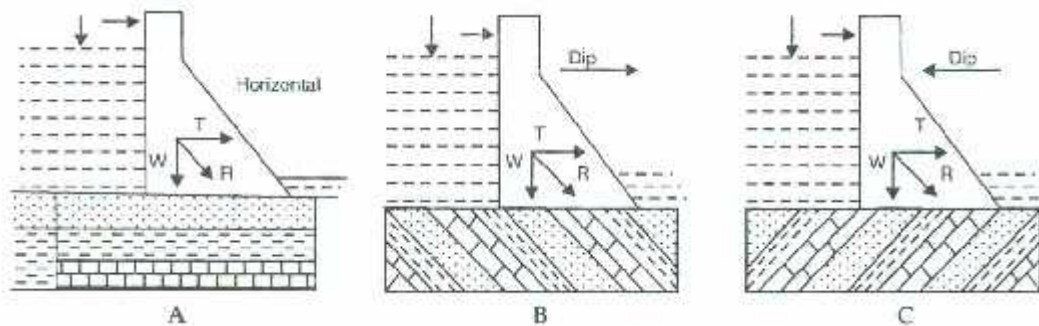
- ∅ While mapping these features, special attention is given to recording their attitude, spacing and nature.
- ∅ Shear zones have to be searched, mapped and treated with great caution.

- ∅ In some cases, these may be developed to such an extent that the rock may necessitate extensive and intensive rock treatment (e.g. excavation, backfilling and grouting etc.).

Following is a brief account of the influence of more important structural features of rocks on dam foundations

Dip and Strike

- ∅ The strength of sound, un fractured stratified rock is always greater when the stresses are acting normal to the bedding planes than if applied in other directions.
- ∅ This being so, horizontal beds should offer best support for the weight of the dam.
- ∅ But as is shown in a latter section, the resultant force is always inclined downstream.



- ∅ the most UNFAVOURABLE strike direction is the one in which the beds strike parallel to the axis of the dam and the dip is downstream
- ∅ It must be avoided as far as possible.
- ∅ Therefore, other conditions being same, beds with upstream dips are quite favorable sites for dam foundations.

Faults

These structures can be source of danger to the dam in a number of ways. Thus,

- ✓ The faulted rocks are generally shattered along the rupture surfaces;
- ✓ Different types of rocks may be present on either side of a fault plane. Hence, sites with fault planes require great caution in calculating the design strength in various sections of the dam.
- ✓ Dams founded on beds traversed by fault zones and on major fault planes are more liable to shocks during an earthquake compared to dams on non-faulted rocks.

5.3 TUNNELS

Definition

- ∅ Tunnels may be defined as underground routes or passages driven through the ground without disturbing the overlying soil or rock cover.
- ∅ Tunnels are driven for a variety of purposes and are classified accordingly.
- ∅ Chief classes of tunnels are:
Traffic Tunnels

hydro-power tunnels and
public utility tunnels.

Geological Investigations

These determine to a large extent solutions to following engineering problems connected with tunnelling:

Selection of Tunnel Route (Alignment).

There might be available many alternate alignments that could connect two points through a tunnel.

the final choice would be greatly dependent on the geological constitution along and around different alternatives

Selection of Excavation Method.

Tunnelling is a complicated process in any situation and involves huge costs which would multiply manifolds if proper planning is not exercised before starting the actual excavation.

And the excavation methods are intimately linked with the type of rocks to be excavated.

Choice of the right method will, therefore, be possible only when the nature of the rocks and the ground all along the alignment is fully known.

This is one of the most important aim and object of geological investigations.

Selection of Design for the Tunnel.

The ultimate dimensions and design parameters of a proposed tunnel are controlled, besides other factors, by geological constitution of the area along the alignment.

Whether the tunnel is to be circular, D-Shaped, horse-shoe shaped or rectangular or combination of one or more of these outlines, is more often dictated by the geology of the alignment than by any other single factor.

Thus, in self-supporting and strong rocks, either, D-shape or horse-shoe shape may be conveniently adopted but these shapes would be practically unsuitable in soft ground or even in weak rocks with unequal lateral pressure.

Assessment of Cost and Stability.

These aspects of the tunnelling projects are also closely interlinked with the first three considerations.

Since geological investigations will determine the line of actual excavation, the method of excavation and the dimensions of excavation as also the supporting system (lining) of the excavation, all estimates about the cost of the project would depend on the geological details.

Similarly tunnels passing through hard and massive rocks even when left unsupported may be regarded as stable.

5.4 ASSESSMENT OF ENVIRONMENTAL HAZARDS

The process of tunnelling, whether through rocks or through soft ground, and for whatsoever purpose, involves disturbing the environment of an area in more than one way.

The tunnelling methods might involve vibrations induced through blasting or ground cutting and drilling, producing abnormal quantities of dust and last but not the least, interference with water supply system of the nearby areas.

A correct appreciation of geological set up of the area, especially where tunnel alignment happens to be close to the populated zones, would enable the engineer for planning and implementing plans aimed at minimizing the environmental hazards in a successful manner.

Methods

These stages are:

A. Preliminary Surveys

Following geological characters are broadly established for the entire area in which the tunnel project is to be located as a result of preliminary surveys:

The general topography

The topography of the area marking the highest and the lowest points, occurrence of valleys, depressions, bare and covered slopes, slide areas, and in hilly regions and cold climates, the snow-line.

The litho logy

The litho logy of the area, meaning thereby, the composition, attitude and thickness of rock formations which constitute the area.

The hydrological conditions

The hydrological conditions in the area, such as depth of water table, possibility of occurrence of major and minor aquifers of simple type and of artesian type and the likely hydrostatic heads along different possible routes or alignments.

The structural condition

The structural condition of the rock, that is, extent and attitude of major structural features such as folding, faulting, unconformities, jointing and shearing planes, if developed.

Existence of buried valleys are also established during the preliminary surveys.

B. Detailed Surveys

Bore-Hole Drilling

bore-hole drilling along proposed alignments and up to desired depths; the number of bore-holes may run into dozens, scores or even hundreds, depending upon the length of the tunnel;
rock samples obtained from bore holes are analysed for their mechanical and geo-chemical properties in the laboratories;

Drilling Exploratory

Drilling shafts and adits, which allow direct approach to the desired tunnel for visual inspection in addition to the usual advantages of drilling;

Driving Pilot Tunnels

Driving pilot tunnels which are essentially exploratory in nature but could better be used as a main route if found suitable by subsequent enlargement.

The actual number of bore holes and shafts and adits and their depth and length are decided by the length and location of the proposed tunnel.

For tunnels with little overburden, these may be driven close to the proposed tunnel.

5.5 GEOLOGICAL CONSIDERATIONS IN TUNNELLING

Rocks may be broadly divided into two categories in relation to tunnelling:

- 1 .consolidated and

2. unconsolidated or soft ground. Only a brief accounts is given below.

(A) Consolidated Rocks

Tunnel design, method of its excavation and stability are greatly influenced by following geological conditions: lithology, geological structures and ground water conditions.

Lithology

It has already been mentioned that information regarding mineralogical composition, textures and structures of the rocks through which the proposed tunnel is to pass is of great importance in deciding

the method of tunneling

the strength and extent of lining and, thus the cost of the project.

Hard and Crystalline Rocks

- Ø These are excavated by using conventional rock blasting methods and also by tunnel boring method
- Ø In the blasting method, full face or a convenient section of the face is selected for blasting up to a pre-selected depth
- Ø These are loaded with predetermined quantities of carefully selected explosives of known strength.
- Ø The loaded or charged holes are ignited or triggered and the pre-estimated rocks get loosened as a result of the blast.
- Ø The blasting round is followed by a mucking period during which the broken rock is hauled out of the excavation so created.
- Ø The excavations in hard and crystalline rocks are very often self supporting so that these could be left unlined and next round of blasting in the new face created is undertaken, ensuring better advance rate.
- Ø Rocks falling in this group include granites, diorites, syenites, gabbros, basalts and all the related igneous rocks, sandstones, limestones, dolomites, quartzites, arkose, greywackes and the like from sedimentary group and marbles, gneisses, quartzites, phyllites and slates from the metamorphic groups.
- Ø When any one of these rocks is stressed, such as during folding or fractured as during faulting, tunnelling in these rocks proves greatly hazardous.
- Ø Rock bursts which occur due to falling of big rock blocks from roofs or sides due to release of stresses or falling of rock block along fractures already existing in these rocks often cause many accidents.
- Ø **Soft Rocks** This group includes shales, friable and poorly compacted sandstones, chalk and porous varieties of limestones and dolomities, slates and phyllites with high degree of cleavage and also decomposed varieties of igneous rocks.
- Ø Their excavation cost, volume for volume, might be lower than those in hard rocks.
- Ø Hence, temporary and permanent lining becomes necessary that would involve extra cost and additional time.
- Ø Rocks like clays, shales, argillaceous and ferruginous sandstones, gypsum bands and cavernous limestones have to be viewed specially with great

caution during tunnelling

- Ø **Fissured Rocks** form a category in themselves and include any type of hard and soft rock that has been deformed extensively due to secondary fracturing as a result of folding, faulting and metamorphic changes of shearing type. (b)

Geological Structures Dip and Strike

These two quantitative properties of rocks determine the attitude (disposition in space) of the rocks and hence influence the design of excavation (tunnel) to a great extent.

Three general cases may be considered.

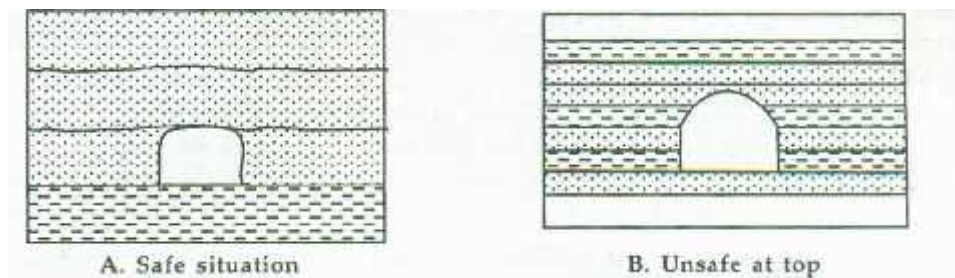
Horizontal Strata

When encountered for small tunnels or for short lengths of long tunnels, horizontally layered rocks might be considered quite favourable.

In massive rocks, that is, when individual layers are very thick, and the tunnel diameter not very large, the situation is especially favourable because the layers would then over bridge flat excavations by acting as natural beams

But when The layers are thin or fractured, they cannot be depended upon as beams; in such cases, either the roof has to be modified to an arch type or has to be protected by giving a lining.

Sides of tunnels, however, could be left unsupported except when the rocks are precariously sheared and jointed.



Moderately Inclined Strata.

Such layers that are dipping at angles up to 45° may be said as moderately inclined.

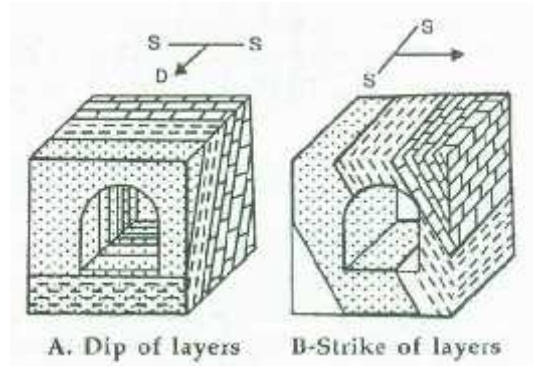
The tunnel axis may be running parallel to the dip direction, at right angles to the dip direction or inclined to both dip and strike directions.

In the first situation, that is, when the tunnel axis is parallel to the dip direction the layers offer a uniformly distributed load on the excavation.

The arch action where the rocks at the roof act as natural arch transferring the load on to sides comes into maximum play.

Even relatively weaker rocks might act as self-supporting in such cases. It is a favourable condition from this aspect.

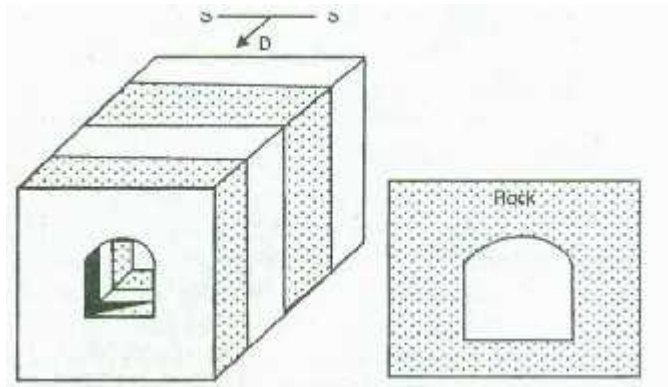
It also implies that the axis of the tunnel has to pass through a number of rocks of the inclined sequence while going through parallel to dip



- ∅ In the second case, that is, when the tunnel is driven parallel to strike of the beds (which amounts to same thing as at right angles to the dip),
- ∅ the pressure distributed to the exposed layers is unsymmetrical along the periphery of the tunnel opening; one half would have bedding planes opening into the tunnel and hence offer potential planes and conditions for sliding into the opening.
- ∅ The bridge action, though present in part, is weakened due to discontinuities at the bedding planes running along the arch
- ∅ Such a situation obviously requires assessment of forces liable to act on both the sides and along the roof and might necessitate remedial measures.
- ∅ In the third case, when the tunnel axis is inclined to both the dip direction and the strike direction, weak points of both the above situations would be encountered.

Steeply Inclined Strata

- ∅ In rock formations dipping at angles above 45° , quite complicated situations would arise when the tunnel axis is parallel to dip or parallel to strike or inclined to both dip and strike directions.
- ∅ In almost vertical rocks for example, when the tunnel axis is parallel to dip direction, the formations stand along the sides and on the roof of the tunnel as massive girders.
- ∅ An apparently favourable condition, of course, provided all the formations are inherently sound and strong



5.6 FOLDING

Folds signify bends and curvatures and a lot of strain energy stored in the rocks. Their influence on design and construction of tunnels is important from at least three angles:

Firstly, folding of rocks introduces considerable variation and uncertainty in a sequence of rocks so that entirely unexpected rocks might be encountered along any given direction.

This situation becomes especially serious when folding is not recognized properly in preliminary or detailed surveys due either to its being localized or to misinterpretation.

Secondly, folding of rocks introduces peculiar rock pressures.

In anticlinal fold, loads of rocks at the crest are transferred by arch action to a great extent on to the limbs which may be highly strained

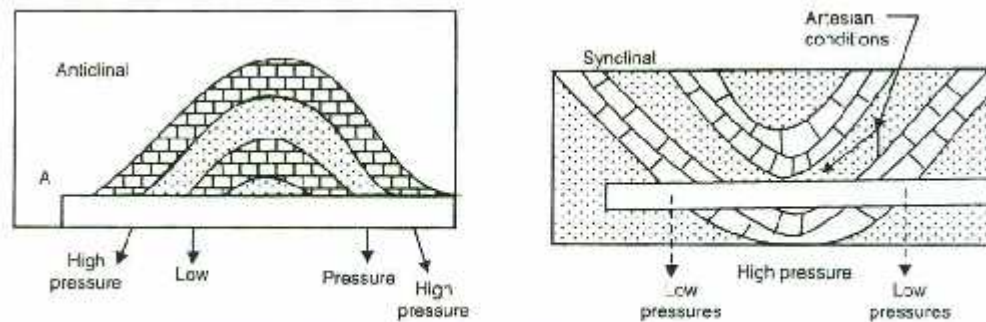
These conditions are reversed when the folds are of synclinal types.

In such cases, rocks of core regions are greatly strained.

Again, the axial regions of folds, anticlinal or synclinal, having suffered the maximum bending are more often heavily fractured.

The alignment of a tunnel passing through a folded region has to take these aspects in full consideration.

When excavations are made in folded rocks, the strain energy is likely to be released immediately, soon after or quite late to tunnelling operations, very often causing the dreaded rock bursts.



A. Anticlinal - low pressure in middle region B. Synclinal - high pressure in middle region

Thirdly, folded rocks are often best storehouses for artesian water and also ideal as aquifers.

When encountered during tunnelling unexpectedly, these could create uncontrollable situations.

The shattered axial regions being full of secondary joint systems are highly permeable.

As such very effective drainage measure are often required to be in readiness when excavations are to pass through folded zones.

5.7 FAULTING

Similarly, fault zones and shear zones are highly permeable zones, likely to form easy avenues for ground water passage.

Inclined fault planes and shear zones over the roof and along the sides introduce additional complications in computation of rock pressure on the one hand and of rock strengths on the other.

This discussion leads to a general conclusion: wherever tunnel is intersected by fault planes or shear zones, it is to be considered as passing through most unsafe situations and hence designed accordingly by providing maximum support and drainage facilities.

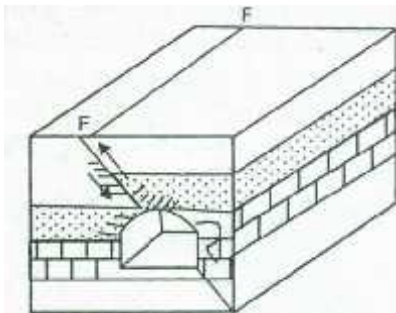
Joint Systems

Joints are cracks or fractures developed in rocks due to a variety of causes. although all types of joints tend to close with depth (due to load of overburden), their presence and orientation, has to be investigated.

Joints are planes of weakness and must always be suspected when the rocks are folded and faulted.

Even originally closed joints may become reactive and open up in the immediate vicinity of tunnel excavation.

Jointed rocks cannot be considered as self-supporting although these might belong to massive



Ground Water Conditions

Determination of ground water conditions in the region of tunnel project is not to be under-estimated at any cost.

In fact ground water level vis-à-vis tunnel axis is a major factor governing

computations of overhead loads on tunnels and also in the choice of method of tunnelling.

Groundwater conditions effect the tunnel rocks in two ways

Firstly, through its physico-chemical action, it erodes and corrodes (dissolves) the susceptible constituents from among the rocks and thereby alters their original properties constantly with the passage of time.

It might have already done much of this type of job when the tunnel is excavated through such water-rich rocks.

Secondly, it effects the rock strength parameters by its static and dynamic water heads.

Such an action may become highly pronounced when an artesian aquifer is actually intercepted by tunnel excavation.

5.8 ROADS AND HIGHWAYS

Their planning, designing, construction and maintenance are among the major duties of civil engineers the world over.

geological investigations play important role in the design, stability and economical construction and maintenance of the roads.

Such investigations are aimed at providing full details regarding topography of the area, lithological characters of the rocks or soil and the ground water conditions.

Topography

Topography or the landform of a region is single most important factor that controls the selection of alignment of a road project.

Topographic maps would reveal the existence of various land features like valleys and the inflowing streams, the hills and their undulations, the plateaus and the plains with all their varying configuration from place to place.

Obviously, knowledge of all such features is not only important but very essential for a right alignment.

Preliminary surveys, including aerial surveys followed by detailed surveys are often necessary to obtain desired topographical

Lithological Character

Broadly speaking, ground may be divided into two types: consolidated, massive hard rock type and soft, unconsolidated type.

The Massive groups of rocks include all varieties of igneous, sedimentary and metamorphic rocks which can stand even with vertical slopes.

For making roads through them, however, these rocks require extensive blasting operations.

They cannot be simply cut out or dug out, Once cut, especially if they are free from joints and fractures and un favorably inclined bedding planes, these rocks stand erect for year without much maintenance.

The Unconsolidated group presents the engineer many complicated problems. Thorough soil investigations regarding their mode of origin, texture, structures, porosity, permeability, degree of compaction, consolidation characteristics or compressibility, etc all are required to be known within broad limits to design safe

and stable roads over them.

Residual soils are generally homogeneous and properties evaluated from selective bore hole samples might prove sufficient.

Geological Structures

The structural features of rocks, especially in those of sedimentary and metamorphic origin, have very important bearing upon the design of cuts as well as on the stability of the road as a whole.

A given rock might be quite hard and otherwise sound for a cut as road foundation.

But, if in the same rock some planes of weakness (such as bedding planes, joints, foliation, cleavage) are present in such a way that these are inclined towards the free side of the valley, the rock could likely fail along these planes.

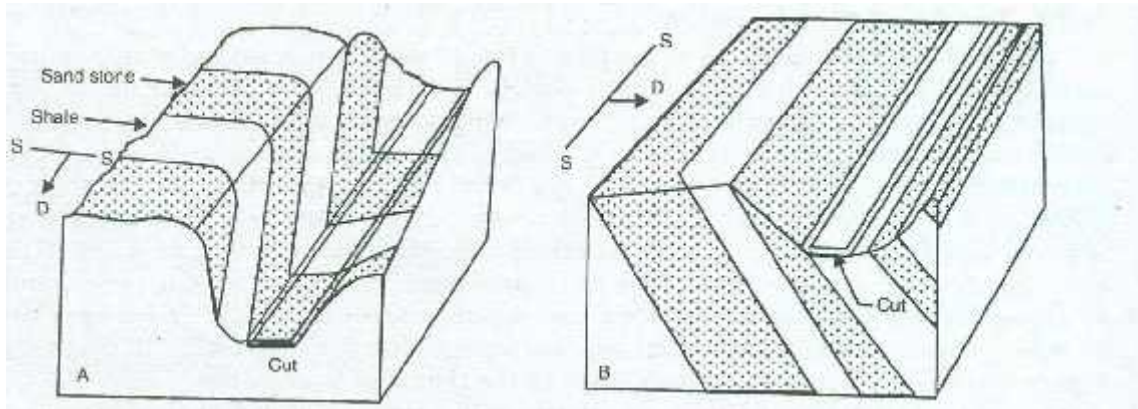
Such structural features include dip and strike, joints, fault planes and shear zones.

Dip and Strike.

There may be three possibilities for making a cut in the inclined beds: it can be made parallel, at right angles or inclined to the dip direction.

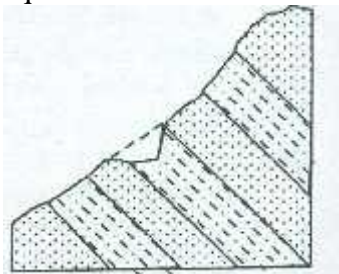
The relative merits of the cut vis-a-vis its stability would be as follows assuming other things are favourable:

Cut is parallel to the dip direction: In such a case, the layers offer a uniform behaviour on either side of the cut and as such the risk of failure is minimal on this account.



Cut is made parallel to the strike, that is, at right angles to the dip direction.

In some cases where the layers dip into the hill rather than in the road, the cut is considered quite stable



5.9 ROAD CUT

Cutting Inclined to Dip and Strike:

In such cases also, the parallel to strike.

Beds strata will dip across the cutting and the slope of cutting dip into the hill
Safe. will be unequal on both sides.

Hence such a condition would give rise to similar difficulties as encountered in
cuts parallel to strike.

When there is no alternative to cuts either parallel to or inclined to strike (other
than at right angles), special measure might become necessary to ensure stability
of slopes.

Such measures would include Enlarging of the section of the cutting, particularly
on the hillside face, to stable Provision of strong, adequately high retaining walls;
Very efficient drainage system to effectively remove water from the affected
slopes.

Joints

These influence the stability of the cuts in the same way as the bedding planes
When present in great abundance, joints reduce even the hardest rock to a mass of
loosely held up blocks on the side of a cut which could tumble down on slight
vibrations.

Further, even if the joints are few, but are continuous and inclined towards the
free side of the cut, these and inclined towards the free side of the cut, these offer
potential surfaces for slips during the presence of moisture.

In major road construction programmes, therefore, jointed rocks have to be
provided artificial support by breastwalls and retaining walls for ensuring
stability.

Faulting generally leads to the crushing of the rock along the fault planes and
shear zones.

Faults Such a condition is, of course, very unfavourable for a cut when it happens to
form upper or lower slope or even base of the cut.

It should not be left untreated in any case. These are the worst type of planes of
potential failure.

UNIT – I
GENERAL GEOLOGY

Two Marks Questions and Answers

1) Write notes on Lithosphere.

Litho is a Greek word, which means stone. Accordingly the lithosphere is the part of the earth, which is solid crust. The thickness of lithosphere is approximately 50 km. The crust thickness is not the same at all places. It is thicker in the continent and thinner on the ocean floors. Lithosphere is a source of various minerals. It contains variety of landforms such as mountains, plateaus, valleys, plains.

2) What is meant by NIFE?

The central part of the earth is called Core or barysphere. It has thickness of 2900km. This layer is made of very hard mineral like Nickel (Ni) and iron (Fe) and so it is called NIFE (Ni + Fe). Here there is intense heat and pressure and this region is elastic and viscous in nature.

3) Distinguish between SIAL and SIMA.

The upper most layers is called the crust of the earth. It has a thickness of 50 km and thus the crust is made of two layers. Silica (Si) and Aluminium (Al) are the elements found in the first layer. Therefore this layer is called SIAL (Si + Al). This layer is also called 'Granitic layer.'

Below the SIAL lies a layer called SIMA which composes of silica (Si) and Magnesium (Mg). This layer is also called Basaltic layer.

4) What are plates?

The surface of the earth is the crust of the earth. It is made of interlocking pieces called plates. The continents and oceans rest in these places and are separated by wide cracks. The plates move constantly.

5) What is meant by 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-million part of the total mass of the earth.

6) Define sea floor spreading.

Divergent boundaries occur at Oceanic ridges. In the process of plate separation, the magma rises up from the asthenosphere and fills the gap they created. In this way new crust is created along the trailing edges of the diverging plates. This phenomenon is called sea floor spreading.

7) What are the subdivisions in geology?

The subdivisions are:

- a) Physical geology
- b) Geomorphology
- c) Mineralogy
- d) Petrology
- e) Historical geology
- f) Economic geology
- g) Geohydrology
- h) Engineering geology
- i) Metrology

8) What is meant by engineering geology?

Engineering geology may be defined as that of applied sciences which deals with the application of geology for a safe, stable land economical design and construction of a civil engineering project.

9) Define seismology.

Seismology is a branch of geophysics that deals with the study of elastic waves within the body of the earth during an earthquake. ie. The study of earthquake is called seismology.

10) Give the two types of discontinuity.

There are two important discontinuities:

- Mohorovicic or Moh discontinuity
- Gutenberg or Oldharm discontinuity

11) Define denudation.

It is general term used when the surface of the earth is worn away by chemical as well as mechanical actions of physical agents and the lower layers are exposed. This happens when the rocks were exposed for a sufficient length of time to the attacks of physical agents.

12) What is mean by continental crust?

The continental crust consists of two layers separated by a well-defined discontinuity known as conard discontinuity. The layers have been defined on the basis of seismic waves velocities and densities.

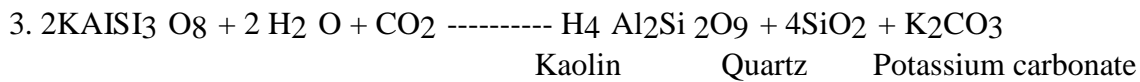
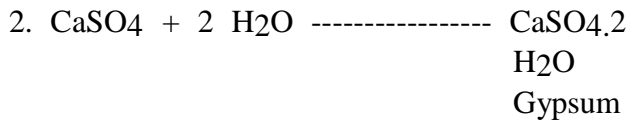
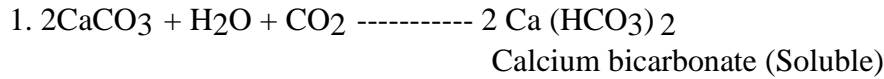
In the upper layer the velocity of seismic waves corresponds to the velocity found by experimental to be characteristic of granite. Hence they are called as Granitic or sialic layer.

13) What is mean by physical weathering?

It is a physical breakdown of rock masses under the attack of certain atmospheric agents. A single rock block is broken gradually into smaller irregular fragments and then into particles of

still smaller dimensions. Temperature variations are irresponsible to a great extent of physical weathering.

14) Give the example for chemical reaction in chemical weathering?



15) Define deflation.

Deflation is the process of simply removing the loose sand and dust sized particles from an area, by fast moving winds. Wind deflation can successfully operate in comparatively dry regions with little or no rainfall and where the mantle is unprotected due to absence of vegetation.

16) What are Barchans?

The barchans are crescent or half moon shaped dunes of variable size. Their 'horns' point in the downward direction. Their height may vary from 15-200 mts. And width from a few to 1000s meter. They have a gentle windward slope and steeper leeward slope.

17) Define the terms

- i) Focus
- ii) Epicenter

Focus:

The exact spot underneath the earth's surface, at which an earthquake originates, is

known as its focus.

Epicenter:

The earthquake then moves in the form of wave which are spread in all directions. These waves first reach the point at the surface, which is immediately above the focus or origin of the earthquake. This point is called epicenter.

18) What are the causes of earthquake?

The earthquake may be caused due to various reasons:

- Earthquakes due to superficial movements.
- Earthquake due to volcanic eruptions.
- Earthquake due to folding or faulting

19) Define aquifer and the names the types of aquifers.

Groundwater occurs in permeable geologic formations is known as aquifers. i.e formations having structures that permit appreciable water to move through them under ordinary field conditions. Aquifers may be classed as unconfined and confined, depending upon the presence or absence of a water table.

20) What do you understand by spheroidal weathering?

When weathering occurs, part of the disintegrated rock material is carried away by running water or any other transporting agent. Some of them are left on the surface of the bedrock as residual boulders. These boulders are then rounded off to spheroidal cores by the simultaneous attack of eroding agents on all sides. It is often seen that these boulders have an onion like structure. This kind of weathering is called spheroidal weathering.

21) Write short notes on:

- *) **Porosity**
- *) **Permeability**

Porosity:

The portion of a rock or soil not occupied by solid mineral matter may be occupied by ground water. These spaces are known as voids, interstices, pores or pore space. The interstices can act as ground water conduits; they are characterized by their size, shape, irregularity, and distribution.

Permeability:

The groundwater is stored in the pores of a rock and will hence be available in the

groundrocks. The porosity of the rock, thus defining the maximum amount of water that can be stored in the rock. This is called permeability.

22) What is mean by water table?

The depth to upper surface of zone of saturation in free ground water is called water table. In other words, a static level of water in wells penetrating the zone of saturation is called water table.

23) What are the movements of the oceans?

There are three movements of oceans:

- i) Waves
- ii) Tides
- iii) Currents.

Waves are only the rise and fall of water caused by the action of the winds. There is no movement forward. These are at the surface and not at great depth.

Currents are rivers in the sea. The water moves forward and falls at the depth as well. These are caused by the unequal temperature of equator and Polar Regions.

Tides are the rise and fall of seawater occurring twice in a lunar day.

24) Distinguish between magnitude and intensity of the earthquake.

Intensity of an earthquake may be defined as the ratio of an earthquake based on actual effects produced by the quakes on the earth.

Magnitude (M) of a tectonic earthquake may be defined as the rating of an earthquake based on the total amount of energy released when the over strained rocks suddenly rebound causing the earthquake.

16 MARKS QUESTIONS AND ANSWERS

1. Write short notes on:

- i. Crust**
- ii. Mantle**
- iii. Core**
- iv. Stratosphere**
- v. Atmosphere**

Crust:

Mohorovicic.He noted that in measurements of seismic wave arriving from an earthquake, those focus lay within 40km of the surface, seismographs within 800 km of the epicenter. Recorded two distinct sets of P and S-waves. He concluded that one pair of waves must have travelled from

the focus to the station by a direct path whereas the other pair of waves had arrived slightly later because they had been refracted.

There are two types of crust:

- i. Continental crust
- ii. Oceanic crust.

Continental Crust:

The continental crust consists of two layers separated by a well-defined discontinuity known as Conrad discontinuity. The layers have been defined on the basis of seismic waves velocities and densities.

In the upper layers the velocity of seismic waves corresponds to the velocity found by experimental to be characteristic of granite. Hence they are called as Granitic or silica layer.

Oceanic Crust:

The earths crust beneath the oceans consist of a low velocity layer of deep sea sediments about 300-400m thick in pacific and 600-700 m in the Atlantic.

The Layer of intermediate velocity called basement about 0,8 km thick, composed of compacted and indurated sediments and lave flows.

The third layer is called the oceanic layer about 4.1 to 5.8 km thick and certain composition. This three-layered oceanic crust is generally 5 to 8 km thick.

Mantle:

Materials making the earth become quite different in properties at the base of the crust. 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 Mohovorovicic discontinuity. In geological literature it is often referred as M-discontinuity or simply as Moho.Hence mantle is that zone within the earth that starts from M-discontinuity and continues up to a depth of 2900km.

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. The material of the mantle is believed to be variably viscous in nature .

Core:

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 centre of the earth, at a depth of 6370km.

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. It has a very high density at mantle core boundary above 10g/cc. The outer core behaves like a liquid towards the seismic waves. The inner core starting from 4800km and extending up to 6370 m is of unknown nature but definitely of solid character and with properties resembling top a metallic body.

Atmosphere:

The outer gaseous part of the earth starting from the surface and extending as far as 700km and even beyond is termed atmosphere. It makes only about one million part of the total mass of the earth. The homogenous structure as follows:

Chemical composition of atmosphere:

Component	Volume Percentage
Nitrogen	78.084
Oxygen	20.946
Argon	00.934
Carbon dioxide	00.033
Others (Ne, He, Kr, Xe)	00.003

Thermally speaking the atmosphere shows an interesting height from the surface. Based on thermal characters the atmosphere is divided into following layers: troposphere, Stratosphere, Mesosphere and Thermosphere.

Stratosphere:

It is the second layer of the atmosphere starting from the tropopause and extending up to an average height of 50km. The stratosphere differs from the lower layer in following respects.

- The temperature becomes constant for a height of 20km and then starts increasing.
- 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.
- The stratosphere itself has a layered structure and there is no significant mixing or turbulence of gases in this layer.

The ozone layer starts at a height of 9km above the surface and continues up to 35km. The

maximum concentration of ozone in this layer is estimated at a height of 20-25km.
The upper boundary of the stratosphere is called Stratopause.

2) Explain briefly about Branches of geology?

Geology is a relatively recent subject. In addition to its core branches, advances in geology in allied fields have lead to specialized sciences like geophysics, geochemistry, seismology, oceanography and remote sensing.

Main and Allied branches of geology:

The vast subject of geology has been subjected into the following branches:

Main Branches

Physical geology
Mineralogy
Petrology
Structural geology
Stratigraphy
Paleontology
Economic geology

Allied Branches

Engineering geology
Mining geology
Geophysics
Geohydrology
Geochemistry

Physical geology:

This is also variously described as dynamic geology, geomorphology etc.
It deals with:

- i) Different physical features of the earth, such as mountains, plateaus, valleys, rivers, lakes, glaciers and volcanoes in terms of their origin and development.
- ii) The different changes occurring on the earth surface like marine transgression, marine regression, formation or disappearance of rivers, springs and lakes.
- iii) Geological work of wind, glaciers, rivers, oceans, and groundwater and their role in constantly moulding the earth surface features
- iv) Natural phenomena like landslides, earthquakes and weathering.

Mineralogy:

This deals with the study of minerals. Minerals are basic units with different rocks and ores of the earth are made up of.

Details of mode of formation, composition, occurrence, types, association, properties uses etc. of minerals form the subject matter of mineralogy. For example: sometimes quartzite and marble resemble one another in shine, colour and appearance while marble disintegrates and

decomposes in a shorter period because of its mineral composition and properties.

Petrology:

Petrology deals with the study of rocks. The earth's crust also called lithosphere is made up of different types of rocks. Hence petrology deals with the mode of formation, structure, texture, composition, occurrence, and types of rocks. This is the most important branch of geology from the civil engineering point of view.

Structural geology:

The rocks, which form the earth's crust, undergo various deformations, dislocations and disturbances under the influence of tectonic forces. The result is the occurrence of different geological structures like folds, faults, joints and unconformities in rocks. The details of mode of formation, causes, types, classification, importance etc of these geological structures form the subject matter of structural geology.

Stratigraphy:

The climatic and geological changes including tectonic events in the geological past can also be known from these investigations. This kind of study of the earth's history through the sedimentary rock is called historical geology. It is also called stratigraphy (Strata = a set of sedimentary rocks, graphy description).

Economic geology:

Minerals can be grouped as general rock forming minerals and economic minerals. Some of the economic minerals like talc, graphite, mica, asbestos, gypsum, magnesite, diamond and gems. The details of their mode of formation, occurrence, classification, association, varieties, concentration, properties, uses form the subject matter of economic geology. Further based on application of geological knowledge in other fields there is many other allied branches collectively called earth science.

Some of them described here are:

- Engineering geology
- Mining geology
- Geophysics
- Geohydrology
- Geochemistry

Engineering geology:

This deals with the application of geological knowledge in the field of civil engineering, for execution of safe, stable and economic constructions like dams, bridges and tunnels.

Mining geology:

This deals with the application of geological knowledge in the field of mining. A mining engineer is interested in the mode and extent of occurrence of ores, their association, properties etc. It is also necessary to know other physical parameters like depth direction inclination thickness and reserve of the bodies for efficient utilization. Such details of mineral exploration, estimation and exploration are dealt within mining geology.

Geophysics:

The study of physical properties like density and magnetism of the earth or its parts. To know its interior form the subject matter of geophysics. There are different types of geophysical investigations based on the physical property utilized gravity methods, seismic methods, magnetic methods. Engineering geophysics is a branch of exploration geophysics, which aims at solving civil engineering problems by interpreting subsurface geology of the area concerned. Electrical resistivity methods and seismic refraction methods are commonly used in solving civil engineering problems.

Geohydrology:

This may also be called hydrogeology. It deals with occurrence, movement and nature of groundwater in an area. It has applied importance because ground water has many advantages over surface water. In general geological and geophysical studies are together taken up for groundwater investigations.

Geochemistry:

This branch is relatively more recent and deals with the occurrence, distribution, abundance, mobility etc, of different elements in the earth crust. It is not important from the civil engineering point of view.

3) Write a critical essay on weathering and its significance in engineering construction?

Weathering is defined as a process of decay, disintegration and decomposition of rocks under the influence of certain physical and chemical agencies.

Disintegration:

It may be defined as the process of breaking up of rocks into small pieces by the mechanical agencies of physical agents.

Decomposition:

It may be defined as the process of breaking up of mineral constituents to form

new components by the chemical actions of the physical agents.

Denudation:

It is a general term used when the surface of the earth is worn away by the chemical as well as mechanical actions of physical agents and the lower layers are exposed.

The process of weathering depends upon the following three factors:

- i) Nature of rocks
- ii) Length of time
- iii) Climate

Two Chief types of weathering are commonly distinguished on the basis of type of agency involved in the process and nature of the end product. They are:

- i) Physical or mechanical weathering
- ii) Chemical weathering

Physical weathering:

It is the physical breakdown of rock masses under the attack of certain atmospheric agents. A single rock block is broken gradually into smaller irregular fragments and then into particles of still smaller dimensions. It is the most active in cold, dry and higher areas of the earth surface. Temperature variations are responsible to a great extent of physical weathering.

Thermal effects:

The effect of change of temperature on rocks is of considerable importance in arid and semi arid regions where difference between daytime and nighttime temperature is often very high. Such temperature fluctuations produce physical disintegration in a normally expected manner. Expansion on heating followed by contraction on cooling. When the rock mass is layered and good thickness additional disturbing stresses may be developed into by unequal expansion and contraction from surface to the lower regions. The rock sometimes is found to break off into concentric shells. This process is known as exfoliation.

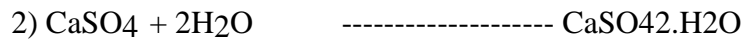
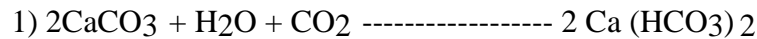
When weathering occurs part of the disintegrated rock material is carried away by running water or any other transporting agent. Some of them are left on the surface of the bedrock as residual boulders. It is often seen that boulders have an onion like structure. This kind of weathering is called spheroidal weathering.

Chemical weathering:

The chemical decomposition of the rock is called chemical weathering which is nothing but chemical reaction between gases of the atmosphere and minerals of the rocks.

The chemical changes invariably take place in the presence of water generally rainwater –in which are dissolved many active gases from the atmosphere like CO₂, nitrogen, Hydrogen etc. These conditions are defined primarily by chemical composition of the rocks humidity and the environmental surrounding the rock under attack.

Chemical weathering is essentially a process of chemical reactions between gases of the atmosphere and the surface rocks. For example:



Engineering importance of rock weathering:

As engineer is directly or indirectly interested in rock weathering specially when he has to select a suitable quarry for the extraction of stones for structural and decorative purposes. The process of weathering always causes a lose in the strength of the rocks or soil.

For the construction engineer it is always necessary to see that:

To what extent the area under consideration for a proposed project has been affected by weathering and

What may be possible effects of weathering processes typical of the area on the construction materials

4) Give an account of geological work of wind explaining briefly some major geological features?

The earth is surrounded by an envelop of gases called the atmosphere. The movement of the atmosphere in a direction parallel to the earth surface is wind.i.e the air in motion is called wind whereas the vertical movement s of the atmosphere are termed as air currents.

Erosion by wind and developed features:

Wind erosion is generally caused by two erosion processes:

- i) Deflation ii) Abrasion.

Deflation:

Deflation is the process of simply removing the loose sand and dust sized particles from as area, by fast moving winds. Wind deflation can successfully operate in comparatively dry regions with little or no rainfall and where the mantle is unprotected due to absence of vegetation.

Such a removal of loose fine particles may at certain places leave a denuded surface consisting mostly of hard rocks or coarse materials like gravel and is called lag gravel. This gravel layer prevents further deflation.

Abrasion:

The wind loaded with such particles attains a considerable erosive power which helps a considerable erosive power which helps in eroding the rock surfaces by rubbing and grinding actions and produce many changes. This type of wind erosion is known as abrasion.

Vertical column of rocks are thus more readily worn out towards their lower portions and as a result pedestal rocks are formed which wider tops have supported on comparatively narrower bases. Such type of rock formations is called Pedestal or Mushroom rocks.

Transportation by wind:

The total sediment load carried by a wind can be divided into two parts.

- a) Bed load
- b) Suspended load

The larger and heavier particles such as sands or gravels, which are moved by the winds but not lifted more than 30 to 60 cm of the earth surface constitute the bed load. Whereas the finer clay or dust particles which are lifted by the moving winds by a distance of hundreds of meters above the earth's surface constitute the suspended load.

Deposition of sediment by wind and the developed features:

The sediments get dropped and deposited forming what are known as Aeolian deposits. There are two types of Aeolian deposits;

- a) Sand dunes
- b) Loess

Sand dunes:

Sand dunes are huge heaps of sand formed by the natural deposition of wind blown sand sometimes of characteristics and recognizable shape. Such deposits are often found to migrate from one place to another due to change in the direction and velocity of wind.

The active dunes can be divided into three types:

- a) Barchans or Crescent shaped dunes
- b) Transverse dunes
- c) Longitudinal dunes

Barchans:

These dunes that look like a new moon in plan are of most common occurrence. They are triangular in section with the steep side facing away from the wind direction and inclined at an angle of about 30° to 33° to the horizontal.

The gently sloping side lies on the windward side, and makes an angle of about 10° to 15° with the horizontal. They may have variable sizes, with a generally maximum height of about 335 meters and horn to horn width of say 350 meters.

Transverse Dunes:

A transverse dune is similar to a barchans in section but in plan it is not curved like barchans such that its longer axis is broadly transverse to the direction of the prevailing winds.

Longitudinal dunes:

Longitudinal dunes are the elongated ridges of sand with their longer axis broadly parallel to the direction of the prevailing wind. When seen in the side view they will appear to be triangular on an average they may be 3 m height and 200 m long.

Loess:

The finest particles of dust travelling in suspension with the wind are transported to a considerable distance. When dropped down under favourable conditions these have been found to accumulate in the different constituents the form of paper-thin laminae, which have aggregated together to form a massive deposit known as Loess.

Engineering considerations:

In general no site is selected for any type of important work on the moving dunes because such dunes are always a source of trouble to an engineer. It has been experienced that sometimes the moving dunes damage certain important works. But if an engineer is compelled to select such a site, special methods should be adopted to check the motion of the moving dunes. For ex:

Either to construct windbreaks or growing vegetation on the surrounding areas.

5) Write short notes on

- a) Hydraulic action
- b) Cavitation
- c) Abrasion

- d) Attrition
- e) Corrosion

Hydraulic action:

It is the mechanical loosening and removal of the material from the rocks due to pressure exerted by the running water. 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. 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.

Cavitation:

It is distinct and rare type of hydraulic action performed by running water. It is particularly observed where river water suddenly acquires exceptionally high velocity such as at the location of a waterfall. In other words there is a spontaneous change from a liquid to vapour state and back to liquid state at that point. The phenomenon of cavitations is also observed in hydropower generation projects.

Abrasion:

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 grain, pebbles and gravels and all such particles that are being carried by its as load. These particles grains and rock fragments moving along with river water are collectively known as tools of erosion. The river valleys, water falls, escarpments, gorges and canyons and river terraces are some of the so well known examples developed principally by river abrasion.

Attrition:

This 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 collisions which they suffer during their transport. Every part of the sediment in load in suspension or being moved along the bed of the stream receives repeated impacts from other particles,. Due to these mutual collisions, the irregularities and angularities of the particles are worn out. These become spherical in outline

and rounded and polished at the surface. Some of the fragments are eventually get reduced to very fine particles that are easily carried along with the running water for considerable distances.

Corrosion:

The slow built steady chemical action of the stream water on the rocks is expressed by the term corrosion. The extent of corrosion depends such on the composition of rocks and also on the composition of flowing water. Thus all rocks are not equally susceptible to corrosive action of stream water. Limestones, gypsum and rock salt bodies are soluble in water to varying degrees. The steam may hardly corrode sandstones, quartzites, granites and gneisses.

6) Explain the causes, classification of earthquake?

The physical forces the surfaces are rearranging rock materials by shifting magmas about altering the structures of solid rocks. The adjustment beneath the surface however involve various crystal movements, some of which because of suddenness and intensity produce tremors in the rocks and they are known as earthquake. The science dealing with the study of earthquakes in all their aspects is called seismology.

Focus and epicenter:

The exact spot underneath the earth surface at which an earthquake originates is known as its focus. These waves first reach the point at the surface, which is immediately above the focus or origin of the earthquake. This point is called epicenter. The point which is diametrically opposite to the epicenter is called anticenter.

Intensity and magnitude:

Intensity of an earthquake may be defined as the ratio of an earthquake based on actual effects produced by the quakes on the earth.

Magnitude of a tectonic earthquake may be defined as the rating of an earthquake based on the total amount of energy released when the over strained rocks suddenly rebound, causing the earthquake.

Causes of earthquake:

The earthquake may be caused due to various reasons, depending upon its intensity. Following causes of earthquake are important:

1. Earthquakes due to superficial movements:

The feeble earthquakes are caused due to superficial movements, i.e., dynamic agencies, and operation upon surface of the earth.

The dashing waves cause vibrations along the seashore.

Water descending along high water falls, impinges the valley floor and causes vibrations along the neighbouring areas.

At high altitudes the snow falling down is an avalanche. also causes vibrations along the neighbouring areas.

2. Earthquake due to volcanic eruptions:

Most of the volcanoes erupt quietly and as consequence, initiate no vibration on the adjoining area. But a few of them when erupt, cause feeble tremors in the surface of the earth. But there may be still a volcanic eruption may cause a severe vibration on the adjoining area and have really disastrous effects.

3. Earthquake due to folding or faulting:

The earthquakes are also caused due to folding of the layers of the earth's crust. if the earthquakes are caused due to folding or faulting then such earthquakes are more disastrous and are known as tectonic earthquakes and directly or indirectly change the structural features of the earth crust.

Classification of earthquakes:

Earthquakes are classified on a no. Of basis. Of these the depth of focus, the cause of origin and intensity are important.

a) Depth of focus:

Three classes of earthquakes are recognized on this basis, shallow, intermediate and deep seated. In the shallow earthquakes the depth of focus lies anywhere up to 50 km below the surface. The intermediate earthquakes originate between 50 and 300 km depth below the surface.

b) Cause of origin:

- i) Tectonic earthquakes are originated due to relative movements of crystal block on faulting, commonly, earthquakes are of this type.
- ii) Non tectonic earthquakes: that owes their origin to causes distinctly different from faulting, such as earthquakes arising due to volcanic eruptions or landslides.

C) Intensity as basis:

Initially a scale of earthquakes intensity with ten divisions was given by Rossi and Ferrel. Which was based on the sensation of the people and the damage caused. However it was modified by Mercalli and later by Wood and Neumann.

Engineering considerations:

The time and intensity of the earthquake can never be predicted. The only remedy that can be done at the best, it is provide additional factors in the design of structure to minimize the losses due to shocks of an earthquake. This can be done in the following way:

- To collect sufficient data, regarding the previous seismic activity in the area.
- To assess the losses, which are likely to take place in furniture due to earthquake shocks
- To provide factors of safety, to stop or minimize the loss due to sever earth shocks.

Following are the few precautions which make the building sufficiently earthquake proof.

- The foundation of a building should rest on a firm rock bed. Grillage foundations should preferably be provided.
- Excavation of the foundation should be done up to the same level, throughout the building.
- The concrete should be laid in rich mortar and continuously
- Masonry should be done with cement mortar of not les than 1:4 max.
- Flat R.CC slab should be provided.
- All the parts of building should be tied firmly with each other.
- Building should be uniform height.
- Cantilivers, projections, parapets, domes etc, should be provided.
- Best materials should be used.

7) Briefly explain the origin and occurrence of ground water?

Groundwater hydrology may be defined as the science of the occurrence, distribution and movement of water below the surface of the earth. Ground water is the underground water that occurs in the saturated one of variable thickness and depth below the earth's surface. Groundwater is an important source of water supply throughout the world. Its use in irrigation, industries, urban and rural home continues to increase.

Origin of ground water:

Almost all groundwater can be thought of as a part of hydrologic cycle, including surface and atmospheric waters. Connate water is water entrapped in the interstices of sedimentary rock at the time it was deposited. It may have been derived from the ocean or fresh water sources and typically is highly mineralized. New water of magmatic, almost all ground water can be thought of as a part of the hydrologic cycle, including surface volcanic or cosmic origin added to the terrestrial water supply is juvenile water.

Ground water constitutes one portion of the earth water circulatory system known as the hydrologic cycle. Water bearing formations, of the earth crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations from the ground surface or from bodies of surface water

After which it travels slowly for varying distances until it returns to the surface by action of natural flow, plants or man. Ground water emerging into surface stream channels aids in sustaining stream flow when surface runoff is low or non-existent. Similarly water pumped from wells represents the sole water source in many regions during much of every year.

All ground water originates as surface water. Principal sources of natural recharge include precipitation, stream flow, lakes and reservoirs. Other contributions known as artificial recharge occur from excess irrigation, seepage from canals and water purposely applied to augment groundwater supplies. Discharge of ground water occurs when it emerges from underground. Most natural discharge occurs as flow into surface water bodies such as streams, lakes and oceans. Flow to the surface appears as spring. Groundwater near the surface may return directly to the atmosphere by evaporation from the soil and by transpiration from vegetation.

Occurrence of ground water:

Ground water occurs in permeable geologic formations known as aquifers. ie, formations having structures that permit appreciable water to move through them under ordinary field conditions. Ground water reservoir and water bearing formation are commonly used synonyms.

An aquitard is a formation, which only seepage is possible and thus the yield is insignificant compared to an aquifer. It is partly permeable. An aquiclude is an impermeable formation which may contain water but incapable of transmitting significant water quantities. An aquifuge is an impermeable formation neither containing nor transmitting water.

Porosity:

The portion of a rock or soil not occupied by solid mineral matter may be occupied by groundwater. These spaces are known as voids, interstices, pores or pore space. Because interstices can act as groundwater conduits they are of fundamental importance to the study of groundwater. Typically they are characterized by their size, shape, irregularity and distribution. Original interstices were created by geologic process governing the origin of the geologic formation and are found in sedimentary and igneous rocks. Secondary interstices developed after the rock was formed. Capillary interstices are sufficiently small so that surface tension forces will hold water within them. Depending upon the connection of interstices with others, they may be classed as communicating or isolated. The amount of pore space per unit volume of the aquifer material is called porosity. It is expressed as the percentage of void space to the total volume of the mass

Permeability:

As stated above the ground water is stored in the pores of rock and will hence be available in the ground rocks, only if they are sufficiently porous. The porosity of the rock, thus defining the maximum amount of water that can be stored in the rock. In fact the water

can enter into a rock only if the rock permits the flow of water through it, it depends on whether the rock is permeable or not. The size of the pores is thus quite an important factor and it should be sufficiently large to make the rock permeable.

Vertical distribution of groundwater:

The subsurface occurrence of groundwater may be divided into:

- i) Zones of saturation
- ii) Zones of aeration

In the Zones of Saturation water exists within the interstices and is known as the groundwater. This is the most important zone for a groundwater hydraulic engineer, because he has to tap out this water. Water in this zone is under hydrostatic pressure. The space above the water and below the surface is known as the zone of aeration. Water exists in this zone by molecular attraction.

This zone is also divided into three classes depending upon the number of interstices present. The capillary fringe is the belt overlying the zone of saturation and it does contain some interstitial water and is thus a continuation to the zone of saturation while the depth from the surface, which is penetrated by the roots of vegetation, is known as the soil zone.

UNIT-II**MINERALOGY****TWO MARKS QUESTIONS AND ANSWERS****1) Define mineralogy.**

It is defined as naturally occurring inorganic solid substance that is characterized with a definite chemical composition and very often with a definite atomic structure. It is a branch of geology, which deals with the various aspects related to minerals such as their individual properties their mode of formation and mode of occurrence.

2) How are minerals are identified and what are the symmetry elements of crystal?

Their colour, streak, hardness, cleavage, crystal form, specific gravity and lustre generally identify minerals. The symmetry elements are:

- i) Plane of symmetry
- ii) Axis of symmetry
- iii) Centre of Symmetry

3) What are the physical properties of minerals?

The physical properties are:

- i) Colour
- ii) Lustre
- iii) Streak
- iv) Hardness
- v) Cleavage
- vi) Fracture
- vii) Tenacity
- viii) Structure
- ix) Specific gravity
- x) Form
- xi) Miscellaneous

4) Define streak.

Streak is the colour of the finely powdered mineral as obtained by scratching or rubbing the mineral over a rough unglazed porcelain plate. The plate often named as streak plate. It is important and diagnostic property of many coloured minerals.

5) What is mean by fracture and types of fracture?

The appearance of the broken surface of a mineral in a direction other than that of cleavage is generally expressed by the term fracture. The types are:

- i) Even
- ii) Uneven
- iii) Conchoidal
- iv) Splinty
- v) Hackly
- vi) Earthy

7) Define Planes/axis/Centre of symmetry.

Plane of symmetry:

It divides a crystal into similar and similarly placed halves. This plane provides crystal so that one half is the mirror image of the other.

Axis of symmetry:

If is a crystal one being rotated, come to occupy the same position in space more than one in a complete turn, the axis about which rotation taken place is called an axis of symmetry.

Centre of symmetry:

A crystal has a centre of symmetry when like faces; edges are arranged in pairs in corresponding positions on opposite sides of a central point. The cube and bricks obviously have centre of symmetry.

9) What is mean by holohedral form?

The maximum symmetry elements of the system. The form is having all the faces, which have same position with regard to the crystallographic axis. The highest symmetry elements of the system. The forms present in normal class of the system are holohedral form since it has the maximum symmetry elements than the other classes.

10) Define hexagonal system.

All those crystals, which can be referred to four crystallographic axes of which three axes are horizontal, equal interchangeable and intersecting each other at 120° between the positive ends. The fourth axes are vertical and at right angles to the three horizontal axes, are grouped under hexagonal system.

11) Give the physical properties and uses of mica?

The mica group only muscovite and biotite are of common occurrence as rock forming

minerals.

S.no	properties	muscovite	biotite
1	Colour	Transparent, grey or light brown	Brown to black
2	Streak	Uncoloured	Same as colour
3	Cleavage	perfect	perfect
4	Lustre	Vitreous	Vitreous
5	Hardness	2-2-5	2-2-5
6	Specific gravity	2.8-3.1	2.6-3.1
7	System	Monoclinic	Monoclinic

12) What are the chemical compositions in feldspar group?

The feldspars are chiefly aluminosilicates of Na, K and Ca with following general formula:



In which W = Na, K, Ca and Ba and Z = Si and Al

Some examples of chemical composition of feldspar minerals are



13) Mention the various types of forms?

Any group of similar faces showing identical mathematical relations with crystallographic axes makes a form. Forms are further distinguished into the following types:

- Holohedral form
- Hemihedral form
- Hemimorphic form
- Enantiomorphic form
- Fundamental form
- Open and closed form

14) What are the five symmetry classes in Isometric system?

The types are:

a) **Axes of symmetry:** 13 in all

- 3 are axes of four-fold symmetry
- 4 are axes of three-fold symmetry
- 6 are axes two fold of symmetry

b) **Planes of Symmetry:** 9 in all

- 3 planes of symmetry are at right angles to each other and are termed the principal planes;
- 6 planes of symmetry are diagonal in position and bisect the angles between the principal planes.

15) Define tetragonal system?

The tetragonal system includes all those crystals, which can be referred to three crystallographic axes so that two axes are equal, interchangeable and horizontal in positions. The third axis is either longer or shorter than the other two and is vertical in position and all three axes are mutually at right angles to each other.

16) Give the three types of pyramid.

Three types of pyramid:

- i) Pyramid of first order: eight faces; each face cuts the two horizontal axis at equal length besides intersecting the vertical axis.
- ii) Pyramid of second order: Eight faces; each face cuts only one of the two horizontal axes.
- iii) Pyramid of third order: It is also called ditetragonal pyramid is a closed form of 16 faces in which each face cuts all the three crystallographic axes.

17) Draw the axial diagram for orthorhombic system?

The three crystallographic axes are arbitrarily designated as a, b and c. The b axis is always longer of the two horizontal axes and is also designated as macro axis. The a axis being shorter is designated as brachy axis.

18) Define dome and types of domes?

A dome is defined as a form whose faces essentially meets the vertical axis and are parallel to one of the two horizontal axes. Two types of domes:

- i) Macrodome: An open form of two faces in which each face meets the vertical axis and the a-axis and is parallel to the macro axis.
- ii) Brachycome: An open form of two faces each face is parallel to the brachy axis and meets the other two axes.

19) What are the forms allowed in monoclinic system?

The forms are:

- i) Pinacoids

- a) a- pinacoid
- b) b-pinacoid
- c) c-pinacoid
- ii) Domes
 - a) Orthodome
 - b) Clinodome
- iii) Prisms
 - a) Unit prism
 - b) Orthoprism
 - c) Clinoprism
- iv) Pyramids
 - a) Unit pyramid
 - b) Orthopyramid
 - c) Clino pyramid

20) Write short notes on:

- i) **Twin plane**
- ii) **Twin axis**

Twin plane:

It is a common to both the halves of the crystal and across which one half may appear to be the reflection of the other. Any plane parallel to a crystal face may be a twin plane.

Twin axis:

It is a crystallographic direction along which a rotation of some degrees seems to have produced the resultant twins. In other words if a backward rotation to the same extent is possible to be given the two parts should take the form of a single crystal.

21) What is the common twin law in Hexagonal system?

The laws are:

Brazilian Law: In this law the prism of Π^{nd} order is twin plane.

Dauphine law: In this law c-axis is the twinning axis. Twins are generally intergrown

Japanese law: In contact twins result on this law in which pyramid is a twinning plane.

22) Define peat.

It is essentially a partly changed vegetable matter in the first stage of transformation to coal. The vegetable structure is easily visible and the evidence of its being in the process of transformation is also clearly seen. Peat is generally composed of remains of moss like plants but

occasionally may contain reeds and partially altered portions of trees of higher order.

23) What is mean by cannel coal?

It is a type of bituminous coal, which is exceptionally rich in spores, and resins of plants, which are believed to have been deposited by wind in subsequence condition. The cannel coal is sometimes further distinguished as bog head coal, if in its constitution the algal remains are dominating over the spores and resins.

24) What are the possibilities may suggest in Inorganic theories?

The possibilities are:

- i) Reaction of alkali metals
- ii) Reaction of iron carbide
- iii) Concentration
- iv) Decomposition

25) Give any one factor in controlling the accumulation?

Lithology: Certain types of rocks are better suited as reservoirs because of their inherent qualities of permeability and effective porosity. Rocks with effective porosity of greater than 15 percent and permeability greater than 1000 millidarcies are considered 'A' class reservoirs.

16 MARKS QUESTIONS AND ANSWERS

1) Explain briefly about physical properties of minerals? (Nov 2005)

The following are the important physical properties:

- i) Color
- ii) Streak
- iii) Lustre
- iv) Structure
- v) Hardness
- vi) Specific gravity
- vii) Cleavage
- viii) Fracture
- ix) Tenacity
- x) Form

Color:

Color is not constant in most of the minerals and commonly the color is due to stain or impurities in the minerals some minerals show peculiar phenomena connected with color.

Play of colors: It is the development of a series of prismatic colors shown by some minerals or turning about in light.

Change of colors: It is similar to play of colors that rate of change of colors on rotation is rather slow.

Iridescence: Some minerals show rainbow colors either in their interior or on the surface. This is termed iridescence.

Streak:

The streak, which is the color of the mineral powder, is more nearly constant than the color. The streak is determined by marking unglazed porcelain or simply by scratching it with a knife and observing the color of the powder.

Lustre:

It is the appearance of a fresh surface of a mineral in ordinary reflected light. The following are the important terms used to denote the lustre of minerals.

Classy or vitreous lustre	-	Lustre like a broken glass
Metallic lustre	-	When a mineral has lustre like metal.
Pearly lustre	-	Lustre like pearls

Structure:

This is a term used to denote the shape and form of minerals. The following are the important terms used to denote the structures of minerals.

Columnar Structure	-	The mineral has a thick or thin column like Structures
Bladed Structure	-	The mineral has blade like structure.
Radiated structure	-	For columnar or fibrous diverging from central Points.
Lamellar structure	-	The mineral made of separable plates.
Botroidal structure	-	For an aggregate like bunch of grapes.
Reniform structure	-	For kidney shaped aggregate.

Hardness:

It is the resistance of mineral offers to abrasion or scratching and is measured relative to a standard scale of ten minerals known as Moh's scale of hardness.

Hardness	Name of the mineral
01	Talc
02	Gypsum
03	Calcite

04	Fluorite
05	Apatite
06	Orthoclase
07	Quartz

The scale comprises ten minerals arranged to order of ascending hardness; the softest is assigned a value of 1 and the hardest value of 10. Hardness of any mineral will lie in between these two limits.

Specific gravity:

It may be defined as the density of the mineral compared to the density of water and as such represents a ratio. i.e. specific gravity of a mineral is the ratio of its weight of an equal volume of water. Specific gravity of a mineral depends upon the weight and spacing of its atoms.

Cleavage:

It is defined as the tendency of a crystallized mineral to break along certain definite planes yielding more or less smooth surfaces. Cleavage is related to the internal structure of a mineral. The cleavage planes are always parallel to some faces of the crystal form typical of mineral. It is also described on the basis of perfection or the degree of easiness with which minerals can split along the cleavage planes.

Fracture:

The fractures of a mineral may be defined as the appearance of its broken surface. Common types of fractures are:

Conchoidal fracture	-	The broken surfaces show concentric rings or curved surface.
Even fracture	-	When the broken surface is smooth and flat.
Uneven fracture	-	When the mineral breaks with an irregular surface. It is a common fracture of many minerals.
Splintery structure	-	When the mineral breaks with a rough.

Tenacity:

Important properties related to tenacity of the minerals are expressed by the terms like malleability, flexibility, elasticity, sectility and mellability etc. when a mineral can be cut with a knife it is termed "sectile" and if the slice cut out from it can be flattened under a hammer. It is also said "malleable" "brittle" minerals. Term elastic is used if it regains its former shape as the pressure is released.

Form:

The internal atomic arrangement of a mineral is manifested outwardly by development of

geometrical shapes or crystal characters. The forms may be following three types:

- | | | |
|-----------------|---|--|
| i crystallized | – | When the mineral occurs in the form of well defined crystals. |
| ii Amorphous | - | When it shows absolutely no signs or evidence of crystallization. |
| iii Crystalline | - | when well-defined crystals are absent but a marked tendency Towards crystallization. |

Miscellaneous:

Some of the special properties are mentioned below:

Magnetism:

Some minerals are highly magnetic, e.g. magnetite, whereas few others may be feebly magnetic like spinels and tourmaline.

Electricity:

Some minerals an electric charge may be developed by heating in some others same effect results by applying pressure.

Fluorescence:

This term express property of some minerals to emit light when exposed to radiation.

Phosphorescence:

It is similar to fluorescence in essential character but in this case light is emitted not during the act of exposure to radiation but after the substance is transferred rapidly to dark place.

2) Write short notes on

- i) Symmetry**
- ii) Crystallographic axis**

Symmetry:

Symmetry is understood a sort of regularity in the arrangement of faces on the body of a crystal. Symmetry is a property of fundamental importance for a crystal. It can be studied with reference to three different characters, commonly called elements of symmetry. These are:

- A plane of symmetry
- An axis of symmetry
- Centre of symmetry

A plane of symmetry

Any imaginary plane passing through the centre of a crystal in such a way that it divides the crystal in two exactly similar halves is called plane of symmetry. In other words, a plane of symmetry is said to exist in a crystal when for each face, edge or solid angle there is another similar face, edge or solid angle occupying identical position on the opposite side of this plane.

An axis of symmetry:

It is defined as an imaginary line in a crystal passing through its centre in such a way that when a crystal is given a complete rotation along this line a certain crystal face comes to occupy the same position at least twice. The nature of the axis of the symmetry is of four types:

Axis of Binary or twofold symmetry

This requires that a crystal must be rotated by an angle of 180° to bring the reference face to occupy the same position.

Axis of Trigonal or threefold symmetry

It is that axis on which a crystal must be rotated by an angle of 120° for a reference face to occupy the same position again in space.

Axis of tetragonal or fourfold symmetry

It is that axis on which the crystal must be rotated by an angle of 90° to bring a reference face to the same position in space.

Axis of hexagonal or six fold symmetry:

In which a rotation of 60° is required to fulfil the condition of repetition of reference face.

Centre of symmetry

A crystal is said to possess a centre of symmetry if on passing an imaginary line from some definite face, edge or corner on one side of the crystal through its centre another exactly similar face or edge or corner is found on the other side at an equal distance from the centre.

ii) CRYSTALLOGRAPHIC AXES

These are also termed as axes of reference and are simply certain imaginary lines arbitrarily selected in such a way that all of them pass through the centre of an ideal crystal. The concept of axes of reference is based on the fact that exact mathematical relations exist between all the faces on a given crystal with reference to its centre.

In crystallography following general assumptions have been universally agreed upon regarding these crystallographic lines:

- a) Three Straight Lines, essentially passing through a common centre and varying in mutual relationships with respect to their lengths and angular inclinations from: all equal, Interchangeable and it is right to all unequal and inclined with each other.
- b) Four straight lines, essentially passing through a common centre; one vertical, being unequal to the other three but at right angles to them. The three horizontal axes are separated from each other at 120°

The concept of crystallographic axis has been the basis of classifying all the crystalline substances into six crystal systems.

3) Define the following terms

- i) **Parameter**
- ii) **Indices**
- iii) **Symbols**
- iv) **Forms**

The numerical expression for such a relationship of a given crystal face with the crystallographic axes is variously termed as Parameters, index or a symbol each term having its own significance.

Parameters

The relative intercepts made by a crystal face on the three crystallographic axes are known as its parameters. For instance in the three crystallographic axes are represented by XOX' , YOY' and ZOZ' . With their relative lengths as $Ox=a$, $Oy=b$ and $Oz=c$

Let us consider a face represented by a plane ijk occurring on this crystal. The intercepts of this plane with the three axes are oi , oj and ok . Which expressed in terms of the lengths of the axes is $1a$, $1/3b$, $1/2c$. Therefore $1a$, $1/3b$ and $1/2c$ are parameters of the face. These are generally expressed as parametrical ratios as $1a:1/3b:1/2c$

Indices

In common practice the relationship of a crystal face with the crystallographic axes is expressed in simple whole numbers, which are called indices. These indices are however always based on and derived from the parameters. There are a number of methods for deriving indices from parameters such as the Neumann system and Miller system.

In the miller system the indices for a given crystal face are derived from its parameters in two simple steps:

- i) By taking the reciprocals of the parameters actually obtained for the given face.
- ii) By clearing fractions if any by simplifications and omitting the letters for the axes in the final expression.

Symbol

It is the simplest and most representative of the indices for a set of similar faces that constitute a crystallographic form. For instance in this fig there are six exactly identical crystal faces, which have same mathematical relationship with all the three crystallographic axes. Obviously the six faces together make a form in which each face has an identical mathematical relationship with the three axes. This statement can also be mathematically written as 100 which as generalization for all the six face of this particular form.

Forms

Any group of similar faces showing identical mathematical relations with crystallographic axes makes a form. Forms are further distinguished into following types:

holohedral form, hemihedral form, and hemomorphic form, enantimorphic form, and fundamental form, open and closed form.

Holohedral form

It is that form in a crystal system which shows development of all the possible faces in its domain. For instance, octahedron is a holohedral form because it shows all the eight faces developed on the crystal; generally holohedral forms develop in the crystals of highest symmetry in a crystal system. Such class of highest symmetry in a system is called its normal class.

Hemihedral form

It shows as the name indicates only half the number of possible faces of a corresponding holohedral form of the normal class of the same system. As such all hemihedral forms may be assumed to have been derived from holohedral forms. The two complimentary hemihedral forms will necessarily embrace all the faces and characters of the parent holohedral form.

Hemimorphic form

It is also derived from a holohedral form and has only half the number of faces as in hemihedral form. In this case however all the faces of the form are developed only i-on one extremity of the crystal. Being absent from the other extremity. In other words such a crystal will not be symmetrical with reference to a centre of the symmetry.

Enantiomorphous form

It is composed of faces placed on two crystals of the same mineral in such a way that faces on one crystal become the mirror image of the form of faces on the other crystal. The forms and the corresponding crystal showing these forms are referred as left and right handed.

Fundamental form

It is also called a unit form. It designates that type of any given form in which the parameters essentially correspond to the unit lengths of the crystallographic axes. A form having a symbol is essentially a fundamental form whereas another form also intercepting the three axes at different lengths.

Open and closed forms

A form is defined as closed when on full development it makes a fully enclosed solid. In an open form space cannot be fully enclosed by it and entry from one or more sides is possible.

4) Give a detailed account of the elements of the symmetry and minerals crystallizing in any two of the following systems.

- i) Isometric system**
- ii) Hexagonal system**
- iii) Monoclinic system**

Isometric system:**Definition:**

All those crystals that can be referred to three crystallographic axes, which are essentially equal in length at right angles to each other, and mutually interchangeable, are said to belong to the isometric or cubic system.

Axial diagram

Since all the three axes are equal and interchangeable these are represented by the letter a. In the study position however the axes may be designated as a_1, a_2 and a_3 the last being vertical.

Classes

Five symmetry classes fall in the Isometric system by virtue of their country. The normal class is known as galena type. It has got the following symmetry.

a) Axes of symmetry: 13 in all

- 3 are axes of four-fold symmetry
- 4 are axes of three-fold symmetry
- 6 are axes two fold of symmetry

b) Planes of Symmetry: 9 in all

3 planes of symmetry are at right angles to each other and are termed the principal planes;

6 planes of symmetry are diagonal in position and bisect the angles between the principal planes.

c) It has centre of symmetry.**Forms**

Following are the forms that commonly develop in the crystals belonging to isometric system.

1. Cube: A form bounded by six similar square faces each of which is parallel to two of three crystallographic axes and meets the third axis.
2. Octahedron: A form bounded by eight similar faces each of the shape of an equilateral triangle each meeting the three crystallographic axes at equal distances.
3. Dodecahedron: It is form with twelve similar faces each of which is parallel to one of the three crystallographic axes and meets the other two at equal distances.
4. Trisoctahedron: A form of twenty four faces; each face meeting two axes at unit length and to the third at greater than unity.
5. Trapezohedron: A form of 24 faces each faces meeting one axes at unit length and to the other two at greater than unity.

6. Hexa octahedron: 48 faces; each face meets the three axis at unequal distances.

7. Tetra hexahedron: 24 faces each face meeting one axes and meet other to at unequal distance which are simple multiple of each other.

Other classes:

Isometric system comprises five symmetry classes in all. Beside the normal class following three classes are also represented among the minerals.

.Pyritohedral Class

a) Symmetry	7 axes of symmetry of which 3 are axial axes of two fold symmetry 4 are diagonal axes of two fold symmetry, 3 planes of symmetry. A centre of symmetry.
b) Forms	Pyritohedron and Diploid are two typical forms of this symmetry class. Diploid is a closed form of twenty-four faces that typically occur in pairs.

2. Tetrahedral class

a) Symmetry	7 axes of symmetry, 6 planes of symmetry diagonal, no centre of symmetry.
b) Forms	Most typical form of this class is a four-sided solid in which each face is an equilateral triangle. It is termed tetrahedron. It has a general symbol.

Hexagonal system

All those crystals, which can be referred to four crystallographic axes of which

- i) Three axes are horizontal, equal, interchangeable and intersecting each other at 120° between the positive ends.
- ii) The fourth axes are vertical and at right angles to the three horizontal axes are grouped under the hexagonal system.

Axial diagram

The horizontal axes all being equal are designated by the letter a(a_1, a_2, a_3) and the vertical axis by the letter 'c' as usual.

Forms

Forms of hexagonal system differ in character from forms of all the other systems in that their parameters, indices and symbols are determined with respect to four crystallographic axes. Thus the general form expresses the relation of any hexagonal form.

1. Base: An open form of two faces in which each face meets the vertical axis only.
2. Prisms: A prism as defined earlier is an open form in which each face is essentially parallel to the vertical axis.

Following three types of prisms are met with in the hexagonal system.

- a) Prism of 1st order. An open form of six faces in which each face is parallel to one of the three horizontal axes besides the vertical axis. It cuts the two horizontal axes at unit length.
- b) Prism of 2nd order. An open form of six faces like prism of 1st order but in this case each face cuts all the three horizontal axes, two axes at equal length and to the third at greater length.
- c) Prism of 3rd order: It is also called a dihexagonal prism as it has double the number of faces compared to the six faces of prism of 1st order.

Monoclinic system

The monoclinic system includes all those forms that can be referred to three crystallographic axes which are essentially unequal in length and further that can be of these is always inclined.

Axial diagram

All the three axes are unequal, they are designated by the letters a, b and c. The c axis is always vertical. The inclined axis is a- axis. It is inclined towards the observer and is also referred as clino axis.

Normal class symmetry

There are three symmetry classes placed in monoclinic system. The symmetry of the normal class is as given below:

a) Axis of Symmetry	1 axis of two fold symmetry only
b) Planes of symmetry	1 plane of symmetry only. And a centre of symmetry. The plane of symmetry is that plane which contains the crystallographic axes a and c

Forms

The common forms of this system are

1) Pinacoid

it is an open form of two faces, each face being parallel to the two axes and cutting the third at a unit length. Three pinacoids are distinguished in the monoclinic system.

2. Domes

A dome is also form of two faces, each face meeting the vertical axis and one of the other two axes. It is a parallel to the third axis. Two types of domes are recognized:

- i) Orthodome
- ii) Clinodome

3. Prisms

There are three types of prisms is there;

- i) Unit prism
- ii) Orthoprism
- iii) Clinoprism

4. Pyramid

These are closed forms and in these each face meets all the three axes.

- i) Unit pyramid
- ii) Orthopyramid
- iii) Clinopyramid

5) What is mean by Twinning and types of twin and common twin laws?

A group of two crystals mutually united and intimately related are called TWINS and the phenomenon of their formation is called twinning.

Terminology

Terms commonly used in the explanation of twin Laws are: Twin plane, Twin axis, and composition plane.

Twin plane:

It is such a plane in a twin crystal, which is common to both the halves of the crystal and across which one half may appear to be the reflection of the other.

Twin axis:

It is a crystallographic direction along which a rotation of some degrees seems to have produced the resultant twins. The twin axis is other than the axis of two fold, four fold, and symmetry.

Types of twins:

The following types are:

Contact Twins:

In this type the component parts of a twin crystal are held together along a well defined composition plane.

Penetration twins:

In these twins the contact plane is not well defined. In fact the two parts of twin crystal may appear to be inter penetrating to each other.

Simple Twins:

When a twin crystals has very well defined two halves held together according to easily understanding relationships these may be said as simple twins.

Common twin laws

Following is a brief outline of the most commonly observed twin laws in different crystallographic system.

Isometric system**Spinal law:**

It is so named because of its presence in minerals of spinal group. In this law, octahedral face is the twin palce, which is also in most cases.

Tetragonal system**Rutile law**

The face of pyramid of IInd order is the twinning plane. This is the most common law for the crystals of the tetragonal system.

Hexagonal system**Brazilian Law:**

In this law the prism of IInd order is a twin plane. Quartz shows development of twins according to this law.

Dauphine law:

In this law c-axis is the twinning axis. Twins are generally intergrown. Some quartz twin also based on this law.

Japanese law:

Contact twins result on this law in which pyramid is a twinning plane.

Orthorhombic system

In this system, crystals show twinning in a variety of ways of which following are more common.

- a) When the prism angle is about 60° and the twinning is repeated.
- b) When the prism angle is 70°

Staurolite Twinning. This mineral shows cruciform twins of two types.

Right angled cross: These result when the face is a twinning plane

Sea horse twin in which the face is a twin plane.

In both cases the twins are of penetration type.

Monoclinic system

The following laws are the most common and in no case exclusive.

Carlsbad law:

The c-axis is the twinning axis. The minerals commonly show interpenetration or contact type of twinning.

Baveno law:

The mineral shows twinning with clino dome as the twinning plane.

Man Bach law:

Here, the basal pinacoid is a twinning plane.

Triclinic system**Albite law**

In this plane parallel to b-pinacoid is the twinning plane.

Per cline law

The twinning axis is easily defined as the one parallel to b-axis. The twins may be repeated polysynthetic type.

6) Describe the classification and formation of coal?

The term coal is generally applied to a sedimentary formation of highly carbonaceous character that is derived from vegetable matter involving set of process such as burial, compaction and biochemical transformation.

Classification

A number of classifications for coals are available of these the one most widely adopted is based on the rank of coal that defines degree of transformation of wood into coal through the natural processes of deposition, compaction and biochemical changes.

Peat

It is essentially a partly changed vegetable mater in the first stage of transformation to coal. The vegetable structure is easily visible and the evidence of its being in the processes of transformation. to coal. Peat is generally composed of remains of moss like plants but occasionally may contain reeds and partially altered portions of trees of higher order.

Types: Two types of peat are commonly recognized:

- i) Bog Peat, which is evolved out of lower type of vegetation, like mosses.
- ii) Mountain Peat that is decomposed and partially altered form of higher type's of trees.

Uses:

Peat is a low value fuel in its application .It finds uses where available in abundance as i) Domestic fuel ii) gas purifier iii) For steam raising.

Lignite

It is a variously coloured variety of coal of lowest rank. In lignite transformation of vegetable matter to coal like material is almost complete. Fibrous texture is also shown by some lignite's.

Composition: Typical lignite has following composition:

Fixed Carbon : 50 percent; oxygen 20-25 percent
Hydrogen : 05 ppercent;nitrogen 02-05 percent
Sulphur: 01-02 percent.

Uses: These are used as domestic fuels and also in industry for distillation and gasification. This

variety of coal has also been used in steam locomotives and for producing gas.

Bituminous

It is also known as the common coal, sometimes as coking coal and is, in fact, the most common and important variety of commercial coals. These are commonly black in colour, compact in structure breaking into almost cubical fragments when struck with hammer. They have a black streak. Bituminous coals burn freely leaving only a small mineral residue.

Types and composition:

The common bituminous coal is sometimes distinguished into three different types on the basis of its carbon content: sub-bituminous, bituminous and semi-bituminous coals.

Anthracite

It is a coal of the highest rank in which the original organic source has been completely transformed into carbonaceous substance. It is very hard, jet black in colour, compact in structure and showing an almost metallic luster.

Uses:

Anthracite is a favourite domestic fuel where available. It is also used for steam raising and other heating purposes. However because of its very low volatile matter content it is not suitable for making coke.

Formation of coal

There is absolutely no doubt regarding the nature of the source material from which coal is derived it is certainly always vegetable matter of one type or another. The two types of sources yielded vegetable material for the formation of the coal.

i) The higher
vegetation:

It includes herbs, shrubs and trees, growing on the plains, plateaus, sub-mountainous areas and characterized with wood tissue rich in cellulose and lignin and protein this type of source has been named as the humic sediment.

ii) The lower
vegetation:

It comprising chiefly plank tonic algae, as often found at the bottom of lakes and seas, submerged under water. This source has been named as sapropelic sediments. On the basis of place of accumulation of the source material, the environment could be distinguished as:

Geosynclinal type:

When accumulation took place in great sea basins characterized with considerable depth.

Intermediate type:

When deposition of source material took place along the sea shores at shallower depths.

Platform type:

Such as lagoons, lake basins and marshes and swamps. In these littoral environments decomposition of cellulose from humic organic matter is an easily accomplished process. IN other environment also the process may take the route of transport of source material its accumulation, compaction, dehydration and polymerisation to bituminous coal to anthracite are all environment dependent. These are completed in a better manner in geosynclinal situations that is under great depths in the presence of heat and pressure and seldom reach completion in littoral conditions.

Summarisingly the transformation of organic source material into coal takes place due to:

- i) Bio chemical decomposition which is achieved by certain type of bacteria and involves breakdown of organic matter of wood into coal constituents.
- ii) Dynamical chemical transformation which involves alteration of original coal structure into more compact, metamorphosed varieties chiefly under the influence of temperature and pressure factors.

UNIT-3 PETROLOGY

1. Define Igneous Rocks?

All rocks that have formed from an original hot, molten material through the process of cooling and crystallization may be defined as Igneous Rocks.

2. Explain about Hypabyssal Rocks?

These Igneous Rocks are formed at Intermediate depths, generally up to 2 Km, below the surface of earth and exhibit mixed characteristics of volcanic and plutonic rocks. Porphyries of various compositions are example of Hypabyssal Rocks.

3. Define Texture of Igneous Rocks?

The term texture has been defined as the mutual relationship of different mineralogical constituents in a rock. It is determine by size, shape and arrangement of these constituents within the body of rock.

4. What are the factors Explaining Texture?

a) Degree of Crystallization

Holocrystalline, Holohyaline.

b) Granularity

Coarse grained, Medium grained, Fine grained.

c) Fabric

Panidiomorphic, Allotrimorphic, Hypidiomorphic.

5. Define Equigranular and Inequigranular Texture?

All those textures in which majority of constituent crystals of rock are broadly equal in size are described as equigranular textures. All those textures in which majority of constituent minerals show marked difference in their relative grain size are grouped as inequigranular textures.

6. Define Structure of Igneous Rocks?

Those feature of Igneous Rocks that are developed on a large scale in the body of an extraction or intrusion giving rise conspicuous shapes or forms are included under the term structures. They may be so well developed as to be recognized easily on visual inspection or they become apparent only when this section of such rocks is examined under microscope. In latter case they are termed microstructure.

7. What are the numbers of factor depending on Igneous Rocks?

a) The structural deposition of the host rock (also called country rock).

b) The viscosity of the magma or lava.

c) The composition of the magma or lava.

d) The environment in which injection of magma or eruption of lava place.

8. Classification of Rocks?

- Ø IGNEOUS ROCKS
- Ø SEDIMENTARY ROCKS
- Ø METAMORPHIC ROCKS

9.. Write about igneous Rocks?

IGNEOUS ROCKS

- Ø Rocks that have formed from an originally hot molten material through the process of cooling and crystallisation may be defined as Igneous rocks.

Important Conditions For The Original Material

- Ø very high temperature and
- Ø a molten state

10.Explain about Magma?

The hot molten material occurring naturally below the surface of the Earth is called magma.

- ✓ It is called lava when erupted through volcanoes.
- ✓ Igneous rocks are formed both from magma and lava.
- ✓ It maybe mentioned here that magma is actually a hypothetical melt.
- ✓ Lava is a thoroughly studied material that has poured out occasionally from volcanoes in many regions of the world again and again.
- ✓ Magma or lava from which igneous rocks are formed may not be entirely a pure melt: it may have a crystalline or solid fraction and also a gaseous fraction thoroughly mixed with it.
- ✓ The solid and gaseous fractions, however, form only a small part of the magma or lava, which are predominantly made up of liquid material igneous rock.

11.What is mean by hypabyssal rocks?

- Ø These igneous rocks are formed at intermediate depths, generally up to 2 kms below the surface of the earth and exhibit mixed characteristics of volcanic and plutonic rocks.
- Ø Porphyries of various compositions are **examples** of hypabyssal rocks.

12. What is mean by Batholiths?

- Ø These are huge bodies of igneous masses that show both concordant and discordant relations with the country rock.
- Ø Their dimensions vary considerably but it is generally agreed that to qualify as a batholith the igneous mass should be greater than 100 square kilometers in area and its depth should not be traceable. This is typical of batholiths: they show extensive downward enlargement
- Ø In composition, batholiths may be made of any type of igneous rock.
- Ø They also exhibit many types of textures and structures. But as, a matter of observation, majority of batholiths shows predominantly granitic composition,

texture and structure.

13. Write about Granites ?

- Ø **Definition** Granites may be defined as plutonic light coloured igneous rocks.
- Ø These are among the most common igneous rocks.
- Ø **Composition.** Two most common and essential mineral constituents of granite are: Quartz and Felspar.
- Ø Quartz is always recognized by its glassy lustre, high hardness ($H = 7$), and cleavage less transparent white appearance.
- Ø Felspars making granites may be of two varieties: the potash felspars, commonly orthoclase and the soda-bearing felspars like albite and oligoclase.

14. Write about Diorite ?

Definition.

Ø It is an intermediate type of igneous rock of plutonic origin with silica percentage generally lying between 52-66 per cent.

Composition.

- Ø Diorites are typically rich in felspar plagioclase of sodic group (e.g. Albite).
- Ø Besides plagioclase and alkali felspars, diorites also contain accessory minerals like hornblende, biotite and some pyroxenes.
- Ø Quartz is not common but may be present in some varieties that are then specially named as quartz-diorites.

15. What is mean by Andesite ?

Definition.

- Ø These are volcanic rocks in which plagioclase felspars (sodic and sub-calcic varieties like albite, andesine and labradorite) are the predominant constituents making the potash felspar only a subordinate member.

16. What is mean by Dolerites ?

Definition.

- Ø These are igneous rocks of typically hypabyssal origin having formed as shallow sills and dykes
- Ø They may be regarded as equivalents of gabbros of plutonic origin and basalts of volcanic origin.

Composition.

- Ø Dolerites are predominantly made up of calcic plagioclase (e.g. anorthite and labradorite).

17. What is mean by Basalts ?

Definition

- Ø Basalts are volcanic igneous rocks formed by rapid cooling from lava flows from volcanoes either over the surface or under water on oceanic floors. They are basic in character.

18. Define Sedimentary Rocks ?

- Ø Sedimentary rocks are also called secondary rocks.
- Ø This group includes a wide variety of rocks formed by accumulation, compaction and consolidation of sediments.

- Ø The sediments may be defined as particles produced from the decay and weathering of pre-existing rocks or may be derived from remains of dead sea or land animals in suitable environments.
- Ø The accumulation and compaction of these sediments commonly takes place under water or at least in the presence of water.

19. Write about sandstones ?

- Ø Sandstones are mechanically formed sedimentary rocks of Arenaceous Group.
- Ø These are mostly composed of sand grade particles that have been compacted and consolidated together in the form of beds in basins of sedimentation.
- Ø The component grains of sandstones generally range in size between 2mm and 1/16 mm. Silica in the form of very resistant mineral QUARTZ is the dominant mineral constituent of most sandstones.

20. Write about Shale ?

- Ø Shale is a fine-grained sedimentary rock of argillaceous (clayey) composition.
- Ø Shales are generally characterized with a distinct fissility (parting) parallel to the bedding planes and are made up of very fine particles of silt grade and to some extent of clay.
- Ø Besides fissility, some shales show the laminated structure.

21. Write about limestone ?

Definition

- Ø These are the most common sedimentary rocks from the non-clastic-group and are composed chiefly of carbonate of calcium with subordinate proportions of carbonate of magnesium.
- Ø They are formed both bio-chemically and mechanically.

Composition

- Ø Pure limestone is invariably made up of mineral calcite (CaCO_3).
- Ø In terms of chemical composition, limestone's are chiefly made up of CaO and CO_2 , Magnesium Oxide is a common impurity in most limestone's; in some its percentage may exceed 2 percent, the rock is then called magnesian limestone.

22. Write about Dolomite ?

Definition.

- Ø It is a carbonate rock of sedimentary origin and is made up chiefly more than 50 percent - of the mineral dolomite which is a double carbonate of calcium and magnesium with a formula of $\text{CaMg}(\text{CO}_3)_2$.

- Ø Ferrous iron is present in small proportions in some varieties.
- Ø Gypsum also makes appearance in some dolomites.
- Ø But the chief associated carbonate is that of calcium, in the form of calcite.

23. What is mean by Coals ?

Definition.

- Ø These may broadly be defined as metamorphosed sedimentary rocks of carbonaceous character in which the raw material has mostly been supplied by plants of various groups.

24. What is mean by Anthracite ?

- Ø It is considered the highest-grade coal with fixed carbon ranging between 92-98 per cent.
- Ø It has highest calorific value in coals and burns almost without any smoke, as the volatile matter is negligible.

25. Write about METAMORPHIC ROCKS ?

METAMORPHISM is the term used to express the process responsible for all the changes that take place in an original rock under the influence of changes in the surrounding conditions of temperature, pressure and chemically active fluids.

26. Define METAMORPHIC ROCKS ?

- Ø Metamorphic rocks are defined as those rocks which have formed through the operation of

Stress Minerals

various types of metamorphic processes on the pre-existing igneous and sedimentary rocks involving changes in textures, structures and mineralogical compositions.

- Ø The direction of change depends upon the type of the original rock and the type of metamorphic process that operates on the rock.
- Ø Heat, pressure and chemically active fluids are the main agents involved in metamorphic processes.
- Ø Plastic deformation, recrystallisation of mineral constituents and development of parallel orientation are typical characters of metamorphic rocks.

27. What is mean by CLASSIFICATION OF METAMORPHIC ROCKS ?

- Ø Metamorphic rocks have been variously classified on the basis of texture and structure, degree of metamorphism, mineralogical composition and mode of origin etc.
- Ø A very general two-fold classification based on the presence or absence of layered structure or

(a) **Foliated Rocks**

(b) **Non-Foliated Rocks**

28. Write about Foliated Rocks ?

- Ø All metamorphic rocks showing development of conspicuous parallelism in their mineralogical and structural constitution falling under the general term foliation are grouped together as foliated rocks.
- Ø The parallelism indicating features include slaty cleavage, schistosity and gneissose structures
- Ø Typical rocks included in this group are slates, phyllites, schists and gneisses of great variety.

29. Write about Non-Foliated Rocks ?

- Ø Included in this group are all those metamorphic rocks characterised with total or nearly total absence of foliation or parallelism of mineralogical constituents.
- Ø Typical examples of non-foliated rocks are quartzites, hornfels, marbles, amphibolites and soapstone etc.

30. What is meant by ROCKS SLATE ?**Definition**

- Ø Slate is an extremely fine-grained metamorphic rock characterized by a slaty cleavage by virtue of which it can be readily split into thin sheets having parallel smooth surfaces.
- Ø The slaty cleavage is due to parallel arrangement of platy and flaky minerals of the slate under the dominant stresses operating during the process of metamorphism.

16 ARK QUESTIONS AND ANSWERS**1. BRIEFLY CLASSIFICATION OF ROCKS?**

- Ø IGNEOUS ROCKS
- Ø SEDIMENTARY ROCKS
- Ø METAMORPHIC ROCKS

IGNEOUS ROCKS

- Ø Rocks that have formed from an originally hot molten material through the process of cooling and crystallization may be defined as igneous rocks.

Important Conditions For The Original Material

- Ø very high temperature and
- Ø a molten state

COMPOSITION**Magma**

- ✓ The hot molten material occurring naturally below the surface of the Earth is called magma.
- ✓ It is called lava when erupted through volcanoes.
- ✓ Igneous rocks are formed both from magma and lava.
- ✓ It maybe mentioned here that magma is actually a hypothetical melt.
- ✓ Lava is a thoroughly studied material that has poured out occasionally from volcanoes in many regions of the world again and again.
- ✓ Magma or lava from which igneous rocks are formed may not be entirely a pure melt: it may have a crystalline or solid fraction and also a gaseous fraction thoroughly mixed with it.
- ✓ The solid and gaseous fractions, however, form only a small part of the magma or lava, which are predominantly made up of liquid material igneous rock.

Igneous rocks are divided into following three sub-groups

Volcanic rocks

- Ø These are the igneous rocks formed on the surface of the Earth by cooling and crystallisation of lava erupted from volcanoes.
- Ø Since the lava cools down at very fast rate (compared to magma), the grain size of the crystals formed in these rocks is very fine, often microscopic.
- Ø Further, cooling of lava may take place on the surface or even under waters of seas and oceans, the latter process being more common.

Plutonic Rocks

- Ø These are igneous rocks formed at considerable depths-generally between 7-10 km below the surface of the earth.
- Ø Because of a very slow rate of cooling at these depths, the rocks resulting from magma are coarse grained.
- Ø These rocks get exposed on the surface of the earth as a consequence of erosion of the overlying strata.
- Ø Granites, Syenites, and Gabbros are a few **examples** of Plutonic rocks.

Hypabyssal Rocks

- Ø These igneous rocks are formed at intermediate depths, generally up to 2 kms below the surface of the earth and exhibit mixed characteristics of volcanic and plutonic rocks.
- Ø Porphyries of various compositions are **examples** of hypabyssal rocks.

COMPOSITION

Mineralogical composition

- Ø Igneous rocks like other rock groups are characterised by the abundance of only a few, minerals.

<i>S.No</i>	<i>Mineral</i>	(%)	<i>S.No</i>	<i>Mineral</i>	(%)
(i)	Felspars	59.5	(v)	Titanium	1.5
(ii)	Pyroxenes & Amphiboles	16.8	(vi)	Apatite	0.6
(iii)	Quartz	12.0	(vii)	Accessory Minerals	5.8
(iv)	Biotite	3.8			

TEXTURES OF IGNEOUS ROCKS

- ∅ The term texture is defined as the mutual relationship of different mineralogical constituents in a rock. It is determined by the size, shape and arrangement of these constituents within the body of the rock.

Factors Explaining Texture

The following three factors will primarily define the type of texture in a given igneous rock:

Degree of Crystallization

- ∅ In an igneous rock, all the constituent minerals may be present in distinctly crystallized forms and easily recognized by unaided eye, or, they may be poorly crystallized or be even glassy or non-crystallized form.
- ∅ The resulting rock textures are then described as:
- (i) Holocrystalline: When all the constituent minerals are distinctly crystallized;
- (ii) Holohyaline: When all the constituents are very fine in size and glassy or non-crystalline in nature.

∅ The term **merocrystalline** is commonly used to express the intermediate type, *i.e.* when some minerals are crystallized and others are of glassy character in the same rock.

∅ Rocks with **holocrystalline** texture are also termed as phaneric and the holohyaline rocks are referred as aphinitic. The term microcrystalline is used for the textures in which the minerals are perceptibly crystallized but in extremely fine grain.

Granularity

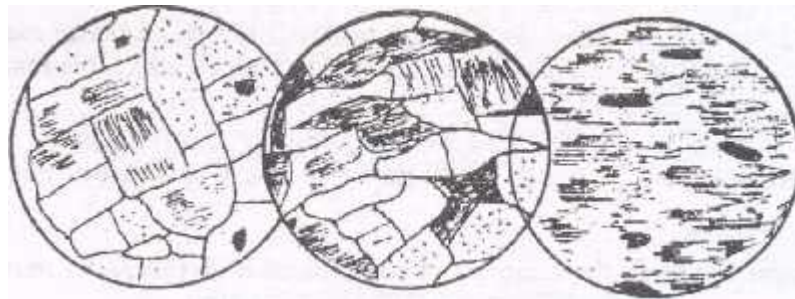
- ∅ The grain size of the various components of a rock are the average dimensions of different constituent minerals which are taken into account to describe the grain size of the rock as a whole. Thus the rock texture is described as :

(i) **Coarse-grained**. When the average grain size is above 5 mm; the constituent

minerals

are then easily identified with naked eye.

(ii) **Medium-grained**. When the average grain size lies between 5 mm and 1 mm. Use of magnifying lens often becomes necessary for identifying all the constituent mineral components.



(iii) **Fine-grained**. When the average grain size is less than 1 mm. In such rocks, identification of the constituent mineral grains is possible only with the help of microscope for which very thin rock sections have to be prepared for microscopic studies

Fabric

- Ø This is a composite term expressing the relative grain size of different mineral constituents in a rock as well as the degree of perfection in the form of the crystals of the individual minerals.
- Ø The texture is termed as equigranular when all the component minerals are of approximately equal dimensions and as inequigranular when some minerals in the rock are exceptionally larger or smaller than the other.
- Ø Similarly, the shape or form of the crystals, which is best seen only in thin sections under microscope, may be described as perfect, semi perfect or totally irregular. The textural terms to describe these shapes are, respectively, euhedral, subhedral and anhedral.
- Ø An igneous rock may contain crystals of anyone type in a predominating proportion; hence its fabric will be defined by one of the following three terms related to fabric:
 - (i) **Panidiomrphi**: when majority of the components are in fully developed shapes;
 - (ii) **Hypidiomorphic**: the rock contains crystals of all the categories: euhedral, subhedral or anhedral;

(iii) **Allotriomorphic**: when most of the crystals are of anhedral or irregular shapes

Types of Textures

These can be broadly divided into five categories:

- . Equigranular textures
- . Inequigranular textures
- . Directive textures
- . Intergrowth textures and
- . Intergranular textures.

(1) Equigranular Textures

- ∅ All those textures in which majority of constituent crystals of a rock are broadly equal in size are described as equigranular textures.
- ∅ In igneous rocks, these textures are shown by granites and felsites and hence are also often named as granitic and felsitic textures
- ∅ In the granitic texture, the constituents are either all coarse grained or all medium grained and the crystals show euhedral to subhedral outlines.
- ∅ In the felsitic texture, the rock is micro granular, the grains being mostly microscopic crystals but these invariably show perfect outlines.
- ∅ Thus felsitic textures may be described as equigranular and panidiomrphic.
- ∅ Orthophyric texture is another type of equigranular texture, which is in between the granitic and felsitic textures. The individual grains are fine in size but not microgranular.

(2) Inequigranular Texture

- ∅ Igneous textures in which the majority of constituent minerals show marked difference in their relative grain size are grouped as inequigranular texture.
- ∅ Porphyritic and Poiklitic textures are important examples of such textures.
- ∅ Porphyritic Texture is characterised by the presence of a few conspicuously large sized crystals
(the phenocrysts) which are embedded in a fine-grained ground mass or matrix.
- ∅ The texture is sometimes further distinguished into mega-porphyritic and microporphyritic depending upon the size of the phenocrysts.

Difference in. molecular concentration

- ∅ When the magma is rich in molecules of particular mineral, the latter has better chance to grow into big crystals which may get embedded in the fine-grained mass resulting from the deficient components.

Change in physico-chemical conditions.

- ∅ Every magma is surrounded by a set of physico-chemical conditions like temperature, pressure and chemical composition, which influence the trend of crystallisation greatly.

- Ø Abrupt and discontinuous changes in these textures may result in the formation of the crystals of unequal dimensions.
- Ø Thus, magma crystallizing at great depths may produce well-defined, large sized crystals.
- Ø When the same magma (carrying with it these large crystals) moves upward, the pressure and temperature acting on it are greatly reduced.
- Ø Crystallisation in the upper levels of magma becomes very rapid resulting in a fine-grained matrix that contains the big sized crystals formed earlier.

Relative insolubility

- Ø During the process of crystallisation, their crystal grains get enlarged whereas crystals of other soluble constituents get mixed up again with the magma; thus, the relatively insoluble constituents form the phenocrysts
- Ø And the soluble constituents make up the ground mass crystallizing towards the end.

(3) Directive Textures

- Ø The textures that indicate the result of flow of magma during the formation of rocks are known as directive textures.
- Ø These exhibit perfect or semi perfect parallelism of crystals or crystallites in the direction of the flow of magma.
- Ø Trachytic and Trachytoid textures are common examples.
- Ø The former is characteristic of certain felspathic lavas and is recognised by a parallel arrangement of feldspar crystals; the latter is found in some syenites.

(4) Intergrowth Textures

- Ø During the formation of the igneous rocks, sometimes two or more minerals may crystallize out simultaneously in a limited space so that the resulting crystals are mixed up or intergrown.
- Ø This type of mutual arrangement is expressed by the term intergrowth texture.
- Ø Graphic and granophyric textures are examples of the intergrowth textures.
- Ø In graphic texture, the intergrowth is most conspicuous and regular between quartz and feldspar crystals. In granophyric textures the intergrowth is rather irregular.

(5) Intergranular Textures

- Ø In certain igneous rocks crystals formed at earlier stages may get so arranged that polygonal or trigonal spaces are left in between them.
- Ø These spaces get filled subsequently during the process of rock formation by crystalline or glassy

masses of other minerals.

∅ The texture so produced is called an intergranular texture. Sometimes the texture is specifically termed intersertal if the material filling the spaces is glassy in nature.

FORMS OF IGNEOUS ROCKS

An igneous mass will acquire on cooling depends on a number of factors such as

- (a) the structural disposition of the host rock (also called the country rock)
- (b) the viscosity of the magma or lava
- (c) the composition of the magma or lava
- (d) the environment in which injection of magma or eruption of lava takes place.

It is possible to divide the various forms of igneous intrusions into two broad classes:

All those intrusions in which the magma has been injected and cooled along or parallel to the structural planes of the host rocks are grouped as concordant bodies.

Forms of concordant bodies

Sills

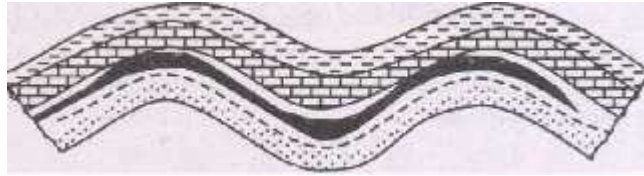
- ∅ The igneous intrusions that have been injected along or between the bedding planes or sedimentary sequence are known as sills.
- ∅ It is typical of sills that their thickness is much small than their width and length. Moreover, this body commonly thins out or tapers along its outer margins.
- ∅ The upper and lower margins of sills commonly show a comparatively finer grain size than their interior portions. This is explained by relatively faster cooling of magmatic injection at these positions
- ∅ In length, sills may vary from a few centimeters to hundreds of meters

Sills are commonly subdivided into following types:

- (a) **Simple Sills:** formed of a single intrusion of magma;
- (b) **Multiple Sills:** which consist of two or more injections, which are essentially of the same kind of magma;
- (c) **Composite Sills:** which result from two or more injections of different types of magma;
- (d) **Differentiated Sills:** these are exceptionally large, sheet-like injections of magma in which there has been segregation of minerals formed at various stages of crystallisation into separate layers or zones.
- (e) **Interformational Sheets:** the sheet of magma injected along or in between the planes of unconformity in a sequence are specially termed as interformational sheets. These resemble the sills in all other general details.

- ∅ These are concordant, small sized intrusive that occupy positions in the troughs and crests of bends called folds. In outline, these bodies are doubly convex and appear crescents or half-moon shaped in cross-section.
- ∅ As regards their origin, it is thought that when magma is injected into a folded sequence of rocks, it passes to the crests and troughs almost passively *i.e.* without exerting much pressure.

Phacoliths



Laccoliths

- Ø These are concordant intrusions due to which the invaded strata have been arched up or deformed into a dome.
- Ø The igneous mass itself has a flat or concave base and a dome shaped top.
- Ø Laccoliths are formed when the magma being injected is considerably viscous so that it is unable to flow and spread for greater distances.
- Ø Instead, it gets collected in the form of a heap about the orifice of eruption. As the magma is injected with sufficient pressure, it makes room for itself by arching up the overlying strata.
- Ø Extreme types of laccoliths are called bysmaliths and in these the overlying strata get ultimately fractured at the top of the dome because of continuous injections from below.

Lopoliths

- Ø Those igneous intrusions, which are associated with structural basins, that are sedimentary beds inclined towards a common centre, are termed as lopoliths.
- Ø It is believed that in the origin of the lopoliths, the formation of structural basin and the injection of magma are "contemporaneous", that is, broadly simultaneous.

DISCORDANT BODIES

- Ø All those intrusive bodies that have been injected into the strata without being influenced by their structural disposition (dip and strike) and thus traverse across or oblique to the bedding planes etc. are grouped as discordant bodies.
- Ø Important types of discordant intrusions are dykes, volcanic necks and batholiths.
- Ø These may be defined as columnar bodies of igneous rocks that cut across the bedding plane or unconformities or cleavage planes and similar structures.
- Ø Dykes are formed by the intrusion of magma into pre-existing fractures.

- Ø It depends on the nature of magma and the character of the invaded rock whether the walls of the fracture are pushed apart, that is, it is widened or not.
- Ø Dykes show great variations in their thickness, length, texture and composition.
- Ø They may be only few centimeters or many hundreds of metres thick.
- Ø In composition, dykes are generally made up of hypabyssal rocks like dolerites, porphyries and lamprophyres, showing all textures between glassy and phaneritic types.
- Ø **Cone sheets and Ring Dykes** may be considered as the special types of dykes.
- Ø The cone sheets are defined as assemblages of dyke-like injections, which are generally inclined towards common centres.
- Ø Their outcrops are arcuate in outline and their inclination is generally between 30° - 40°.
- Ø The outer sheets tend to dip more gently as compared to the inner ones
- Ø **Ring Dykes** are characterised by typically arcuate, closed and ring shaped outcrops.
- Ø These may be arranged in concentric series, each separated from the other by a screen of country rock.
- Ø They show a great variation in their diameter; their average diameter is around 7 kilometers. Few ring dykes with diameters ranging up to 25 kms are also known.
- Ø **Origin of dykes** It has been already mentioned that dykes are intrusions of magma into pre-existing fractures present in the rocks of the crust.
- Ø These original fractures are generally caused due to tension.
- Ø Their original width might have been much less than the present thickness of the dykes.
- Ø This indicates widening of the cracks under the hydrostatic pressure of magmatic injection.

Volcanic Necks

- Ø In some cases vents of quiet volcanoes have become sealed with the intrusions.
- Ø Such congealed intrusions are termed volcanic necks or volcanic plugs.
- Ø In outline these masses may be circular, semicircular, or irregular and show considerable variation in their diameter. The country rock generally shows an inwardly dipping contact.

Batholiths

- Ø These are huge bodies of igneous masses that s

how both concordant and discordant relations with the country rock.

- Ø Their dimensions vary considerably but it is generally agreed that to qualify as a batholith the igneous mass should be greater than 100 square kilometers in area and its depth should not be

traceable. This is typical of batholiths: they show extensive downward enlargement

- Ø In composition, batholiths may be made of any type of igneous rock.
- Ø They also exhibit many types of textures and structures. But as, a matter of observation, majority of batholiths shows predominantly granitic composition, texture and structure.

2. EXPLAIN ABOUT IMPORTANT IGNEOUS ROCKS?

Granites

- Ø Definition Granites may be defined as plutonic light coloured igneous rocks.
- Ø These are among the most common igneous rocks.
- Ø Composition. Two most common and essential mineral constituents of granite are: Quartz and Felspar.
- Ø Quartz is always recognized by its glassy lustre, high hardness ($H = 7$), and cleavage less transparent white appearance.
- Ø Felspars making granites may be of two varieties: the potash feldspars, commonly orthoclase and the soda-bearing feldspars like albite and oligoclase.
- Ø Felspar microcline may also be present in some granites.
- Ø Among the accessory minerals in granites, micas deserve first mention. Both varieties (muscovite or white mica and biotite or black mica) are present in small proportions in most apatite, garnet and tourmaline.

Granites are generally coarse to medium grained, holocrystalline (phaneric) and equigranular rocks. Granitic, graphic, porphyritic and intergrowth textures are the most common types of textures met with in granites of different varieties.

- Ø As regards structures, granites occur in large massive bodies, often as batholiths, stocks and bosses beside in usual intrusive bodies like sills and dykes.
- Ø Many types of granites are distinguished on the basis of relative abundance in them of some particular accessory mineral.
- Ø For instance, when white mica, muscovite is present as a prominent accessory mineral, the granite may be distinguished as muscovite granite.
- Ø Similarly, when it is the black mica or biotite, which is a prominent accessory mineral, the granite may be called a biotite-granite. When both the biotite and muscovite are present

Types

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- Ø For instance, when white mica, muscovite is present as a prominent accessory mineral, the granite may be distinguished as muscovite granite.
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Occurrence

- Ø Granites are the most widely distributed igneous rocks in the crust of the earth.
- Ø They occur chiefly as deep-seated intrusive bodies like sills, bosses, stocks and batholiths.
- Ø Their occurrence on the surface of the earth is attributed to prolonged weathering and erosion of the overlying strata through historical times running over millions of years.

Megasacopic Identification. Granites may be identified in hand specimens by their:

- (i) Light-coloured (leucocratic) appearance, such as grey, pink, brownish and yellowish.
Some of the shades may take brilliant polish to make it eminently suitable as a decorative building stone.
- (ii) Coarse to medium-grained texture; fine-grained granites are rare specimens.
- (iii) Abundance of quartz and felspar orthoclase as essential minerals.

Use

- Ø Granites find extensive use in architectural and massive construction where they are found in abundance.
- Ø These rocks have been used extensively in monuments and memorials, as columns and steps and as flooring in buildings.

Orgin

- Ø Many minor granitic bodies occurring as sills and similar masses are clearly of igneous plutonic origin.
 - Ø Their formation from parent magma through the normal process of cooling and crystallisation is easily accepted.
 - Ø But exceptionally large bodies like batholiths and stocks and bosses running over hundreds of square kilometers close to or on the surface are not accepted by many as simple igneous intrusions mainly because of their extensive dimensions.
 - Ø These large granitic masses are believed by many to have been formed from pre-existing rocks through the process of granitization.

Variations

Following variations appear in the composition of these rocks:

- Ø the relative proportion of quartz (SiO_2) falls gradually so that in diorites it is reduced to a subordinate
- Ø felspar orthoclase, which is a dominant mineral in granites, is reduced in relative amount and replaced by felspar plagioclase in granodiorites.
- Ø In diorites, it is felspar plagioclase that makes the bulk of felspar constituent. A number of rock types get distinguished on the basis of this variation.
- Ø For example, adamellite is a variety of granodiorites that contains felspar orthoclase and plagioclase in equal proportion.

3.Explain about Diorite ?

Definition.

Ø It is an intermediate type of igneous rock of plutonic origin with silica percentage generally lying between 52-66 per cent.

Composition.

- Ø Diorites are typically rich in felspar plagioclase of sodic group (e.g. Albite).
- Ø Besides plagioclase and alkali felspars, diorites also contain accessory minerals like hornblende, biotite and some pyroxenes.
- Ø Quartz is not common but may be present in some varieties that are then specially named as quartz-diorites.

Texture.

Ø In texture, diorites show quite close resemblance to granites and other plutonic, rocks. They are coarse to medium grained and holocrystalline.

Occurrence

- Ø Diorites commonly occur as small intrusive bodies like dikes, sills, stocks and other irregular intrusive masses.
- Ø They also get formed at the margins of bigger igneous masses.

4. Explain about Andesite ?

Definition.

- Ø These are volcanic rocks in which plagioclase felspars (sodic and sub-calcic varieties like albite, andesine and labradorite) are the predominant constituents making the potash felspar only a subordinate member.

Composition.

- Ø Besides plagioclase and potash felspars, andesites may contain small amount of quartz as well as biotite, hornblende, augite, olivine and hypersthene from the dark minerals giving them an overall grayish or darker appearance.

Occurrence

- Ø Andesites are known to be quite abundant volcanic rocks, next only to basalts and may occur as crystallized lava flows of extensive dimensions.
- Ø Petrologists are sharply divided over the origin of andesites. Some believe them to be the products of normal crystallisation from a mafic magma whereas others think that some andesites may be the products from mixed magmas or magmas enriched with fragments from the wall rocks.
- Ø The second view is supported by the presence of some foreign materials in andesites.

Syenites

Definition

- Ø Syenites are defined as igneous, plutonic, even-grained rocks in which alkali-felspars (including orthoclase and albite) are the chief constituent minerals.
- Ø They may contain, besides these essential constituents, dark minerals- like biotite, hornblende, augite and some accessories

Composition.

- Ø The most common feldspars of syenites are orthoclase and albite; microcline, oligoclase and anorthite are also present in them in subordinate amounts.
- Ø In some syenites, the feldspathoids (nepheline, leucite) also make appearance.
- Ø Common accessory minerals occurring in syenites are apatite, zircon, and sphene.
- Ø Quartz so common in granites is altogether absent or is only a minor accessory in syenites.

Texture

- Ø Syenites show textures broadly similar to those of granites, that is, they are coarse to medium- grained, holocrystalline in nature and exhibiting graphic, inter- grown or porphyritic relationship among its constituents.

5. Explain about Dolerites?**Definition.**

- Ø These are igneous rocks of typically hypabyssal origin having formed as shallow sills and dykes
- Ø They may be regarded as equivalents of gabbros of plutonic origin and basalts of volcanic origin.

Composition.

- Ø Dolerites are predominantly made up of calcic plagioclase (e.g. anorthite and labradorite).
- Ø Dark minerals like augite, olivine and iron oxide etc. are also present in good proportion in dolerites along with the plagioclase minerals.
- Ø Dolerites are mostly medium to fine grained rocks.
- Ø Ophitic and porphyritic textures are quite common in many dolerites.

Occurrence.

- Ø Sills and dykes of doleritic composition have been recorded at many places associated with magmatic activity.
- Ø In the Singhbhum region of south Bihar, India, many doleritic dykes traverse the Singhbhum granites.

6. Discuss about Basalts?**Definition**

- Ø Basalts are volcanic igneous rocks formed by rapid cooling from lava flows from volcanoes either over the surface or under water on oceanic floors. They are basic in character. .

Composition.

- Ø Basalts are commonly made up of calcic plagioclase feldspars (anorthite and labradorite) and a number of ferro-magnesian minerals like augite, hornblende, hypersthene, olivine, biotite and iron oxides etc.

- Ø In fact many types of basalts are distinguished on the basis of the type and proportion of ferro- magnesian minerals in them.
 - Ø Thus, for instance, Basanite is an olivine-rich basalt and Tephrite is an olivine-free type basalt.
- The olivine free basalts, that are quite abundant in occurrence, are sometimes named collectively as Tholeiites.

Occurrence.

- Ø Basaltic rocks form extensive lava flows on the continents and also on the oceanic floors in almost all the regions of the world.
- Ø In India, the Deccan Traps, which are of basaltic and related rocks, are spread over more than four hundred thousand square kilometers in Maharashtra, Gujarat, Madhya Pradesh and adjoining parts of Indian Peninsula.

Pegmatites

- Ø These are exceptionally coarse-grained igneous rocks formed from hydrothermal solutions emanating from magmas that get cooled and crystallized in cavities and cracks around magmatic intrusions.
- Ø These rocks are searched for their containing big sized crystals of minerals. Some of these crystals may be gems and other precious minerals.

Composition

- Ø Pegmatites exhibit great variation in their mineral composition.
- Ø The granite pegmatites contain alkali feldspars and quartz as the dominant minerals. Crystals of some minerals in exceptionally big sizes have been found from pegmatites at many places.

Texture and Structure

- Ø Pegmatites do not show any special textures and structures except that they are invariably coarse grained and mostly inequigranular.
- Ø In many pegmatites, the so-called complex pegmatites, a zonal structure is commonly observed.
In such cases, different minerals of pegmatite occur in different zones starting from the periphery and proceeding towards the centre.
- Ø In a five-zoned pegmatite, for instance, the outermost zone is made up of muscovite and feldspar, the second zone is of quartz and feldspar, third zone of microcline and fourth of quartz. The central zone is polymineralic containing albite and spodumene besides quartz and mica.

Origin.

- Ø Petrologically, pegmatites of complex composition are known to occur.
- Ø **First.** Pegmatites have been formed from magmatic melts towards the end of the process of crystallisation, The hydrothermal fractions left behind at this stage are capable of taking in solution all metallic and non-metallic components by virtue of their temperature, pressure and chemical reactivity.
- Ø Most of the granite- and syenite -pegmatites are believed to have been formed through this mode.
- Ø **Second.** Pegmatites have formed due to replacement reactions between the hydrothermal solutions and the country rock through which these liquids happen to pass.
- Ø Hydrothermal liquids at elevated temperatures are considered quite effective in replacing original minerals by new minerals.

Occurrence.

- Ø Pegmatites occur in a variety of forms as dykes, veins, lenses and patches of irregular masses.

Use

- Ø Pegmatites are the source of many precious stones, gems, ores of rare-earths and heavy metals besides the industry grade muscovite mica.

Aplites

- Ø These are igneous rocks of plutonic origin but characterized with a fine-grained, essentially equigranular, allotriomorphic texture.
- Ø Essential minerals of the aplites are the same as that of granites, that is, feldspars and quartz.
- Ø They commonly occur as dykes and are formed from magmas that have different gaseous content compared to magmas from which granites are formed.

Lamprophyre**Texture.**

- Ø Panidiomorphic (in which most of crystals show perfect outline), fine grained and holocrystalline.

Composition

- Ø Lamprophyres show a great variation in their mineralogical composition.
- Ø Mostly they are rich in ferro-magnesian silicates. Important minerals forming lamprophyres are:
biotite, augite and other pyroxenes, hornblende and other amphiboles, feldspars and olivine.

Types.

- Ø Many types of lamprophyres are distinguished on the basis of the type of feldspar and the dark minerals occurring in them.
- Ø Thus, Minette is, a lamprophyre containing feldspar orthoclase and the black mica, biotite; Vogesite is another variety having feldspar orthoclase and augite or

hornblende.

Peridotites

Definition

- Ø The term peridotite is commonly used to express the ultra-mafic igneous rocks that are highly rich in a ferro-magnesian mineral OLIVINE, which has a composition of $(Mg,Fe)SiO_4$.

The chief characteristics of peridotites are:

- (i) **Low silica index**; such rocks invariably contain less than 45% silica.
- (ii) **High colour index**; rich as they are in dark minerals, the colour index of peridotites is always above 70, generally in the range of 90-100.

Texture. Peridotites are generally massive and coarse grained in texture.

Varieties. A number of types of peridotites are distinguished on the basis of the accessory minerals, e.g. hornblende-peridotite, pyroxene-peridotite etc. Kimberlite is a peridotite in which olivine is altered to serpentine.

Occurrence. Peridotites generally form sills and dykes of moderate size.

Origin

- Ø A number of modes of origin have been suggested for peridotites.
- Ø Hess believes them to be the products of primary peridotitic magma, a view that is very strongly objected by many others.
- Ø Another view holds them having been formed from a primary basic (basaltic) magma from which olivine and other mafic minerals were separated by some process.
- Ø A third possibility suggested regards the development of peridotite bodies simply as a result of hydrothermal (pneumatolytic) transport of their material and its subsequent reaction with rocks of appropriate composition.

ENGINEERING IMPORTANCE

- Ø Many of igneous rocks, where available in abundance, are extensively used as materials for construction.
 - Ø Granites, syenites and dolerites are characterized by very high crushing strengths and hence can be easily trusted in most of construction works.
 - Ø Basalts and other dark coloured igneous rocks, though equally strong, may not be used in residential building but find much use as foundation and road stones.
 - Ø The igneous rocks are typically impervious, hard and strong and form very strong foundations for most of civil engineering projects such as dams and reservoirs.
 - Ø They can be trusted as wall and roof rocks in tunnels of all types unless traversed by joints. At the same time, because of their low porosity, they cannot be expected to hold oil or groundwater reserves.

- Ø Some igneous rocks like peridotites and pegmatites are valuable as they may contain many valuable minerals of much economic worth.

7. BRIEFLY EXPLAIN ABOUT SEDIMENTARY ROCKS ?

- Ø Sedimentary rocks are also called secondary rocks.
- Ø This group includes a wide variety of rocks formed by accumulation, compaction and consolidation of sediments.
- Ø The sediments may be defined as particles produced from the decay and weathering of pre-existing rocks or may be derived from remains of dead sea or land animals in suitable environments.
- Ø The accumulation and compaction of these sediments commonly takes place under water or at least in the presence of water.

FORMATION

- Ø The process of formation of sedimentary rocks is ever prevailing.
- Ø The sediments so produced are transported to the settling basins such as sea floors where they are deposited, get compacted and consolidated and finally transformed into a cohesive solid mass.
That is a sedimentary rock.
- Ø Some chemical processes especially evaporation and precipitation regularly operate on surface of water bodies containing dissolved salts and produce solids that settle down in those bodies.
- Ø Sedimentary rocks are broadly grouped into three classes on the basis of their mode of formation: Mechanically formed or Clastic Rocks; Organically formed Rocks and Chemically formed Rocks
- Ø The last two groups are considered as a single class and named as Non-Clastic Rocks.
Clastic (Mechanically Formed) Rocks
- Ø A series of well-defined steps are involved in the formation of clastic rocks.

Decay and Disintegration

- Ø Rocks existing on the surface of the earth are exposed to decay and disintegration by the action of natural agencies like atmosphere, water and ice on them
- Ø The original hard and coherent rock bodies are gradually broken down into smaller and still smaller fragments, grains and particles.
- Ø The disintegrated, loosened material so formed and accumulated near the source is called detritus.
Hence, clastic rocks are often also called as detrital rocks

Transport of Sediments

- ∅ The detritus produced from the decay and disintegration of the pre-existing rocks forms the source of the sedimentary rocks but it has to be transported to a suitable place for transformation again into a rock mass.
- ∅ The wind, running water and ice in the form of glaciers are the very strong and common agents of transport for carrying millions of tonnes of sediments and particles from one place to another including seas and oceans.
- ∅ The winds transport the sediments from ploughed fields, the deserts and dry lands in series of jumps (saltation) and in suspension modes.
- ∅ These loads of sediments are dropped down wherever intercepted by rains.
- ∅ The mightiest agents of transport of sediments are, of course, streams and rivers, all terminating into lakes or seas.
- ∅ The running water bodies transport the sediment load as bed-load, suspended-load and dissolved load, all dumped at the settling basins.
- ∅ Ice in the form of huge moving bodies called glaciers also breaks the rocks along their bases and sides (in valley glaciers) and dumps the same at snow lines thereby making large volumes of the clastic load available for further transport by other agencies. It is easy to imagine that millions of tonnes of land mass as scratched by these surface agencies is transported to seas and oceans every year and deposited there.

Dradual deposition

- ∅ The sediments as produced through weathering and erosion are transported to settling basins.
These basins may be located in different environments such as on the continents, along the seashores or in deep-sea environments.
- ∅ As such sedimentary rocks formed in different environments will show different inherent characters.
- ∅ In the continental environments may be included the glacial deposits, the fluvial deposits, the glacio-fluvial deposits and the eolian deposits, each type giving rise to a definite type of sediment accumulation.
- ∅ In the marine deposits, some sediments may be dropped just along the sea-shore, or at some shallow depth within the sea or miles away in the deep-sea environment.

Diagenesis

- ∅ The process of transformation of loose sediments deposited in the settlement basins to solid cohesive rock masses either under pressure or because of cementation is collectively known as diagenesis.
- ∅ It may be achieved by either of the two methods: **welding or cementation.**

- Ø **Welding** is the process of compaction of the sediments accumulated in lower layers of a basin due to the pressure exerted by the load of the overlying sediments.
- Ø This results in squeezing out all or most of the water from in between the sediments, thus bringing them closer and closer and consolidating them virtually in a solid rock mass.
- Ø In fact the degree of packing of sediments in a sedimentary rock is broadly directly proportional to the load of the overlying sediments.
- Ø **Cementation** is the process by which loose grains or sediments in a settlement basin get held together by a binding material.
- Ø The binding material may be derived from within the accumulated particles or the fluids that percolate through them and also evaporate or precipitate around those particles thus binding them in a rock like mass.

Chemically Formed (Non-clastic) Rocks

- Ø Water from rains, springs, streams, rivers, lakes and underground water bodies dissolves many compounds from the rocks with which it comes into contact.
- Ø In most cases all these dissolved salts are carried by the running water to its ultimate destination the sea.
- Ø Hence the brackish or saltish taste of the sea water.
- Ø In many other cases also, the local water-bodies may get saturated with one or other dissolved salt.
- Ø In all cases, a stage may be reached when the dissolved salts get crystallized out either through evaporation or through precipitation.
- Ø Thus, limestone may be formed by precipitation from carbonated water due to loss of carbon dioxide.
- Ø Rock salt may be formed from sodium-chloride rich seawater merely by the process of continued evaporation in bays and lagoons.
- Ø Chemically formed rocks may be thus of two types: precipitates and evaporites. Examples are lime stones, rock salt, gypsum, and anhydrite.

Organically Formed (Non-clastic) Rocks

- Ø These extensive water bodies sustain a great variety of animal and plant life.
- Ø The hard parts of many sea organisms are constituted chiefly of calcium and/or magnesium, carbonates.
- Ø Death and decay of these organisms within the water bodies gradually results into huge accumulations of carbonate materials, which get compacted and consolidated in the same manner as the normal sediments.
- Ø Lime stones are the best examples of organically formed sedimentary rocks

TEXTURES

(i) Origin of Grains

- ∅ A sedimentary rock may be partially or wholly composed of clastic (or allogenic) grains, or of chemically formed or organically contributed parts.
- ∅ Thus the rock may show a clastic texture or a non-clastic texture.

(ii) Size of Grains

- ∅ The grain size in the sedimentary rocks varies within wide limits.
- ∅ Individual grains of less than 0.002 mm and more than 250 mm may form a part or whole of these rocks.

Three textures recognized on the basis of grain size are:

- | | |
|------------------------|--|
| Coarse -grained rocks; | average grain size > 5 mm |
| Medium grained rocks; | average grain size between 5 and 1 mm. |
| Fine-grained rocks; | average grain size < 1 mm |

(iii) Shape of Grains

- ∅ The sediments making the rocks may be of various shapes: rounded, sub rounded, angular and sub angular.
- ∅ They may show sphericity to various degrees.
- ∅ Roundness and sphericity are the indications of varying degree of transport and abrasion suffered during that process.
- ∅ Thus, Breccias are made up mostly of rough and angular fragments indicating least transport and abrasion.
- ∅ Conglomerates are full of rounded and smooth-surfaced pebbles and gravels indicating lot of transport and rubbing action during their transport before getting deposited and consolidated into a rock mass.

(iv) Packing of Grains.

- ∅ Sedimentary rocks may be open-packed or porous in textures or densely packed depending upon their environment of formation.
- ∅ The degree of packing is generally related to the load of the overlying sediments during the process of deposition.

(v) Fabric of Grains

- ∅ A given sedimentary rock may contain many elongate particles.
- ∅ Their orientation is studied and described in terms of orientation of their longer axes.
- ∅ If all or most of the elongated particles are arranged in such a way that their longer axes lie in the same general direction, the rock is said to show a high degree of preferred orientation. This direction is generally indicative of the direction of flow of the current during the period of deposition.

(vi) Crystallisation Trend

- ∅ In sedimentary rocks of chemical origin, the texture is generally defined by the degree and nature of crystallized grains.
- ∅ Rocks may show perfectly interlocking grains giving rise to crystalline granular texture or they may be made up of non-crystalline, colloidal particles when they are

termed as amorphous.

IMPORTANT SEDIMENTARY ROCKS

1. Breccia

- ∅ It is a mechanically formed sedimentary rock classed as Rudite.
- ∅ It consists of angular fragments of heterogeneous composition embedded in a fine matrix of clayey material.
- ∅ The fragments making breccia are greater than 2mm average diameter but some times these may be quite big in dimensions.
- ∅ The angularity of the fragments indicates that these have suffered very little or even no transport after their disintegration from the parent rocks. On the basis of their source, following types of breccia are commonly recognized:

∇ Basal Breccia

This rock is formed by the sea waters advancing over a coastal region covered with fragments of chert and other similar rocks. The advancing waters supply the fine mud, which is spread over the rock fragments and acts as a binding material. Once the seawater retreats, the loose chert fragments get cemented together as breccia rocks.

∇ Fault Breccia

This rock is also called crush-breccia. Such rocks are so named because they are made up of angular fragments that have been produced during the process of faulting.

The fragments so produced due to crushing effect of the block movements subsequently get embedded in clay and other fine material (often also derived during the faulting process and called gouge) and ultimately form a cemented rock the crush-breccia

∇ Agglomeratic Breccia

It is a specific type of breccia containing angular and sub angular fragments derived from volcanic eruptions.

It may also contain some fused material that has been cemented together with the solid material broken and thrown out of the craters.

2. Conglomerates

Definition

- ∅ These are sedimentary rocks of clastic nature and also belong to rudaceous group.
- ∅ They consist mostly of rounded fragments of various sizes but generally above 2mm. cemented together in clayey or ferruginous or mixed matrix.
- ∅ The roundness of gravels making the rock is a useful characteristic to differentiate it from breccia in which the fragments are essentially angular.

- Ø The roundness indicates that the constituent gravels have been transported to considerable distances before their deposition and transformation into conglomerate rock.

Types

On the basis of the dominant grade of the constituent gravels in following three types:
 Boulder-Conglomerates Cobble-Conglomerate Pebble-Conglomerate (gravels > 256mm) (gravels: 64-256 mm) (gravels: 2-64 mm)

On the basis of source of the gravels, as

- (i) **Basal-conglomerates** Having gravels derived from advancing sea-waves over subsiding land masses;
 (ii) **Glacial-conglomerates** In which gravel making the conglomerates are distinctly of glacial origin;
 (iii) **Volcanic-conglomerates** In which gravels are of distinct volcanic origin but have subsequently been subjected to lot of transport resulting in their smoothening and polishing by river transport before their deposition and compaction or cementation.

On litho logical basis

- (a) **Oligomictic** Simple in composition, these gravels are made up of quartz, chert and calcite;
 (b) **Polymictic**. In these conglomerates the constituent gravels are derived from rocks of all sorts: igneous, sedimentary and metamorphic, all cemented together. The so-called Fonglomerates are conglomerates formed and found at the base of alluvial fans and cones.

3. Sandstones

- Ø Sandstones are mechanically formed sedimentary rocks of Arenaceous Group.
 Ø These are mostly composed of sand grade particles that have been compacted and consolidated together in the form of beds in basins of sedimentation.

- Ø The component grains of sandstones generally range in size between 2mm and 1/16 mm. Silica in the form of very resistant mineral QUARTZ is the dominant mineral constituent of most sandstones.

Composition.

- Ø Quartz (SiO₂) is the most common mineral making the sandstones. In fact some varieties of sandstone are made up entirely of quartz.
 Ø Besides quartz, minerals like feldspars, micas, garnet and magnetite may also be found in small proportions in many sand stones composition.

Texture.

- Ø Sandstones are, in general, medium to fine-grained in texture.
 Ø The component grains show a great variation in their size, shape and

arrangement in different varieties.

Thus, when the texture is determined on the basis of the grade of the component grains, three types are recognized:

Type:	Coarse-grain	Medium-grain	Fine -grain
Size-range:	2 mm-1/2 mm	1/2 mm-1/4 mm	1/4 mm-1/16 mm

Colour

- Ø Sandstones naturally occur in a variety of colours: red, brown, grey and white being the most common colours.
- Ø The colour of sandstone depends on its composition, especially nature of the cementing material.
For example, presence of iron oxide is responsible for the red, brown and yellow shades;
presence of glauconite gives a greenish shade to the sandstones.

Types

On the basis of their composition and the nature of the cementing material.

Siliceous Sandstones

- Ø Silica (SiO₂) is the cementing material in these sandstones.
- Ø Sometimes the quality of the siliceous cement is so dense and uniform that a massive compact and homogeneous rock is formed.
- Ø This is named QUARTZITE. This type of sedimentary quartzite, when subjected to loading fractures across the grains showing clearly very dense nature and homogeneity of the cementing silica with the main constituent silica of the rock.

Calcareous Sandstones. are those varieties of sandstones in which carbonates of calcium and magnesium are the cementing materials.

Argillaceous Sandstones These are among the soft varieties of sandstone because the cementing material is clay that has not much inherent strength.

Ferruginous Sandstones As the name indicates, the cementing material is an iron oxide compound. On the basis of mineralogical composition

Arkose.

- Ø This is a variety of sandstone that is exceptionally rich in felspar minerals besides the main constituent quartz.
- Ø It is believed that these rocks are formed due to relatively quick deposition of detritus derived from weathering and disintegration of crystalline igneous and metamorphic rocks like granites and gneisses respectively.
- Ø Arkose rock generally occurs in horizons that can be genetically related to some crystalline massif occurring in close neighbourhood.

Greywacke.

- Ø These are broadly defined as grey coloured sandstones having a complex mineralogical composition.
- Ø They contain a fine-grained matrix. In this matrix, grains of quartz and some felspars are found embedded side by side with fragments of rocks like felsites, granites, shales etc.
- Ø The exact composition of the matrix is so complex that it may not be easily determined in most cases.

Flagstone

- Ø It is a variety of sandstone that is exceptionally rich in mica dispersed in parallel or sub parallel layers.
- Ø The abundance as well as arrangement of mica, typically muscovite, renders the stone weak and easily splitting. Hence its use in load bearing situations is not recommended.

Freestone.

- Ø It is a massive variety of sandstone that is rich in quartz and does not contain bedding planes or any mica. It is compact, dense, massive and a strong rock suitable for construction demanding high crushing strength.
- Ø Ganister. It is another type of sandstone consisting of angular and sub angular quartz grains and cement of secondary quartz with some kaolin.

Uses

- Ø Sandstones of hard, massive and compact character are very useful natural resources.
- Ø They are most commonly used as materials of construction: building stones, pavement stones, road stones and also as a source material for concrete.
- Ø The Red Fort of India is made up of red sandstones.

Distribution.

- Ø Next to shales, sandstones are the most abundant sedimentary rocks found in the upper 15 km of the crust and make an estimated 15 percent of total sedimentary rocks of the earth.

4. Shale

- Ø Shale is a fine-grained sedimentary rock of argillaceous (clayey) composition.
- Ø Shales are generally characterized with a distinct fissility (parting) parallel to the bedding planes and are made up of very fine particles of silt grade and to some extent of clay.
- Ø Besides fissility, some shales show the laminated structure.

Compsition

- Ø The exact mineralogical composition of shales is often difficult to ascertain because of the very fine size of the constituents.
- Ø shales are very intimate mixtures of quartz, clay minerals and accessory minerals like oxides of iron, carbonates, and organic matter.

- Ø Silica and clay minerals together make more than seventy percent of shales in most cases.
- Ø Chemically speaking, shales exhibit still greater variation.

Average Chemical Composition of Shales

S.N	Oxide	% age	S.No	Oxide	%age
1	-	58%	5	Ca	3%
2	SiO ₂	15%	6	O	3%
3	Al ₂ O ₃	6%	7	K ₂ O	1%
4	Fe ₂ O ₃	2%	8	MgO	5%

Types

- Ø Shales have been classified variously. Three Classes On The Basis Of Their Origin: .

Residual Shales:

- _ These are formed from decay and decomposition of pre-existing rocks followed by compaction and consolidation of the particles in adjoining basins without much mixing;.

Transported Shales:

- _ These are deposits of clastic materials of finer dimensions transported over wide distances before final settlement in basins of deposition.

Hybrid Shales

- _ In such shales, materials derived both from clastic sources and non clastic especially those from organic sources make up the rock.

on the basis of their mineralogical composition:

Quartz shales: rich in free quartz content.

Felspathic shales: in which feldspars and clay minerals predominate; silica becomes a secondary constituent. **Chloritic shales:** in these shales, minerals of chlorite group and clay-group make the bulk of the shales. **Micaceous shales:** these are rich in muscovite mica and other flaky and play minerals.

8. Explain about LIMESTONES?

Definition

- Ø These are the most common sedimentary rocks from the non-clastic-group and are composed chiefly of carbonate of calcium with subordinate proportions of carbonate of magnesium.
- Ø They are formed both bio-chemically and mechanically.

Composition

- Ø Pure limestone is invariably made up of mineral calcite (CaCO₃).
- Ø In terms of chemical composition, limestone's are chiefly made up of

CaO and CO₂, Magnesium Oxide is a common impurity in most limestone's; in some its percentage may exceed 2 percent, the rock is then called magnesian limestone.

- Ø Other oxides that may be present in limestone are: silicon dioxide, ferrous and ferric oxides (or carbonates); and aluminium oxide. Strontium oxide is also present in some limestone's as a trace element.

Texture.

- Ø The most important textural feature of limestone's is their fossiliferous nature.
- Ø Fossils in all stages of preservation may be found occurring in limestone's.
- Ø Other varieties of limestone's show dense and compact texture; some may be loosely packed and highly porous; others may be compact and homogeneous.
- Ø Concretionary texture is also common in limestone's.

Types.

- Ø Many varieties of limestone's are known.
- Ø Broadly speaking these can be divided into two groups: autochthonous and allochthonous.
- Ø Autochthonous includes those varieties which have been formed by biogenic precipitation from seawaters.
- Ø Allochthonous types are formed from the precipitated calcareous sediments that have been transported from one place to another where they were finally deposited.

Following are common types of limestones.

Chalk.

- Ø It is the purest form of limestone characterised by fine-grained earthy texture. Common colour of chalk is white. Some chalks may be exceptionally rich in the remains of very small sea organisms called foraminifera.

Shelly Limestone.

- Ø Also called fossiliferous limestone, it has a rich assemblage of fossils that are fully or partly preserved. When the limestone is made up entirely of fossils, it is termed coquina.

Argillaceous Limestone

- Ø These limestones contain clay as a significant constituent and are clearly of allochthonous origin.
When the clay and carbonate fractions are present in almost equal proportions, the rock is termed marl.

Lithographic Limestones

- Ø These are compact massive homogeneous varieties of pure limestones that find extensive use in litho- printing.

Kankar

- ∅ It is a common nodular or concretionary form of carbonate material formed by evaporation of subsoil water rich in calcium carbonate just near the soil surface.
- ∅ It is non-marine in origin.

Calc-Sinter.

- ∅ It is a carbonate deposit formed by precipitation from carbonate rich spring waters.
- ∅ These deposits are also known as travertine or calc-tuffa and commonly occur around margins of Hot Springs.

9.Explain about DOLOMITE ?**Definition.**

- ∅ It is a carbonate rock of sedimentary origin and is made up chiefly more than 50 percent - of the mineral dolomite which is a double carbonate of calcium and magnesium with a formula of $\text{CaMg}(\text{CO}_3)_2$.
- ∅ Ferrous iron is present in small proportions in some varieties.
- ∅ Gypsum also makes appearance in some dolomites.
- ∅ But the chief associated carbonate is that of calcium, in the form of calcite.

Texture

- ∅ Dolomite shows textures mostly similar to limestones to which it is very often genetically related.
- ∅ In other varieties, dolomites may be coarsely crystalline, finely crystalline or showing interlocking crystals.

Formation.

- ∅ Dolomites are formed in most cases from limestones by a simple process of replacement of Ca^{++} ions by Mg^{++} ions through the action of Mg^{++} ion rich waters.
- ∅ This ionic replacement process is often termed dolomitization
- ∅ The replacement may have started shortly after the deposition of limestone or quite subsequent to their compaction.
- ∅ **Direct precipitation** of dolomites from magnesium rich waters is also possible.
- ∅ Such directly precipitated deposits of magnesium carbonate occur in association with gypsum, anhydrite and calcite.
- ∅ It is believed that in such cases, it is the calcite, which is precipitated first, depleting the seawater of CaCO_3 and enriching it with MgCO_3 .
- ∅ The $\text{CaMg}(\text{CO}_3)_2$ precipitates at a later stage.
- ∅ Dolomitization by replacement method, however, is believed to be the most common method of formation of dolomites.

Occurrence

- ∅ Dolomite is a widespread sedimentary rock and is found commonly associated with limestones.
- ∅ It forms intervening layers between limestone formations spread over wide areas.
- ∅ Also, it may occur at the extended boundaries of many limestone deposits.
- ∅ These indicate locations where 'magnesium rich ground waters could have an easy access for the replacement process to take place in an original limestone" rock.

- Ø Dolomite is so closely related to limestone in composition, texture, structure and physical properties that it may not always be easily possible to differentiate between the two rocks in hand specimens.

7. Coals

Definition.

- Ø These may broadly be defined as metamorphosed sedimentary rocks of carbonaceous character in which the raw material has mostly been supplied by plants of various groups.
- Ø The original raw material passes through many biomechanical and biochemical processes before it becomes a coal in technical terms;

Formation.

- Ø In most cases coals represent carbonized wood.
- Ø The process of coal formation involves a series of stages similar to formation of sedimentary rocks such as wastage of forests and transport of the wood material through different natural agencies to places of deposition, accumulation of the material in huge formations.
- Ø Its burial under clays and other matter and its compaction and consolidation under superimposed load.
- Ø Biochemical transformation of the organic matter so accumulated starts and is completed under the influence of aerobic and anaerobic bacteria available at the place of deposition.
- Ø The degree of carbonification depends to a great extent on the time and type of environment in which the above processes have operated on the source material giving rise to different varieties of coal.

Types

Peat.

- Ø It is the lowest grade coal that consists of only slightly altered vegetable matter. It may not be even considered as a coal. It has very low calorific value, high percentage of moisture and is rich in volatile matter.

Lignite.

- Ø It is also known as brown coal and forms the poorest grade of coal with calorific value ranging between 6300-8300 B.th.V.
- Ø It is compact and massive in structure with an upper specific gravity of 1.5 and hardness of 2.5 on Mohs' Scale of Hardness.
- Ø Some varieties of lignite may still show to a good extent the traces of original vegetable structure.

Bituminous Coals

- Ø These form a broad group of common coals having essential properties varying within wide limits.

- Ø The fixed carbon ranges between 69-78 per cent and the calorific value between 9,500 B.th.V to 14,000 B.th.V.
- Ø Their common character is that they contain enough volatile matter, which makes them quite soft on heating, and they start agglomerating.
- Ø Some of bituminous coals may contain volatile matter to such a high extent as 30 per cent of their bulk.

Anthracite

- Ø It is considered the highest-grade coal with fixed carbon ranging between 92-98 per cent.
- Ø It has highest calorific value in coals and burns almost without any smoke, as the volatile matter is negligible.

Occurrence

- Ø Coals of different varieties are found to occur almost in all countries of the world, though in varying proportions.
- Ø Coals form all-purpose fuels, some varieties being more suitable for specific industrial uses.

8. Iron Ores of Sedimentary Origin

- Ø The iron ores form beds or layers of variable thickness that occur interstratified with other sedimentary rocks.
- Ø Sedimentary iron deposits are regarded having formed chiefly as chemical precipitates in the form of oxides, carbonates and silicates from marine waters rich in corresponding salts.
- Ø Metasomatic replacement has also been suggested as another important process for formation of many iron ore deposits.
- Ø It is also suggested that certain type of bacteria play considerable role in the precipitation of iron.

9. Gypsum

- Ø It is a sedimentary rock composed of the mineral of the same name-gypsum, which has a composition of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.
- Ø Its common colour is white but it may also occur in other shades such as yellow, red or dark grey due to impurities present in the rock.
- Ø Gypsum is formed in nature as a result of evaporation from sea-waters rich in sulphate salts.

ANHYDRITE is a granular aggregate of mineral anhydrite, CaSO_4 and is genetically related to the mineral gypsum: hydration of anhydrite results in gypsum.

These rocks are commonly associated in occurrence

Uses: Gypsum finds extensive uses in many industries, e.g.

- (i) as a raw material in the manufacture of fertilizers;
- (ii) as an essential ingredient in the manufacture of Cement;
- (iii) in the manufacture of Plaster of Paris.
- (iv) as fire proofing component of gypsum boards.

10. Rock Salt

- Ø It is also a sedimentary rock composed of mineral halite (NaCl).
- Ø The texture of rock salt varies from coarse-grained crystalline to fine-grained massive.
- Ø The purest rock salt is white in colour but it may occur in various other shades as grayish and reddish due to presence of impurities
- Ø Rock salt occurs in many parts of the world interbedded with other sedimentary formations.
- Ø It is commonly associated with other evaporites.
- Ø Subsidence of the basin of deposition during the process of evaporation has been suggested by some as a possible explanation.

11. Flint and Chert

- Ø Flint is a dark coloured sedimentary rock of siliceous composition consisting chiefly of chalcedony and extremely fine-grained quartz.
- Ø It occurs commonly as concretions or nodules in chalk (limestone) deposits.
- Ø Chert is also a sedimentary rock composed of cryptocrystalline silica showing great variety of colours.
- Ø It is more common in occurrence compared to flint and occurs in the form of beds or layers within limestones and other deposits.

Their origin may be due to any of following two causes:

(a) Primary Precipitation.

- Ø It is believed that under special environments chert gets precipitated inorganically from seawater rich in amorphous silica.
- Ø The theory is yet considered inadequate because modern seawaters are generally quite under saturated with amorphous silica.

(b) Replacement.

- Ø Waters containing amorphous silica from siliceous skeletal sources are thought to have replaced lime stones forming concretions and nodules of flint by the process of replacement.

12. Tillite

- Ø It is a sedimentary rock of glacial origin.
- Ø It is characterised by a structure less matrix that has fragments of various sizes, shapes and composition embedded in it.
- Ø Most of these embedded fragments bear striations and other evidence of their transport by glaciers before their deposition and compaction.
- Ø The name is derived from the fact the rock is merely a compacted and consolidated form of the glacial debris called till.
- Ø The matrix or ground mass of the till is generally of grey to greenish appearance whereas the embedded fragments are of extremely heterogeneous character.

ENGINEERING IMPORTANCE

- Ø Sedimentary rocks cover a great part of the crust of the earth; they make up more than 75 percent of the surface area of the land mass.

- Ø It is with these types of rocks that an engineer has to deal with in majority of cases.
- Ø It is, therefore, essential for a civil engineer to know as much as is possible about the salient features of these rocks.
- Ø He has to see, for instance, if such rocks would withstand loads under heavy construction and also, if they could be trusted in cuts and tunnels in highway construction and also as reservoirs.
- Ø They are the most important rocks to act as natural reservoirs of oil and ground water supplies.

9. Write about METAMORPHIC ROCKS ?

METAMORPHISM

METAMORPHISM is the term used to express the process responsible for all the changes that take place in an original rock under the influence of changes in the surrounding conditions of temperature, pressure and chemically active fluids.

METAMORPHIC ROCKS

Definition

- Ø Metamorphic rocks are defined as those rocks which have formed through the operation of

Stress Minerals

various types of metamorphic processes on the pre-existing igneous and sedimentary rocks involving changes in textures, structures and mineralogical compositions.

- Ø The direction of change depends upon the type of the original rock and the type of metamorphic process that operates on the rock.
- Ø Heat, pressure and chemically active fluids are the main agents involved in metamorphic processes.
- Ø Plastic deformation, recrystallisation of mineral constituents and development of parallel orientation are typical characters of metamorphic rocks.

MINERALOGICAL COMPOSITION

Metamorphic rocks exhibit a great variation in their mineralogical composition that depends in most cases on

- (i) the composition of the parent rock;
- (ii) the type and degree of metamorphism undergone by the rock.

Two broad groups of minerals formed during metamorphism are:

- ▼ Stress minerals and
- ▼ Anti-stress minerals

Stress minerals

- Ø The minerals, which are produced in the metamorphic rocks chiefly under the stress factor, are known as stress minerals.
- Ø They are characterised by flaky, platy, lamellar, flattened and elongated forms.

Examples:

kyanite, staurolite, muscovite, chlorite and some amphiboles.

Anti-Stress Minerals

- Ø These are metamorphic minerals produced primarily under the influence of temperature factor.
- Ø Such minerals are generally of a regular equidimensional outline. **Examples:** sillimanite, olivine, cordierite and many pyroxenes

Textures of Metamorphic Rocks

These can be broadly grouped under two headings:

(a) Crystalloblastic

- Ø Textures which include all those textures that have been newly imposed upon the rock during the process of metamorphism and are, therefore, essentially the product of metamorphism.

(b) Palimpsest (Relict)

- Ø Textures that include textures which were present in the parent rock and have been retained by the rock despite metamorphic changes in other aspects.
- Ø Among the crystalline textures, Porphyroblastic and Granoblastic types are most common. outlines) of stronger minerals.
- Ø In the granoblastic texture, the rock is made of equidimensional recrystallised minerals without there being any fine grained ground mass.
- Ø Palimpsest textures are similar in essential details as in the parent rock with little or no modifications taking place during metamorphism.
- Ø These are described by using the term blasto as a prefix to the name of the original texture retained by the rock.

CLASSIFICATION OF METAMORPHIC ROCKS

- Ø Metamorphic rocks have been variously classified on the basis of texture and structure, degree of metamorphism, mineralogical composition and mode of origin etc.
- Ø A very general two-fold classification based on the presence or absence of layered structure or

FOLIATION as defined above is as follows:

(a) Foliated Rocks

- Ø All metamorphic rocks showing development of conspicuous parallelism in their mineralogical and structural constitution falling under the general term foliation are grouped together as foliated rocks.
- Ø The parallelism indicating features include slaty cleavage, schistosity and gneissose structures

Ø Typical rocks included in this group are slates, phyllites, schists and gneisses of great variety.

(b) **Non-Foliated Rocks**

Ø Included in this group are all those metamorphic rocks characterised with total or nearly total absence of foliation or parallelism of mineralogical constituents.

Ø Typical examples of non-foliated rocks are quartzites, hornfels, marbles, amphibolites and soapstone etc.

IMPORTANT METAMORPHIC ROCKS

Definition

Ø Slate is an extremely fine-grained metamorphic rock characterized by a slate cleavage by virtue of which it can be readily split into thin sheets having parallel smooth surfaces.

Ø The slaty cleavage is due to parallel arrangement of platy and flaky minerals of the slate under the dominant stresses operating during the process of metamorphism.

Composition

Ø Mineralogically, slate is made up of very fine flakes of mica, chlorite and microscopic grains of quartz, feldspar, oxides of iron and many other minerals, all of which cannot be easily identified even under microscope because of their fine grain size.

Origin.

Ø Slate is a product of low-grad regional metamorphism of argillaceous rock: like clays and shales.

Ø When slate is subjected to further action of dynamothermal metamorphism, recrystallisation leads to the development in number and size of some minerals, especially micas.

Ø Such metamorphic rocks with conspicuous micaceous constituents and general slaty appearance are termed **PHYLLITES**.

Uses.

Ø Slate is used locally (where available) for construction purpose as a roofing and paving material only.

Schists:

Schists are megascopically crystalline foliated metamorphic rocks characterised by a typical schistose structure.

The constituent flaky and platy minerals are mostly arranged in parallel or sub parallel layers or bands.

Texture and Structure

Ø Most varieties are coarsely crystalline in texture and exhibit a typical schistose structure.

Ø Quite a few types show lineation and porphyroblastic fabric.

Composition

- Ø Platy and rod-like acicular minerals form the bulk of most of the schists.
- Ø Micas (both muscovite and biotite), chlorite, hornblende, tremolite, actinolite and kyanite are quite common constituents of most of the schists
- Ø Quartz and feldspars are comparatively rare but not altogether absent.
- Ø Porphyroblasts of granular minerals like staurolite, garnet and andalusite make their appearance in many schists.

Varieties

- Ø Specific names are given to different types of schists on the basis of predominance of any one or more minerals.
- Ø Thus some commonly found schists are: muscovite schists, biotite schists, sericite-schist, tourmaline-schist etc.
- Ø Sometimes schists are grouped into two categories on the basis of degree of metamorphism as indicated by the presence of index minerals:

a) Low-grade schists

- Ø Formed under conditions of regional metamorphism at low temperature.
- Ø These are rich in minerals like albite, muscovite and chlorite that are unstable at high temperature.
- Ø **Examples** Mica-schist, chlorite-schist and talc-schist are a few from this group.

b) High-grade schists

- Ø These are formed under conditions of regional metamorphism and are rich in minerals that are stable at high temperatures such as andalusite, cordierite, garnet, staurolite and sillimanite etc.
- Ø Garnet-schists, cordierite-schists and staurolite-schists are common examples.

Origin

- Ø Slates and Schists are generally the product of dynamothermal metamorphism of argillaceous sedimentary rocks like clays and shales.
- Ø These indicate the final and stable stage in the metamorphism of shales through the intervening stages of slates and phyllites.

GNEISS Definition

- Ø A gneiss is a megascopically crystalline foliated metamorphic rock characterised by segregation of constituent minerals into layers or bands of contrasting colour, texture and composition.
- Ø A typical gneiss will show bands of micaceous minerals alternating with bands of equidimensional minerals like feldspars, quartz and garnet etc.

Composition

- Ø Gneisses are generally rich in the minerals of parent rocks that are simply recrystallised during the process of metamorphism.
- Ø Feldspar and quartz are more common in gneisses than in schists.
- Ø Dark minerals of pyroxene and amphibole groups are also common, as are the typical metamorphic minerals like staurolite, sillimanite, garnet, kyanite and epidote etc.

Texture and Structure

- Ø Gneisses show a variety of textures and structures, the most common being

coarsely crystalline texture and the gneissose structure.

- Ø Augen-gneisses show a typical cataclastic structure in which the hard minerals are flattened and elongated.

Varieties

Important types are:

- Ø **Orthogneiss** formed as a result of metamorphism of granites and other igneous rocks.
 - Ø **Paragneiss** these are formed from the metamorphism of sedimentary rocks like sandstones;
 - Ø **Banded gneiss** typical gneiss in which the tabular and flaky minerals are segregated in very conspicuous bands of alternating dark and light colours.
- Ø Gneisses of all varieties are generally the result of advanced stages of metamorphism of a variety of parent rocks such as sandstones, conglomerates, granites and rhyolites etc.
- Ø There is difference of opinion on the origin of the granitic gneisses; their mineralogical composition is close to granites but in structure they appear more metamorphic.

Uses

- Ø Compact, dense and massive varieties of gneisses find applications as road stones and in some cases as building stones.

10. Explain about QUARTZITE ?

Definition

- Ø Quartzites are granular metamorphic rocks composed chiefly of inter sutured grains of quartz.
- Ø The name Orthoquartzite is used for a sedimentary rock of similar composition but having a different (sedimentary) origin, in which quartz grains are cemented together by siliceous cement.

Composition

- Ø Besides quartz, the rock generally contains subordinate amounts of micas, feldspars, garnets and some amphiboles which result from the recrystallisation of some impurities of the original sandstone during the process of metamorphism.

Origin

- Ø Metamorphic quartzites result from the recrystallisation of rather pure sandstones under the influence of contact and dynamic metamorphism.

Uses

- Ø The rock is generally very hard, strong, dense and uniformly grained.
- Ø It finds extensive use in building and road construction.

11. Explain about MARBLE ?

Definition

- Ø Marble is essentially a granular metamorphic rock composed chiefly of recrystallised limestone (made of mineral calcite).

- Ø It is characterized by a granulose texture but the grain size shows considerable variation in different varieties;
- Ø It varies from finely saccoidal to highly coarse grained. Marbles often show a banded structure also; coarse varieties may exhibit a variety of structures.

Composition

- Ø Small amounts of many other granular minerals like olivine, serpentine, garnet and some amphiboles are also present in many varieties, which are derived from the impurities present in the original limestone during the process of metamorphic recrystallisation.

Varieties

- Ø Various types of marble are distinguished on the basis of their colour, composition and structure.
White marble, pink marble and black marble are known on the basis of their colours, which is basically due to fine dispersion of some impurity.
- Ø Dolomitic marble is a variety distinguished on the basis of composition; it may show slightly schistose structure.

Origin

- Ø Marble is formed from contact metamorphism of carbonate group of sedimentary rocks: pure white marble results from pure limestone; coloured marbles from those limestones that have some impurities and dolomitic marbles from magnesian limestones.

Uses

- Ø Marble is commonly used in the construction of palatial and monumental buildings in the form of blocks, slabs, arches and in the crushed form as chips for flooring.
- Ø Because of its restricted occurrence and transport costs, it is mostly used as ornamental stone in costly construction.

UNIT- 4 STRUCTURAL GEOLOGY AND GEOPHYSICAL METHOD

1. Define Dip?

The inclination of the bedding planes, with the horizontal, is called dip and is always expressed in degrees.

2. Explain true dip?

It is the maximum inclination of bedding planes with the horizontal, or in other words it is the inclination of the direction of which water would flow, if poured on the upper surface of the bed.

3. Explain apparent dip?

The inclination of the bedding planes, with the horizontal, in any other direction, other than the direction of the true dip, is known as the apparent dip. The value of apparent dip is always less than the true dip.

4. Define strike?

It is the direction, measured on a horizontal surface, of a line formed by the intersection of a dipping bed with the horizontal plane. It is always expressed in terms of main direction i.e., North, South, East or West.

5. What is meant by folds?

The earth's crust is tilted out of the horizontal and is bent into folds. Such a fold may range from a microscopic crinkle to great arches and troughs even up to 100 kms across. A set of such arches and troughs is called a fold.

6. What is meant by Anticline and Syncline?

When the beds are folded in an arch-like structure, it is called an anticline. When the beds are down folded in a trough-like structure, it is called a syncline. It may be noted that in an anticline the oldest rock is in the centre, whereas in a syncline the youngest rocks are in the centre.

7. Explain Causes of folding?

The interior of the earth is getting cooler and cooler day by day, which is sure to cause some shrinkage in the earth's crust. This shrinkage is responsible for the compressive and shearing stress to be developed within the earth's crust. Some time these stresses are small in magnitude but go on exerting pressure for a sufficient length of time and result in buckling or folding of the layers of the earth's crust.

8. What are types of folds?

- a) Symmetrical fold
- b) Asymmetrical fold
- c) Overturned fold
- d) Isoclinal fold
- e) Recumbent fold
- f) Plunging fold

- g) Open fold
- h) Closed fold
- i) Anticlinorium
- j) Synclinorium
- k) Dome
- l) Basin
- m) Nonoclnal fold.

9. Define Faults?

Faults are fractures, along which the movement of one block with respect to other, has taken place. This movement may vary from a few centimeters to many kilometers depending upon the magnitude of the stresses, and the resistance offered by the rocks.

10. Explain the Causes of Faulting?

The interior of the earth becoming cooler day by day, which is sure to cause some shrinkage in the earth's crust. This shrinkage is responsible for the stress to be developed within the earth's crust. These stresses, when greater in magnitudes exert so much pressure that the layers of the earth's crust are fold due to compressive stresses and after wards when the stresses are released, fractures are formed. If the stresses still continue, the blocks move up or down along the fault plane depending upon the direction of stresses and their intensity. Such a fracture, along which a movement has taken place, is called a fault.

11. What are the classifications of faults?

Faults are classified on the basis of their apparent displacement, ie, the direction of movement, of one block, with respect to the other along the fault plane.

12. What are the criteria for the recognition of a fault?

- 1) Discontinuity of strata
- 2) Repetition and omission of strata
- 3) Physiographic features
- 4) General.

13. What is mean by Joints?

When sufficient tensile stress is developed between two successive points, a crack is developed at right angle to the direction of the stress, such cracks are called joints.

14. What is mean by Master joints?

The joints always occur in sets and groups. A set of joints means, joint occurring in the same dip or strike. A group of joints means a few sets of joints having almost the same trend. If a few sets or groups of joints appear for a considerable length in a rock, such joints are called major joints or master joints.

15. Define out crop?

A little consideration will show that the out crop of a rock is affected by the angle of dip also. If a rock has a vertical dip then the outcrop will be less, than that when the same rock is dipping at some angles.

16. What are the different forms of out crops?

- a) Outlier

- b) Inlier
- c) Unconformity
- d) Overlap
- e) Cross bedding.

17. Define overlap?

An overlap is particular type of an unconformity, in which the overlying strata extends so as to overlap the underlying strata.

18. Define cross bedding?

Sedimentary beds or layers are generally parallel to one another. But, sometimes, it has been observed that the beds lie slightly oblique to the major bedding planes.

19. What are the classifications of joints?

- a) Geometrical classification
Strike joints, Dip joints, Oblique joints
- b) Genetic classification
Tension joints, shear joints

20. What are the methods of Geophysical Exploration?

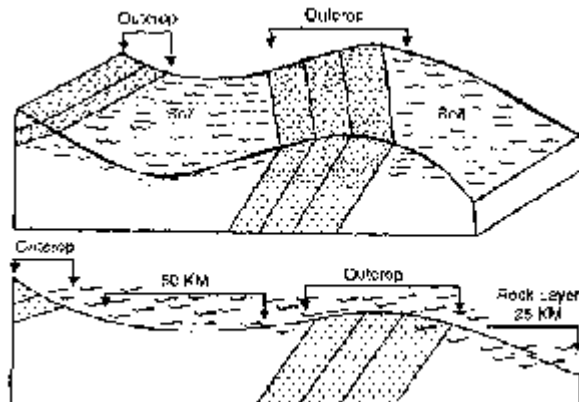
Depending upon the type of energy field used, the following methods may be used. Seismic method, Electrical method, Gravitational method, Magnetic method, Radiometric method, Geothermal method.

16 MARKS QUESTION AND ANSWER

1.Explain about OUTCROP ?

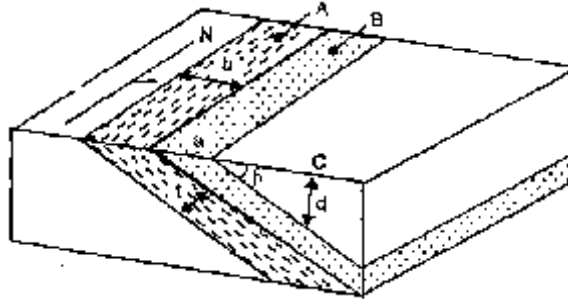
In the mountainous and sub-mountainous tracts and also in shallow plains, exposures of rocks may be easily seen forming sides of valleys or caps of hills or even uplands and slopes in level fields.

An **outcrop** is simply defined as an exposure of a solid rock on the surface of the earth.



Outcrop Dimensions

- Ø The **width or breadth** of the outcrop of a particular bed is given by the distance between the top and bottom edges of the bed as measured on the surface of the ground in a direction perpendicular to the strike of that particular bed
- Ø Many variations are induced in the breadth of an outcrop of a rock by the topography of the area.
- Ø The **thickness** of a particular layer or bed is the perpendicular distance between the top and bottom surface of the same layer as seen in a vertical section at right angles to the strike of the layer



- Ø The **depth** to a particular layer or bed at any place from the surface, if believed to be present on the basis of general geology and dip of the formation, is given by the perpendicular distance between the ground surface and the top surface of that particular layer.
- Ø When the ground surface is horizontal, depth d to the bedrock of known dip may be obtained by the relationship

$$d = aC \times \tan \beta$$

- Ø where β is the angle of true dip of the bed exposed at a place, say at B and C is the distance from that exposure to the place C where it is desired to find out depth to that bedrock.

2.Explain about FOLDS ?

Definition

- Ø FOLDS may be defined as undulations or bends or curvatures developed in the rocks of the crust as a result of stresses to which these rocks have been subjected from time to time in the past history of the Earth.

Development of folds

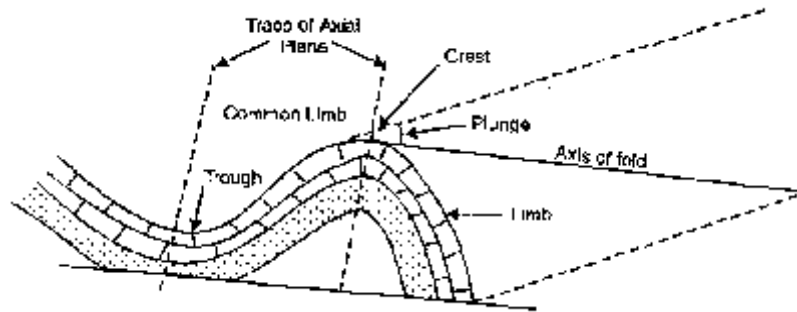
- Ø The folds may develop in any type of rock and may be of any shape and geometry ranging from simple up arched bends or downward curvatures to completely overturned flexures.
- Ø The ultimate shape and extent of a fold depends upon a number of factors like the nature, magnitude and the direction of and duration for which these forces act upon the rocks and also the nature of the rocks being effected.

- Ø The process of development of folds in the rocks is called **Folding**.
- Ø It is a very slow geological process and indicates an effort of the rocks in a particular environment to adjust themselves to the changing force fields operating on, within or around them.
- Ø Folding is a ductile type of deformation experienced by the rocks compared to the brittle deformation where the rocks actually get broken and displaced when stressed.

PARTS OF A FOLD

Limbs

- Ø These are the sides or flanks of a fold. An individual fold will have a minimum of two limbs but when the folds occur in groups, as they very often do, a middle limb will be common to two adjacent folds.



Hinge

- Ø In a folded layer, a point can be found where curvature is maximum and one limb ends and the other limb starts from that point. This is the **hinge point**.
- Ø When rocks occur in a sequence and their all hinge points are joined together, they make a line, called the **hinge line**.

Axial surface

- Ø When the hinge line is traced throughout the depth of a folded sequence a surface is obtained which may be planar or non-planar. It is referred to as axial surface

Axial plane

- Ø Axial plane is the imaginary plane that passes through all the points of maximum curvature inclined or horizontal in nature.
- Ø A fold surface is planar in nature; otherwise it is in a folded sequence.
- Ø It may be vertical, is sometimes called a planar fold if the axial is a non-planar fold.

Axis of a fold

- Ø It is simply defined as a line drawn parallel to the hinge line of a fold.
- Ø A more precise definition of an axis of a fold would be the line representing the intersection of the axial plane of a fold with any bed of the fold.

Plunge of a fold

- Ø The angle of inclination of the fold axis with the horizontal as measured in a vertical plane is termed the plunge of the fold.

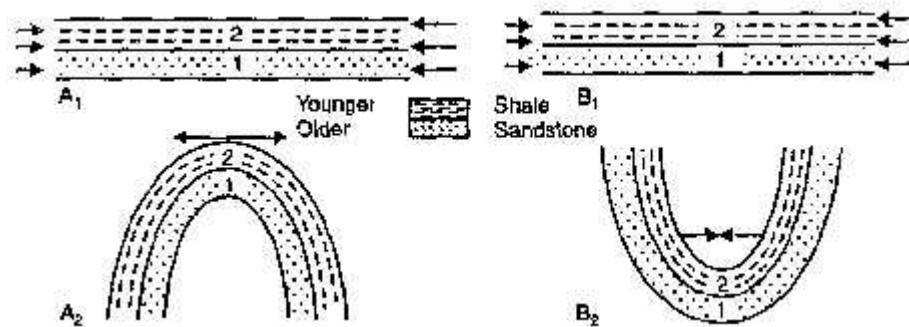
Crest and Trough.

- ∅ Most folds are variations of two general forms; uparched and downarched bends. The line running through the highest points in an uparched fold defines its crest.
- ∅ A corresponding line running through the lowest point in a downarched fold makes its trough. The crest and trough may or may not coincide with the axis of the fold.

3. CLASSIFICATION OF FOLDS ?

Anticlines are defined as those folds in which

- ✚ the strata are uparched, that is, these become CONVEX UPWARDS;
- ✚ the geologically older rocks occupy a position in the interior of the fold, oldest being positioned at the core of the fold and the youngest forming the outermost flank,
- ✚ the limbs dip away from each other at the crest in the simplest cases.



Synclines

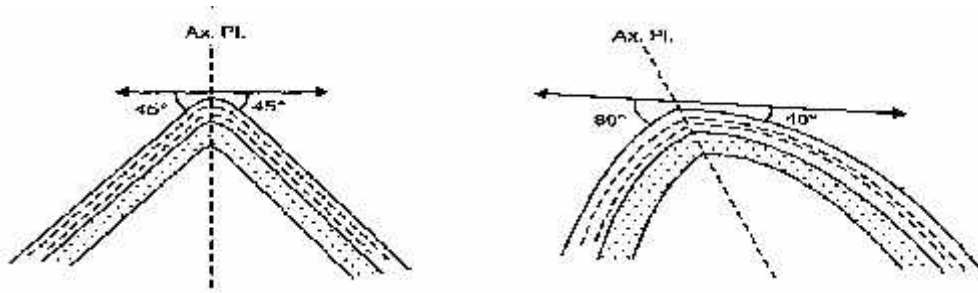
- ✚ the strata are downarched, that is, these become CONVEX DOWNWARDS;
- ✚ the geologically younger rocks occupy a position in the core of the fold and the older rocks form the outer flanks, provided the normal order of superposition is not disturbed,
- ✚ in the simplest cases in synclines, the limbs dip towards a common center.

Position of Axial Plane

Depending upon the nature and direction of the stresses the axial plane in a resulting fold may acquire any position in space, that is, it may be vertical, inclined or even horizontal. Following main types are recognized on the basis of position of the axial plane in the resulting fold:

Symmetrical Folds

- ∅ These are also called normal or upright folds. In such a fold, the axial plane is essentially vertical.
- ∅ The limbs are equal in length and dip equally in opposite directions.
- ∅ it may be an anticline or syncline and when classified, may be described as symmetrical anticline/ syncline as the case may be.

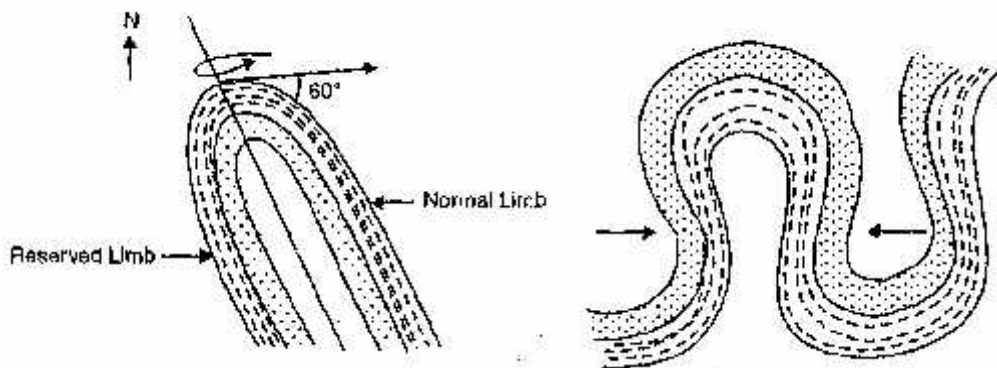


Asymmetrical Folds

- Ø All those folds, anticlines or synclines, in which the limbs are unequal in length and these dip unequally on either side from the hinge line are termed as asymmetrical folds.

Overtaken folds

- Ø These are folds with inclined axial planes in which both the limbs are dipping essentially in the same general direction.
- Ø The amount of dip of the two limbs may or may not be the same.
- Ø Overfolding indicates very severe degree of folding.
- Ø One of the two limbs (the reversed limb) comes to occupy the present position after having suffered a rotation through more than 90 degrees.
- Ø The other limb is known as the normal limb.

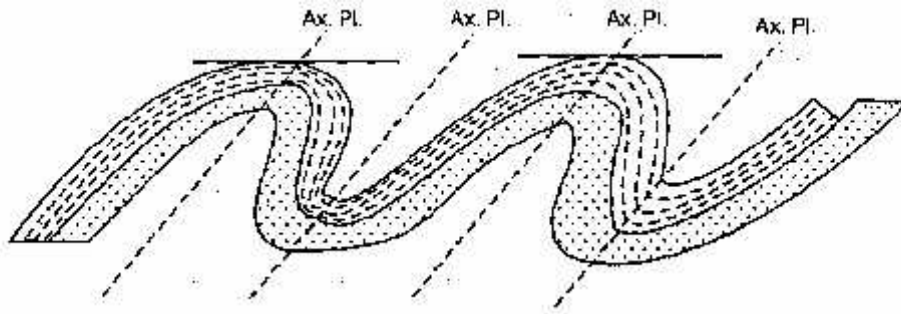


- Ø In certain cases, both the limbs of a fold may get overturned because of very high lateral compression.

- Ø It may be originally either an anticline or a syncline but the extreme compression from opposite sides results in bringing the limbs so close to each other that the usual dip conditions may get reversed —anticlinal limbs dip towards each other and the synclinal limbs dip away from each other.
- Ø Such a type of fold is commonly referred to as a fan fold
- Ø In such folds, the anticlinal tops are said to have opened up into a broad, fan-shaped outline due to intense compression in the lower region.

Isoclinal Folds

- Ø These are group of folds in which all the axial planes are essentially parallel, meaning. that all the component limbs are dipping at equal amounts.
- Ø They may be made up of series of anticlines and synclines



Recumbent Folds

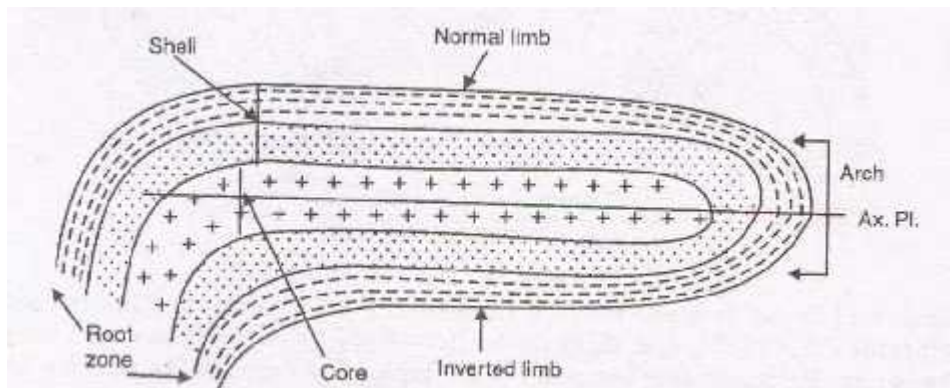
- Ø These may be described as extreme types of overturned folds in which the axial plane acquires an almost horizontal attitude.
- Ø In such folds, one limb comes to lie exactly under the other limb so that a drill hole dug at the surface in the upper limb passes through the lower limb also.
- Ø The lower limb is often called the inverted limb or the reversed limb.
- Ø Other parts of a recumbent fold are sometimes named as follows:

the arch, which is zone of curvature corresponding to crest and trough in the upright folds;

the shell, which is the outer zone made up mostly of sedimentary formations;

the core, which is the innermost part of the fold and maybe made mostly of crystalline igneous or metamorphic rocks;

the root or the root zone, which is the basal part of the fold and may or may not be easily traceable; once traced it can throw light whether the fold was originally an anticline or syncline that has suffered further inversion.



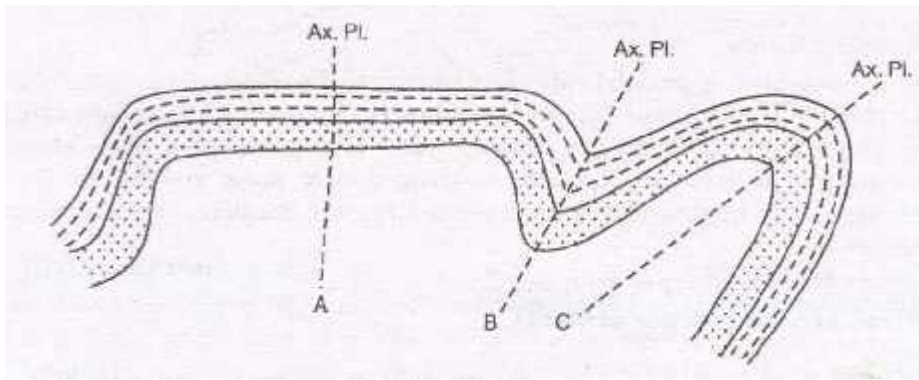
Conjugate Folds

In certain cases a pair of folds that are apparently related to each other may have mutually inclined axial planes.

Such folds are described as conjugate folds.

The individual folds themselves may be anticlinal or synclinal or their

modifications.



Box Fold

It may be described as a special type of fold with exceptionally flattened top and steeply inclined limbs almost forming three sides of a rectangle.

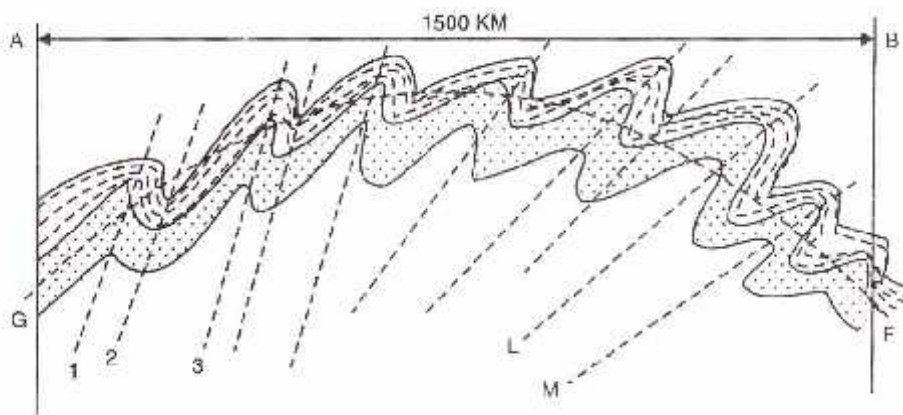


Fig. 6.23. A-B Anticlinorium

- ∅ In both the anticlinorium and synclinorium, presence of large number of secondary folds, faults and fracture systems is a characteristic feature.
- ∅ Similar folding but signifying still larger bending and uplifting of strata on sub-continental scales is expressed by the terms GEANTICLINES AND GEOSYNCLINES respectively.
- ∅ Great importance is attached to the major depressions, the geosynclines, in the process of mountain building discussed elsewhere.
- ∅ The geosynclines are believed to serve as depositional fields or basins of

sedimentation to which sediments derived by the erosion of the adjoining gentilities get accumulated and compacted.

- Ø This material is then compressed and uplifted in the second stage of orogeny, to gradually take the shape of mountain systems.

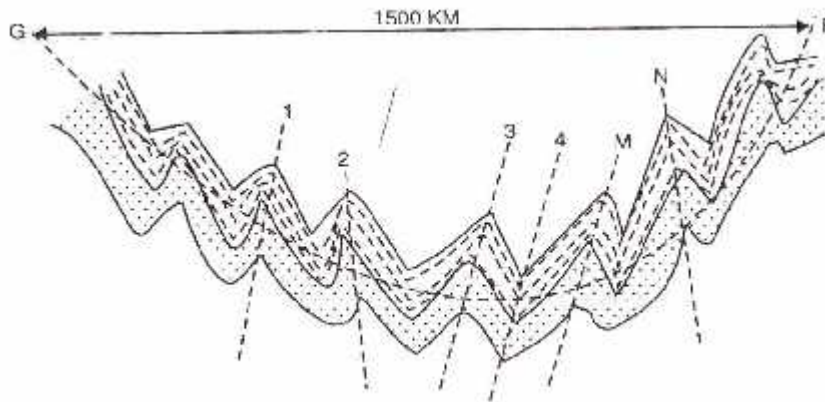


Fig. 6.23. G-F Synclinalorium

4. CAUSES OF FOLDING ?

The Tectonic Folding may be due to any one or more of the following mechanisms:

Folding Due to Tangential Compression

Lateral Compression is believed to be the main cause for throwing the rocks of the crust into different types of folds depending upon the types of rocks involved in the process and also the direction and magnitude of the compression effecting those rocks.

In general, this primary force is believed to act at right angles to the trend of folds. under the influence of the tangential stresses, folding may develop in either of the three ways: flexural folding, flowage folding and shear folding.

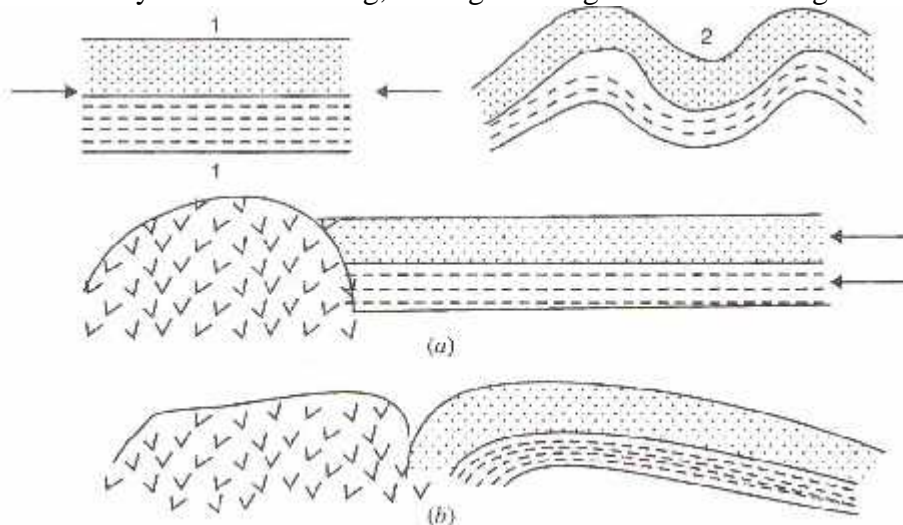


Fig. 6.29. Flexural folding

Flexural Folding.

It is that process of folding in which the competent or stronger rocks are thrown into folds due to their sliding against each other under the influence of lateral compression.

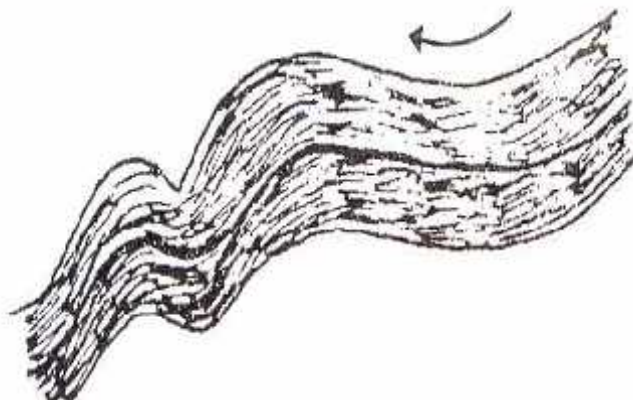
This is also distinguished as flexural-slip-folding in which the slip or movement of the strata involved takes place parallel to the bedding planes of the layers.

It has been established that in flexural folding, the amount of slip (and hence the ultimate type of fold) depends on a number of factors such as:

- ✚ thickness of the layers and nature of the contact; thicker the layers, greater is the slip; further, cohesionless contacts favour easy and greater slips;
- ✚ distance from the hinge point; greater the distance from the hinge points, larger is the
- ✚ displacement, so much so that it may be negligible at the hinge point;
- ✚ type of the rocks involved; siltstones, sandstones and limestones are more prone to flexure slip folding compared to soft clays and shales.

Flowage Folding

- Ø It is the principal process of folding in incompetent or weaker, plastic type of rocks such as clays, shales, gypsum and rock salt etc.
- Ø During the compression, the material of the involved layers behaves almost as a viscous or plastic mass and gets buckled up and deformed at varying rates suffering unequal distortion.
- Ø In such cases the thickness of the resulting fold does not remain uniform.



Shear Folding.

- Ø In many cases, folding is attributed to shearing stresses rather than simple compression.
- Ø It is assumed that in such a process, numerous closely spaced fractures develop in the rock at the first stage of the process.
- Ø This is followed by displacement of the blocks so developed by different amounts so that ultimately the rocks take up folded or bent configuration.
- Ø The folded outline becomes more conspicuous when the minor fractures get sealed up due to subsequent recrystallisation.

Folding Due to Intrusions

- Ø Intrusion of magma or even rock salt bodies from beneath has been found to be the cause of uparching of the overlying strata.
- Ø In magmatic intrusions, highly viscous magma may be forced up very gradually and with considerable force so that the overlying sedimentary host rocks are bodily lifted up to provide space for the rising magma.
- Ø In extreme cases, the magma may even rupture the overlying strata to flow out as lava



Fig. 6.31. A. Folding due to Intrusion; B. Folding due to Salt Plug

Folding Due to Differential Compression

- Ø Strata that are being compacted under load in a basin of sedimentation develop, with passage of time, downward bending especially in the zones of maximum loading.
- Ø If the strata in question is not homogeneous, the bending may not be uniform in character and results in warping or folding of different types.
- Ø Such folds are, however, totally dependent on the load from above and are attributed to superficial causes.
- Ø These are, therefore, non- tectonic folds.

ENGINEERING CONSIDERATIONS

- Ø Folds developed in the areas of work are important for a civil engineer in that these make his work more complicated.
- Ø If these structures are not thoroughly investigated and properly interpreted, any civil engineering project standing on or driven through the folded rocks may prove not only uneconomical in the ultimate analysis but also, unsafe as well.
- Ø Due consideration is, therefore, always to be given to the presence of folds in deciding about the designing and construction of such structures as driving of traffic and hydropower tunnels, selection of sites for dams and reservoirs and in fixing the alignments of roads, bridges and highways.

Change in Attitude

- ∨ Folding of any type would cause a change in the attitude (dip and strike) of the

same strata in the aerial extent and also in depth.

- ✓ Hence same layers may be repeated along an alignment or one or more different layers may be unexpectedly encountered.
- ✓ If it happens so and the unexpectedly repeated or encountered layers are of undesirable nature, the project costs may be effected as also the time schedule and safety of the project.

Shattering of Rocks.

- ✓ The stresses are often strong enough to break or shatter the rocks, especially in the axial zones, which are the places of maximum concentration of these forces.
- ✓ hence, in folded rocks, axial regions are likely to be the areas containing fractured zones.
- ✓ This effect is of utmost importance because shattered rocks become:
 - weak in strength parameters of all types;
 - porous and pervious in character;
 - ✓ Axial regions in the folded rocks should be thoroughly studied and if possible, should be avoided for other better alignments or sites as the case may be.
 - ✓ If it is not possible to avoid them, these areas must be subjected to suitable processes of rock treatment for developing in them desired qualities of strength and imperviousness.

Strained Nature.

- ✓ All the stresses that have acted on the rocks during their folding are generally absorbed by these rocks by undergoing strain.
- ✓ In essence, the folded rocks are considerably strained, the magnitude of strain varying from point to point in the folded sequence.
- ✓ Now, as and when there is an effort by nature or by the engineer to disturb this adjustment of the rocks to the stresses, the rock may respond by release of some strain energy.
- ✓ Enough stored strain energy is released as soon as (or soon after) the excavations are made and huge blocks of rocks start caving in or falling with great force called the rock bursts.
- ✓ This often involves fatal accidents besides causing considerable delay in the progress of the work.
- ✓ A proper planning of the work in folded areas is, therefore, of utmost importance to avoid these possible hazards in construction work.

5. Explain about FAULT & FAULTING ?

Ø Those fractures along which there has been relative movement of the blocks past each are termed as **FAULTS**.

Ø The entire process of development of fractures and displacement the

blocks against each other is termed as

FAULTING CLASSIFICATION OF FAULTS

Following factors are more commonly considered important in classification of faults:

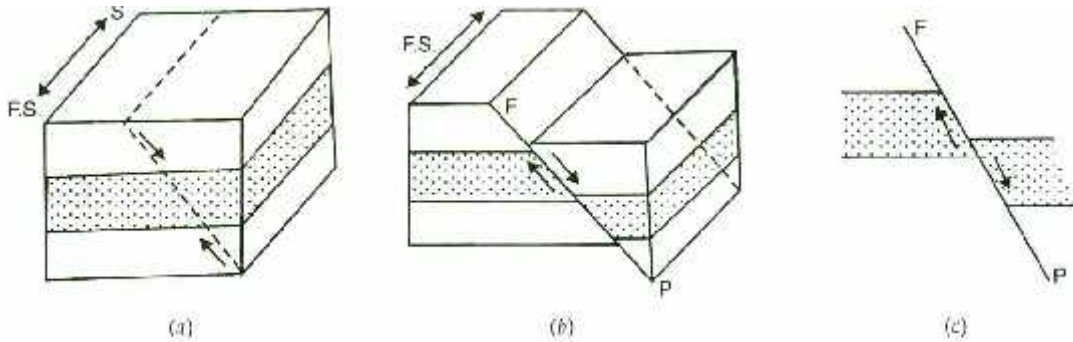
- ✓ The apparent movement of the disrupted blocks along the fault plane;
- ✓ The direction of slip;
- ✓ The relation of fault attitude with the attitude of the displaced beds;
- ✓ The amount of dip of the fault;

∨ Mode of Occurrence.

Three fundamental types of faults are commonly distinguished on the basis of apparent movement: normal faults, reverse faults and strike slip faults.

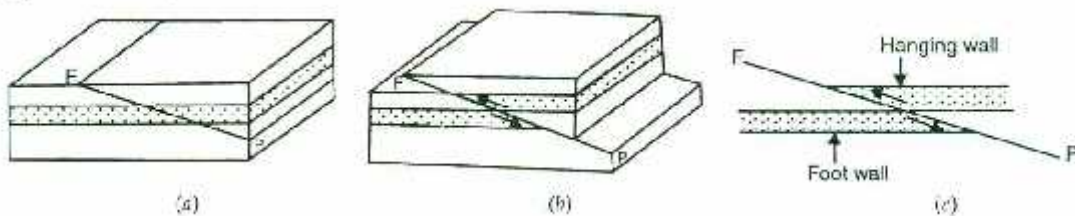
Normal Faults

- ∅ Such a fault in which hanging wall has apparently moved down with respect to footwall is classified as a Normal Fault.
- ∅ In this definition it is clearly implied that nothing can be said with certainty whether it was the hanging wall which moved down or the foot wall which moved up or both the walls moved down, the hanging wall moving more than the foot wall and hence the appearance.
- ∅ when the fault satisfies the definition of hanging wall standing at a lower position with respect to the footwall it may be classed as a normal fault.
- ∅ In normal faults, the fault plane may be inclined at any angle between horizontal and vertical, but most commonly, the fault angles are between 45 and vertical.
- ∅ further, due to the inclined nature of the fault plane and downward displacement of a part of the strata, normal faults cause an extension in the crust wherever they occur.



Reverse Faults

- ∅ It is such a type of fault in which the hanging wall appears to have moved up with respect to the footwall.
- ∅ In reverse faults, the fault plane is generally inclined between horizontal and 45 degrees although reverse faults with steeply inclined fault surface have been also encountered.
- ∅ By virtue of their inclination and direction of movement, reverse faulting involves shortening of the crust of the Earth (compare with normal faults).

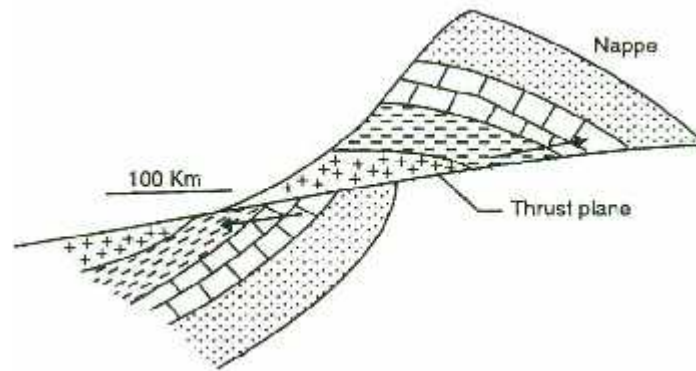


Thrust Faults

- ∅ These are, broadly speaking, such varieties of reverse faults in which the hanging wall has moved up relative to the footwall and the faults dip at angles below 45 degrees.
- ∅ The thrust faults or simply thrusts are of very common occurrence in folded mountains and seem to have originated as a further step in the process of adjustment of rocks to the imposed stresses.
- ∅ Thrusts are sometimes further distinguished into two sub-types: the over thrusts and the under thrusts.

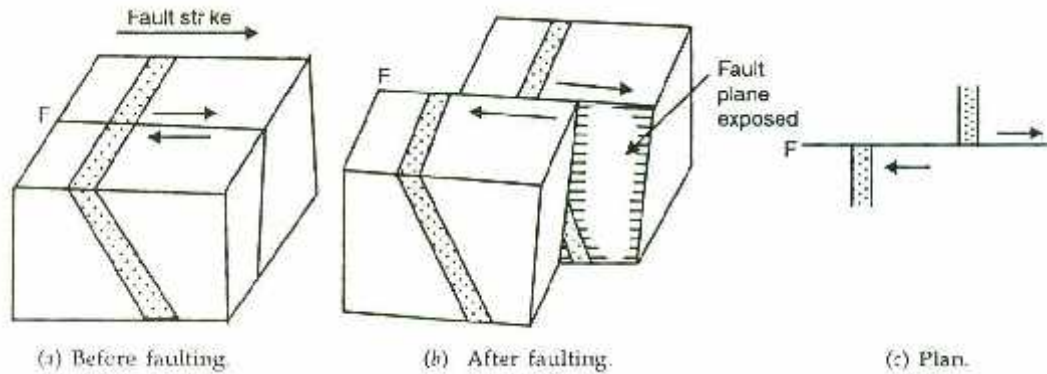
Nappes

- ∅ This term is used for extensive blocks of rocks that have been translated to great distances, often ranging to several hundred kilometers, along a thrust plane.
- ∅ The large-scale movement maybe attributed to a major over thrusting or a recumbent folding followed by thrust faulting.
- ∅ When a series of thrust faults occur in close proximity, thrust blocks are piled up one above another and all fault surfaces dip in the same direction, the resulting interesting structure is known as an imbricate Structure.



Strike-Slip Faults

- ∅ These may be defined as faults in which faulted blocks have been moved against each other in an essentially horizontal direction.
- ∅ The fault plane is almost vertical and the net slip may be measured in great distances.
- ∅ There are some other terms used for strike slip faults such as lateral faults, transverse faults, wrench faults and transform faults.
- ∅ Of these, the transform faults are very common and denote strike slip faults specially developed in oceanic ridges.



ENGINEERING CONSIDERATIONS

- Ø The safety of a civil engineering structure built on or near a faulted rock can be ascertained only in a general way.
- Ø The tectonic history of the area under consideration must be known (or studied if not known) thoroughly.
- Ø Faults of any significance are always associated with earthquakes.
- Ø So, such a study would virtually mean obtaining information about frequency of the earthquakes as also their magnitude and effects that they have left from time to time on the rocks of the region.
- Ø The exact position of the area of construction with respect to the seismic zoning of the country must be thoroughly established.
- Ø Even if the evidence collected from the study of the tectonic history of the area leads to the conclusion that no movement may be expected in the rocks of the area during the projected life span of the structure raised on them, some factor of safety must be introduced into the design of the structure, especially in the big projects in faulted areas, so that if the unexpected happens, there is minimum loss to the project.
- Ø In all big countries, maps of seismic classification are available.
- Ø In most cases recommendations of the statutory authorities are available about introducing suitable factor of safety in major civil engineering projects of any public importance that are proposed to be constructed in areas of known seismic zones.

6. Briefly explain JOINTS AND JOINTING ?

Terminology

- Ø Joints are defined as divisional planes or fractures along which there has been no relative displacement.
- Ø These fractures divide the rocks into parts or blocks and unlike the faults, the parts have not suffered any movement along the fracture plane.
- Ø There may be or may not be an opening up of blocks perpendicular to the joint planes.
- Ø Nature. Joints may be **open or closed** in nature.
- Ø **Open joints** are those in which the blocks have been separated or opened up for small distances in a direction at right angles to the fracture surface.

- ∅ These may be gradually enlarged by weathering processes and develop into fissure in the rocks.
- ∅ In **closed joints**, there is no such separation.
- ∅ Even then, these joints may be capable of allowing fluids (gases and water) to pass through the rock
- ∅ Similarly, the joints may be smooth or rough on the surface and the surface may be straight or curved in outline the joints may be small in their extension

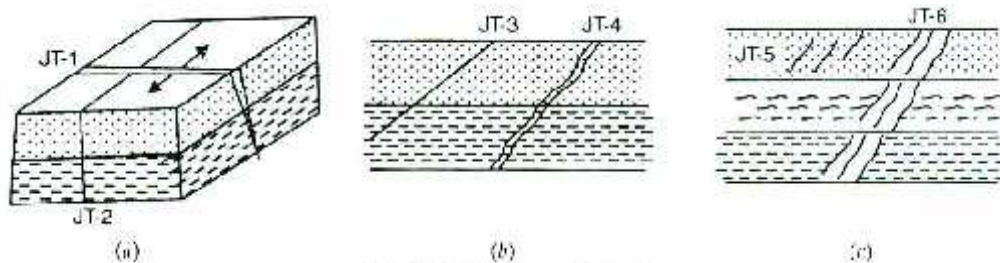


Fig. 7.26 Nature of Joints

JT-1, Open joint JT-2, Closed joint,
 JT-3, Smooth joint JT-4, Rough joint,
 JT-5, Small joint JT-6, Master joints

Attitude

- ∅ Joints are fracture planes or surfaces and their occurrence often takes place in such a way that their position in space or attitude (dip and strike) may be described conveniently either independently or with respect to the attitude of the rocks in which they occur.

CLASSIFICATION

- ∅ Joints have been classified on the basis of spatial relationships, geometry and genesis.

A. Spatial Relationship

All joints are divided into two main groups on the basis of presence or otherwise of some regularity in their occurrence:

1. Systematic joints (regular joints).

- ∅ These show a distinct regularity in their occurrence which can be measured and mapped easily.
- ∅ Such joints occur in parallel or sub-parallel joint sets that are repeated in the rocks at regular intervals.
- ∅ The columnar joints and the mural joints described below are examples of regular or systematic jointing.

2. Nonsystematic (or irregular) joints.

- ∅ As the name implies, these joints do not possess any regularity in their occurrence and distribution.
- ∅ They appear at random in the rocks and may have incompletely defined surfaces. In many cases these are related to the systematic joints in that these occur between them.
- ∅ At other times, the non-systematic joints may show no relationship with the

systematic joints and their curved and rough surfaces may even cut across the former.

B. Geometry

In stratified rocks, joints are generally classified on the basis of relationship of their attitude with that of the rocks in which they occur.

Three types recognized on this basis are :

Strike joints in which the joint sets strike parallel to the strike of the rocks.

Dip joints in which the joint sets strike parallel to the dip direction of the rocks;

Oblique joints are those joints where the strike of the joints is at any angle between the dip and the strike of the layers. These are also called diagonal joints when they occur midway between the dip and strike of the layers.

C. Genesis (Origin)

In such cases, joints are classified into one of the following genetic types:

Tension joints are those, which have developed due to the tensile forces acting on the rocks. The most common location of such joints in folded sequence is on the outer margins of crests and troughs. They are also produced in igneous rocks during their cooling. Joints produced in many rocks during the weathering of overlying strata and subsequent release of stresses by expansion are also thought to be due to the tensile forces (Fig. 7.31).

Shear joints. These are commonly observed in the vicinity of fault planes and shear zones where the relationship with shearing forces is clearly established (Fig. 7.32). In folded rocks, these are located in axial regions.

Compression joints. Rocks may be compressed to crushing and numerous joints may result due to the compressive forces in this case. In the core regions of folds where compressive forces are dominant, joints may be related to the compressive forces.

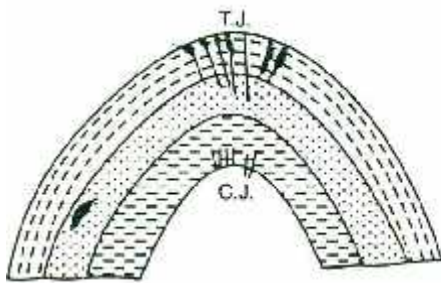


Fig. 7.31 Tension Joints (T.J).

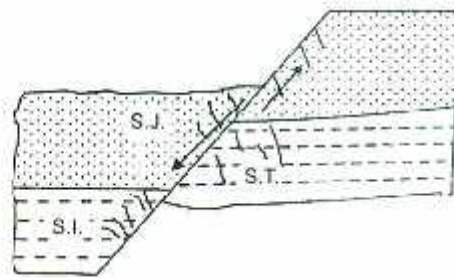


Fig. 7.32 Shear joints (S.J) and Compression Joints (C.J).

5. BRIEFLY EXPLAIN ABOUT GEOPHYSICAL INVESTIGATIONS ?

A. Electrical Methods

Principle.

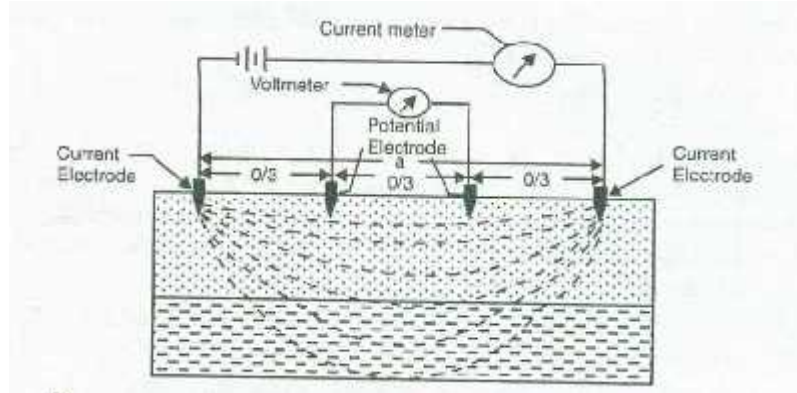
- Ø All electrical method are based on the fundamental fact that different materials of earth's crust possess widely different electrical properties.
- Ø Resistivity, electrochemical activity and dielectrical constant are some of these properties that are generally studied through these methods
- Ø potential-drop methods: the natural potential may be due to electrochemical reactions between the solutions and the surrounding - subsurface rocks.
- Ø These reactions are not always of the same order throughout the dimensions of the rock masses thereby creating a potential difference and conditions for flow of

current from one end to the other end.

- ∅ Elongated ore bodies of magnetite and pyrite etc. are easily delineated by this method.
- ∅ Natural electrical potential is measured with the help of nonpolarising electrodes along definite directions and results are plotted in terms of potential gradient along horizontal distances which are then interpreted.

Potential Drop Methods.

- ∅ These include a variety of methods in which electrical current is artificially introduced from an external source at certain points and then its flow through subsurface materials recorded at different distances.
- ∅ In the Equipotential Method two primary electrodes are inserted into the ground, 6-7 meters apart from each other, across which current is introduced.
- ∅ The position of these primary electrodes remains fixed in the subsequent investigations.
- ∅ Potential between these primary electrodes is determined with the help of two search electrodes and points of equal potential found out along the entire region under investigations, which are jointed to get equipotential lines.



- ∅ Under normal conditions, that is, when the material below is of uniform nature, electrically equipotential lines would be regular in character.
- ∅ But in cases when the material is not of uniform character (that is, it contains patches of high or low conductivity), equipotential lines would show clear distortions or irregularities which would include probable location of rock masses of different characteristics.
- ∅ The Resistivity Method is similar to equipotential method but in this case it is the resistivity of the material of the subsurface which is determined and from which important interpretations are made
- ∅ Here also, a known current is introduced through two electrodes- current electrodes, which are inserted at some distances apart from each other.,

$$\rho = 2\pi \frac{d \cdot v}{I}$$

Investigation.

- ∅ The depth of penetration of electrical current in these investigations is broadly equal to although there are many conditions attached to this generalization.
- ∅ The resistivity method envisages interpretation of the qualitative as well as quantitative characters of the subsurface materials which are governed by two basic principles
 - (i) If material below is of uniform nature, the resistivity values would be of regular character.
 - (ii) If the material is non-uniform, that is, it consists of layers or masses of different character, then these would be indicated by irregularities or anomalies in the resistivity values.
 - (iii) The depths at which these anomalies occur can be calculated and also the nature of the subsurface material broadly understood.

Applications:

(a) In Prospecting: The electrical methods have been successfully employed in delineation of ore bodies occurring at shallower depths. For such surveys at great depths, these are not of much help.

In table 1, some typical value-ranges of resistivity are given. As may be seen, rocks exhibit a great variation ranging from as high resistivity as $> 10^6$ ohm-meters in igneous rocks to as low as less than 1 ohm-m for clayey mans.

In Civil Engineering: Resistivity methods have been widely used in engineering investigation for determination of

Depth to the bed rock —as for instance, in important projects like dams, buildings and bridge foundations, where it would be desirable that the structure should rest on sound hard rocks rather than on overburden or soil

Location of geological structures —like folds, buried valleys, crushed and fractured zones due to shearing and faulting.

Location of Aquifers —and other water bearing zones which could be easily interpreted on the basis of known resistivity values of moisture rich rocks and dry rocks.

SEISMIC METHODS**Principle.**

Shocks or explosions within the earth's crust are always accompanied by generation of elastic waves, which travel in all directions from the point or place of shock, the focus.

Velocity of these shock waves is related to the nature of the medium through which they travel. In nature these waves are produced during earthquakes. The

seismic waves reveal a great deal of information about the internal constitution of the earth.

Although different types of waves are generated when a shock occurs, these are the P waves (longitudinal waves), which are the fastest and strongest. Their velocity, V_p , is related broadly to the medium (rocks) through the following equation:

$$V_p = \left[E \cdot \frac{(1 - \nu)}{e(1 + \nu)(1 - 2\nu)} \right]^{1/2}$$

where E is Modulus of elasticity, e is density and ν is the Poisson's Ratio of the medium.

The controlling factor is, obviously, the modulus of elasticity which itself is dependent upon nature of rock, its chemical and mineralogical composition, degree of freedom from structural discontinuities and degree of saturation with water and other fluids.

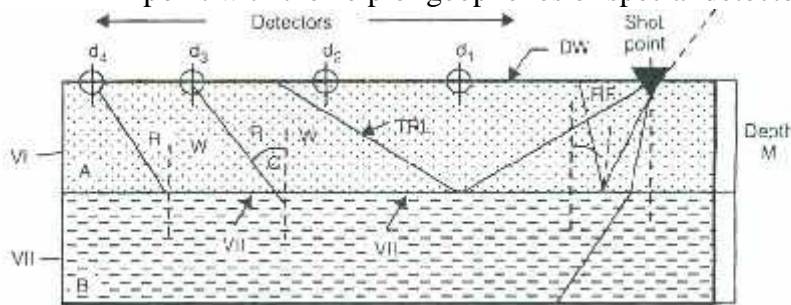
From experimental investigations, characteristic velocity values for P waves have been broadly established for different rock types.

As such, if the velocity of seismic waves travelling through a section of the ground is known, nature of the ground can be fairly assessed.

This is the underlying principle of all the seismic methods.

Method.

- ∅ The fundamental procedure in all seismic investigations for subsurface explorations is the same: a shock is created at a chosen point or location either by exploding a charge, or dynamite;
- ∅ the waves so produced are recorded at different distances from the shot point with the help of geophones or special detectors.



- ∅ The instant of shot, that is the shot time and the first arrival are recorded very carefully from which time — distance plots are prepared in a selected manner.
- ∅ A proper interpretation of these time-distance plots may reveal presence of unusually high or low velocity media at certain depths.
- ∅ Reflection methods have been found especially useful for subsurface studies under! bodies of water (e.g. lakes, rivers, and estuaries) because in such surveys signals from surface and shear waves are obliterated by water and arrival times of only longitudinal waves are recorded clearly

and easily.

- ∅ It may be pointed out that for correct inferences, it is imperative that reflection and refraction records are properly distinguished from each other as well as from records of other associated events.
- ∅ These demand considerable skill and expertise.

6. EXPLAIN ABOUT GRAVITATIONAL METHODS ?

Principle Gravity or the force by which the earth attracts other objects towards itself is a well-known principle in Physics. It can be theoretically calculated for any part of the earth from the relationship:

$$g = 978.049 (1 + 0.0052884 \sin^2 \theta - 0.00059 \sin^2 \theta)$$

where g is the normal gravity value at sea level and θ is the latitude of the place under consideration.

- ∅ In these calculations it is assumed that the earth is ideally homogenous in nature. Actually, however, the earth is far from homogenous.
- ∅ Thus, we have another means to locate the materials which are 'less' or 'more' dense than the ideal material of the earth.
- ∅ Procedure is simple: for any given area, we would know its latitude and thus calculate the value of normal gravity (the theoretical value).
- ∅ Then observations are made with sensitive instruments to determine the actual value of gravity at that place.
- ∅ This is called observed value. Under ideal conditions the two values should be identical but when there is considerable difference, a gravity anomaly is believed to exist and that would be a pointer towards existence of some unusual rock mass below the place of gravity anomaly.
- ∅ The unit for gravity is gal, which is acceleration of 1 cm/sec/ sec and that of gravity anomaly a milligal (which is a thousandth part of a gal).

Methods.

- ∅ A number of methods and instruments are available to determine the value of gravity.
- ∅ The earlier used pendulum method and the torsion balance method are almost obsolete now.
- ∅ The gravimetric method is most commonly used at present. In this method, the value of gravity is measured directly by instruments known as gravimeters.
- ∅ Two important versions of these instruments are: the stable gravimeter and the unstable gravimeter.

In the stable gravimeter,

- ✓ the spring in the gravimeter remains unchanged in its position if the gravity pull is same.
- ✓ when there is a change in the value of gravity at a place, there is a change in the length of the spring: it increases or decreases compared to original length.
- ✓ With the help of an external element, the spring can be made to acquire the original position and thereby indicate the amount of change.

In the unstable type

- ✓ the spring once disturbed due to change in gravity at the place of measurement is not brought back to the balanced state there and then.
- ✓ instead its deflections are recorded directly on a suitable magnified scale, which give a measure of gravity anomaly.
- ✓ Isogams or lines passing through points of same gravity anomaly are drawn as a result of gravimetric observations which could be then interpreted to reveal important conclusions.

6. EXPLAIN ABOUT MAGNETIC METHODS ?**Principle.**

These include some of the oldest geophysical methods of exploration and take into account the fact the earth is a gigantic magnet with definite magnetic field, the intensity of which can be calculated for any part of the earth.

But, as the earth is not ideally homogenous, the theoretical values of magnetic intensity may be quite different (higher or lower) than the values observed at given locations.

The difference between these two values is a magnetic anomaly (compare gravity anomaly) and forms the basis for interpreting bodies of magnetic ores and also such structures that can cause magnetic “highs” or “lows”.

Method.

- Ø The magnetic intensity of rocks of earth at a given location is measured directly by very sensitive instruments called magnetometers.
- Ø specially designed magnetometers are used for measuring horizontal intensity or vertical intensity.
- Ø These observations are repeated in different directions over the selected area, and from the values so obtained, the magnetic anomalies are calculated.
- Ø Lines are then drawn through the points of similar anomalies.
- Ø This gives the isoanomalies map.
- Ø From such maps the location and extension of materials of highly magnetic or less magnetic bodies can be determined.
- Ø Another instrument for measuring the magnetic intensity over wider areas in the shortest possible time is Airborne Magnetometer.
- Ø It consists of a highly sensitive detector element that is made to hang down from a plane or helicopter.
- Ø This helps in recording total magnetic intensity along the line of flight
- Ø The lines of flight, the height of flight and speed of the plane are controlling parameters which require very careful planning and execution of the aerial magnetic surveys.

Interpretation

- Ø In the simplest cases, an unusually high magnetic intensity as shown by the isoanomaly map can be taken as indicative of a magnetic ore body in that area.

- Ø In actual practice, however, a number of factors have to be considered and corrections applied for arriving at reliable results. Of these, corrections due to magnetic storms are quite important.

Applications. The magnetic methods have been successfully used in prospecting for magnetic ore bodies and for oil exploration.

ACOUSTIC METHODS

- Ø This method has been specially useful in locating weathered zones, caves and major and minor cavities in rocks of susceptible compositions in the foundations.
- Ø In this method these are the sound waves which are transmitted in a controlled manner from the boreholes through the bodies of rocks and their transmission velocities recorded.
- Ø The acoustic wave velocity sketches are prepared for the site from which the size and position of caves can be interpreted.
- Ø The acoustic surveys are reliable when the site is made up of broadly homogenous rocks and the wave transmission velocities are recorded very carefully.

UNIT-5**GEOLOGICAL INVESTIGATIONS IN CIVIL ENGINEERING**

1. Define remote sensing.

Every object on earth emits its own internal energy according to its molecular and atomic structure, in addition to reflecting sun light during the day time. This radiations being registered by sensors in several wavelengths, including those in the infrared and microwave regions of the spectrum. When such sensors are installed on aircrafts or on satellites they can record the earth's objects from far off distances.

Such distant (**acquisition of information about the objects on the earth's surface is known as remote sensing**)

2. What is meant by aerial photography & Imageries.

The photographs of the earth taken from aircrafts are called the aerial photographs; the pictures taken from the satellites are called the imageries.

3. Define aerial photographs.

Aerial photographs of the region are taken by cameras placed in the aircrafts. Aerial photos give three dimension of the photographed area. These photos contain a detailed cord of the ground at the time exposure.

4. Define satellite imageries.

The satellite imageries can either be read manually like aerial photographs, or with the help of computers.

5. What is meant by geographic information system?

The modern computers can process maps and data with suitable computer programmer. The process of integrating and analyzing various types of data with the help of computer is known as geographic information system.

6. What are applications of remote sensing?

General geological mapping, mineral prospecting, petroleum exploration, ground water exploration, engineering .uses of site rocks, disaster studies, coastal geological studies.

7. What are geological considerations involved in the construction of buildings.

Basic requirements of a building foundation, building foundation on soils, building foundation carried to the deep hard rocks, building founded on surface bed rocks, types of settlement in buildings.

8. What are the characteristics of air photos?

Shape, size, flight, photo data and scale.

9. What are the kinds of air photos?

Vertical air photos, oblique air photos, anusaics ,hotostrrips, stereoprain.

10. Define stereo meter

The instrument is used under a mirror stereoscope for measuring heights and areas of objects from air photos.

11. What is meant by measuring dots?

A stereo meter consists of two small transparent glass or plastic plates attached to a long metallic bar. A clear dot is etched on each of the plates called "measuring dots".

12. Define land slide.

A land slide is a slow or sudden downhill movement of slope-forming rock and soil materials under the force of gravity.

13. Places in which land slides occur.

They occur in hill valley slopes, sea coasts, river banks and bends, on the slopes of volcanic cones and in earthquake-prone areas. They also occur under water as on lake or sea floor.

14. What are the classifications of land slides?

Presence or absence of a definite slip plane, materials involved and their water content, kind and rate of movement.

15. What are the parts of atypical slides

Crown, scarp, head, slip plane, flanks, transverse ridges, foot, toe, length, width, height, depth.

16. What are the types of land slides?

(1) Slides:

Translational, Rotational

(2) Falls

(3) Flows

Slow, Soil creep, Rock creep

(4) Complex slides.

17. What are the characteristics of land slides?

1, Steep scarps in their upper parts and irregular ridges and furrows at lower parts.

2, Land slides vary in extent from several square meters to several kilometers. Its thickness may be several meters.

3, Land slide velocities range from very small movement to more than 100 km/h.

18. What are the causes of land slides?

a) Natural causes.

1, Internal factors.

2, External factors.

b) Man-induced causes.

19. What are the Geological considerations involved in Road cutting?

a. Topography

b. Lithological characters

c. Structural features of the rocks

d. Ground water conditions

20. What are the structural features of tunnel sites?

- a. Dip and strike
- b. Folds
- c. Faults
- d. Joints.

16 MARKS QUESTIONS AND ANSWERS

1.GEOLOGICAL CONDITIONS NECESSRY FOR CONSTRUCTION OF DAMS

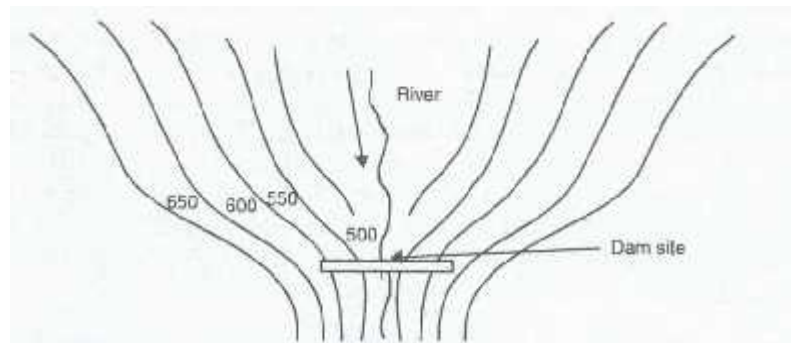
DEFINITION ?

- Ø A DAM may be defined as a solid barrier constructed at a suitable location across a river valley with a view of impounding water flowing through that river. (1) generation of hydropower energy;

SELECTION OF SITES

Topographically

- Ø It would be a narrow gorge or a small valley with enough catchments area available behind so that when a dam is placed there it would easily store a calculated volume of water in the reservoir created upstream.
- Ø This should be possible without involving significant uprooting of population, loss of cultivable land due to submergence or loss of existing construction.



Technically

- Ø The site should be as sound as possible: strong, impermeable and stable.
- Ø Strong rocks at the site make the job of the designer much easy: he can evolve best deigns.
- Ø Impermeable sites ensure better storage inventories.
- Ø Stability with reference to seismic shocks and slope failures around the dam, especially upstream, are a great relief to the public in general and the engineer in particular.
- Ø The slips, slides, and slope failures around and under the dam and susceptibility to shocks during an earthquake could prove highly hazardous.

Constructionally

- Ø The site should not be far off from deposits of materials which would be required for its construction.
- Ø All types of major dams require millions of cubic meters of natural materials — earth, sand, gravel and rock —for their construction.

Economically

- Ø The benefits arising out of a dam placed at a particular site should be realistic and justified in terms of land irrigated or power generated or floods averted or water stored.
- Ø Dams are invariably costly structures and cannot be placed anywhere and everywhere without proper analysis of cost-benefit aspects.

Environmentally

- Ø The site where a dam is proposed to be placed and a reservoir created, should not involve ecological disorder, especially in the life cycles of animals and vegetation and man.
- Ø The fish culture in the stream is the first sector to suffer a major shock due to construction of a dam. Its destruction may cause indirect effects on the population.
- Ø These effects require as thorough analysis as for other objects. The dam and the associated reservoir should become an acceptable element of the ecological set up of the area.

Geological Characters for Investigation**Geology of the Area**

Preliminary geological surveys of the entire catchments area followed by detailed geological mapping of the reservoir area have to be conducted. These should reveal main topographic features, natural drainage patterns, general characters and structures of rock formations such as their stratification, folding and faulting and igneous intrusions, and the trend and rate of weathering and erosion in the area.

Geology of the site**Lithology.**

- Ø The single most important feature that must be known thoroughly at the site and all around and below the valley up to a reasonable depth is the Lithology, i.e. types of the rocks that make the area.
- Ø Surface and subsurface studies using the conventional and latest techniques of geological and geophysical investigations are carried out.
- Ø Such studies would reveal the type, the composition and textures of the rocks exposed along the valley floor, in the walls and up to the required depth at the base.
- Ø Rocks are inherently anisotropic materials, showing variation in properties in different directions.
- Ø Complex lithology definitely poses challenging design problems.

Structures

- Ø This involves detailed mapping of planes of weakness like bedding planes, schistosity, foliation, cleavage, joints, shear zones, faults and fault zones, folding

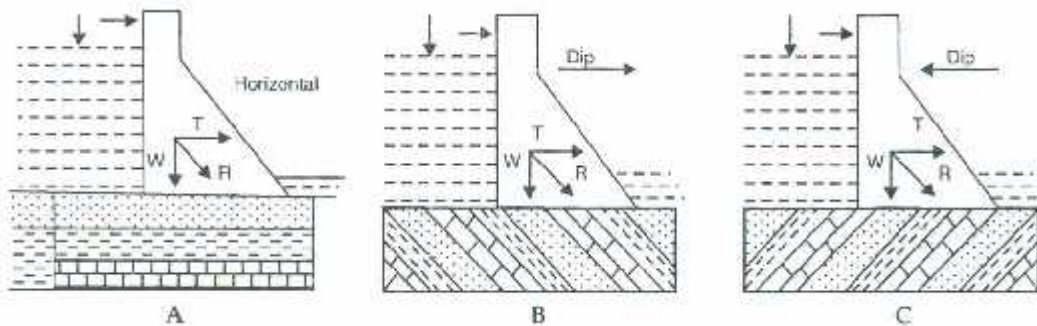
and the associated features.

- Ø While mapping these features, special attention is given to recording their attitude, spacing and nature.
- Ø Shear zones have to be searched, mapped and treated with great caution.
- Ø In some cases, these may be developed to such an extent that the rock may necessitate extensive and intensive rock treatment (e.g. excavation, backfilling and grouting etc.).

Following is a brief account of the influence of more important structural features of rocks on dam foundations

Dip and Strike

- Ø The strength of sound, un fractured stratified rock is always greater when the stresses are acting normal to the bedding planes than if applied in other directions.
- Ø This being so, horizontal beds should offer best support for the weight of the dam.
- Ø But as is shown in a latter section, the resultant force is always inclined downstream.



- Ø the most UNFAVOURABLE strike direction is the one in which the beds strike parallel to the axis of the dam and the dip is downstream
- Ø It must be avoided as far as possible.
- Ø Therefore, other conditions being same, beds with upstream dips are quite favorable sites for dam foundations.

Faults

These structures can be source of danger to the dam in a number of ways. Thus,

- ✓ The faulted rocks are generally shattered along the rupture surfaces;
- ✓ Different types of rocks may be present on either side of a fault plane. Hence, sites with fault planes require great caution in calculating the design strength in various sections of the dam.
- ✓ Dams founded on beds traversed by fault zones and on major fault planes are more liable to shocks during an earthquake compared to dams on non-faulted rocks.

2. TUNNELS

Definition

- Ø Tunnels may be defined as underground routes or passages driven through the

ground without disturbing the overlying soil or rock cover.

Ø Tunnels are driven for a variety of purposes and are classified accordingly.

Ø Chief classes of tunnels are:
Traffic Tunnels
hydro-power tunnels and
public utility tunnels.

Geological Investigations

These determine to a large extent solutions to following engineering problems connected with tunnelling:

Selection of Tunnel Route (Alignment).

There might be available many alternate alignments that could connect two points through a tunnel.

the final choice would be greatly dependent on the geological constitution along and around different alternatives

Selection of Excavation Method.

Tunnelling is a complicated process in any situation and involves huge costs which would multiply manifolds if proper planning is not exercised before starting the actual excavation.

And the excavation methods are intimately linked with the type of rocks to be excavated.

Choice of the right method will, therefore, be possible only when the nature of the rocks and the ground all along the alignment is fully known.

This is one of the most important aim and object of geological investigations.

Selection of Design for the Tunnel.

The ultimate dimensions and design parameters of a proposed tunnel are controlled, besides other factors, by geological constitution of the area along the alignment.

Whether the tunnel is to be circular, D-Shaped, horse-shoe shaped or rectangular or combination of one or more of these outlines, is more often dictated by the geology of the alignment than by any other single factor.

Thus, in self-supporting and strong rocks, either, D-shape or horse-shoe shape may be conveniently adopted but these shapes would be practically unsuitable in soft ground or even in weak rocks with unequal lateral pressure.

Assessment of Cost and Stability.

These aspects of the tunnelling projects are also closely interlinked with the first three considerations.

Since geological investigations will determine the line of actual excavation, the method of excavation and the dimensions of excavation as also the supporting system (lining) of the excavation, all estimates about the cost of the project would depend on the geological details.

Similarly tunnels passing through hard and massive rocks even when left unsupported may be regarded as stable.

Assessment of Environmental Hazards:

The process of tunnelling, whether through rocks or through soft ground, and for whatsoever purpose, involves disturbing the environment of an area in more than one way.

The tunnelling methods might involve vibrations induced through blasting or ground cutting and drilling, producing abnormal quantities of dust and last but not the least, interference with water supply system of the nearby areas.

A correct appreciation of geological set up of the area, especially where tunnel alignment happens to be close to the populated zones, would enable the engineer for planning and implementing plans aimed at minimizing the environmental hazards in a successful manner.

Methods

These stages are:

A. Preliminary Surveys

Following geological characters are broadly established for the entire area in which the tunnel project is to be located as a result of preliminary surveys:

The general topography

The topography of the area marking the highest and the lowest points, occurrence of valleys, depressions, bare and covered slopes, slide areas, and in hilly regions and cold climates, the snow-line.

The lithology

The lithology of the area, meaning thereby, the composition, attitude and thickness of rock formations which constitute the area.

The hydrological conditions

The hydrological conditions in the area, such as depth of water table, possibility of occurrence of major and minor aquifers of simple type and of artesian type and the likely hydrostatic heads along different possible routes or alignments.

The structural condition

The structural condition of the rock, that is, extent and attitude of major structural features such as folding, faulting, unconformities, jointing and shearing planes, if developed.

Existence of buried valleys are also established during the preliminary surveys.

B. Detailed Surveys

Bore-Hole Drilling

bore-hole drilling along proposed alignments and up to desired depths; the number of bore-holes may run into dozens, scores or even hundreds, depending upon the length of the tunnel;

rock samples obtained from bore holes are analysed for their mechanical and geo-chemical properties in the laboratories;

Drilling Exploratory

Drilling shafts and adits, which allow direct approach to the desired tunnel for visual inspection in addition to the usual advantages of drilling;

Driving Pilot Tunnels

Driving pilot tunnels which are essentially exploratory in nature but could better be used as a main route if found suitable by subsequent enlargement.

The actual number of bore holes and shafts and adits and their depth and length are decided by the length and location of the proposed tunnel.

For tunnels with little overburden, these may be driven close to the proposed tunnel.

3. GEOLOGICAL CONSIDERATIONS IN TUNNELLING

Rocks may be broadly divided into two categories in relation to tunnelling:

- ∨ consolidated and
- ∨ unconsolidated or soft ground.

Only a brief accounts is given below.

(A) Consolidated Rocks

Tunnel design, method of its excavation and stability are greatly influenced by following geological conditions: lithology, geological structures and ground water conditions.

Lithology

It has already been mentioned that information regarding mineralogical composition, textures and structures of the rocks through which the proposed tunnel is to pass is of great importance in deciding

- the method of tunneling
- the strength and extent of lining and, thus the
- cost of the project.

Hard and Crystalline Rocks

- ∅ These are excavated by using conventional rock blasting methods and also by tunnel boring method
- ∅ In the blasting method, full face or a convenient section of the face is selected for blasting up to a pre-selected depth
- ∅ These are loaded with predetermined quantities of carefully selected explosives of known strength.
- ∅ The loaded or charged holes are ignited or triggered and the pre-estimated rocks get loosened as a result of the blast.
- ∅ The blasting round is followed by a mucking period during which the broken rock is hauled out of the excavation so created.
- ∅ The excavations in hard and crystalline rocks are very often self supporting so that these could be left unlined and next round of blasting in the new face created is undertaken, ensuring better advance rate.
- ∅ Rocks falling in this group include granites, diorites, syenites, gabbros, basalts and all the related igneous rocks, sandstones, limestones, dolomites, quartzites, arkose, greywackes and the like from sedimentary group and marbles, gneisses, quartzites, phyllites and slates from the metamorphic groups.
- ∅ When any one of these rocks is stressed, such as during folding or fractured as during faulting, tunnelling in these rocks proves greatly hazardous.
- ∅ Rock bursts which occur due to falling of big rock blocks from roofs or sides due to release of stresses or falling of rock block along fractures already existing in these rocks often cause many accidents.
- ∅ **Soft Rocks** This group includes shales, friable and poorly compacted sandstones, chalk and porous varieties of limestones and dolomities, slates

and phyllites with high degree of cleavage and also decomposed varieties of igneous rocks.

- ∅ Their excavation cost, volume for volume, might be lower than those in hard rocks.
- ∅ Hence, temporary and permanent lining becomes necessary that would involve extra cost and additional time.
- ∅ Rocks like clays, shales, argillaceous and ferruginous sandstones, gypsum bands and cavernous limestones have to be viewed specially with great caution during tunnelling
- ∅ **Fissured Rocks** form a category in themselves and include any type of hard and soft rock that has been deformed extensively due to secondary fracturing as a result of folding, faulting and metamorphic changes of shearing type. **(b)**

Geological Structures Dip and Strike

These two quantitative properties of rocks determine the attitude (disposition in space) of the rocks and hence influence the design of excavation (tunnel) to a great extent.

Three general cases may be considered.

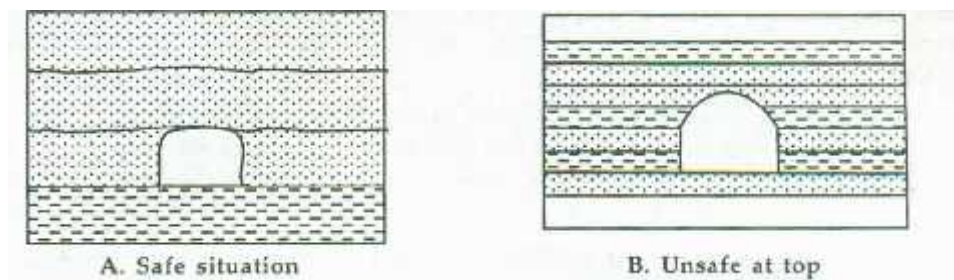
Horizontal Strata

When encountered for small tunnels or for short lengths of long tunnels, horizontally layered rocks might be considered quite favourable.

In massive rocks, that is, when individual layers are very thick, and the tunnel diameter not very large, the situation is especially favourable because the layers would then over bridge flat excavations by acting as natural beams

But when The layers are thin or fractured, they cannot be depended upon as beams; in such cases, either the roof has to be modified to an arch type or has to be protected by giving a lining.

Sides of tunnels, however, could be left unsupported except when the rocks are precariously sheared and jointed.



Moderately Inclined Strata.

Such layers that are dipping at angles up to 45° may be said as moderately inclined.

The tunnel axis may be running parallel to the dip direction, at right angles to the dip

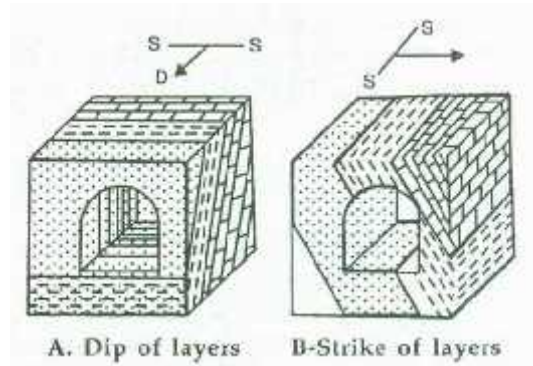
direction or inclined to both dip and strike directions.

In the first situation, that is, when the tunnel axis is parallel to the dip direction the layers offer a uniformly distributed load on the excavation.

The arch action where the rocks at the roof act as natural arch transferring the load on to sides comes into maximum play.

Even relatively weaker rocks might act as self-supporting in such cases. It is a favourable condition from this aspect.

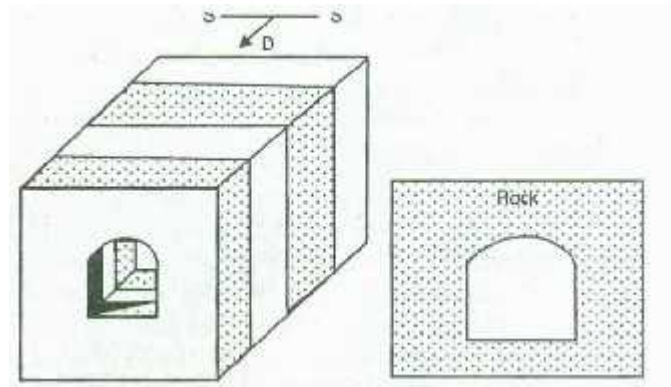
It also implies that the axis of the tunnel has to pass through a number of rocks of the inclined sequence while going through parallel to dip



- ∅ In the second case, that is, when the tunnel is driven parallel to strike of the beds (which amounts to same thing as at right angles to the dip),
- ∅ the pressure distributed to the exposed layers is unsymmetrical along the periphery of the tunnel opening; one half would have bedding planes opening into the tunnel and hence offer potential planes and conditions for sliding into the opening.
- ∅ The bridge action, though present in part, is weakened due to discontinuities at the bedding planes running along the arch
- ∅ Such a situation obviously requires assessment of forces liable to act on both the sides and along the roof and might necessitate remedial measures.
- ∅ In the third case, when the tunnel axis is inclined to both the dip direction and the strike direction, weak points of both the above situations would be encountered.

Steeply Inclined Strata

- ∅ In rock formations dipping at angles above 45° , quite complicated situations would arise when the tunnel axis is parallel to dip or parallel to strike or inclined to both dip and strike directions.
- ∅ In almost vertical rocks for example, when the tunnel axis is parallel to dip direction, the formations stand along the sides and on the roof of the tunnel as massive girders.
- ∅ An apparently favourable condition, of course, provided all the formations are inherently sound and strong



4. Folding

Folds signify bends and curvatures and a lot of strain energy stored in the rocks. Their influence on design and construction of tunnels is important from at least three angles:

Firstly, folding of rocks introduces considerable variation and uncertainty in a sequence of rocks so that entirely unexpected rocks might be encountered along any given direction.

This situation becomes especially serious when folding is not recognized properly in preliminary or detailed surveys due either to its being localized or to misinterpretation.

Secondly, folding of rocks introduces peculiar rock pressures.

In anticlinal fold, loads of rocks at the crest are transferred by arch action to a great extent on to the limbs which may be highly strained

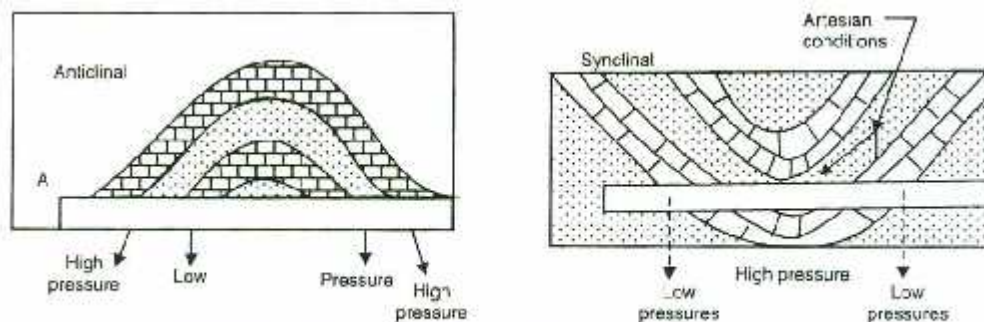
These conditions are reversed when the folds are of synclinal types.

In such cases, rocks of core regions are greatly strained.

Again, the axial regions of folds, anticlinal or synclinal, having suffered the maximum bending are more often heavily fractured.

The alignment of a tunnel passing through a folded region has to take these aspects in full consideration.

When excavations are made in folded rocks, the strain energy is likely to be released immediately, soon after or quite late to tunnelling operations, very often causing the dreaded rock bursts.



A. Anticlinal - low pressure in middle region **B. Synclinal - high pressure in middle region**

Thirdly, folded rocks are often best storehouses for artesian water and also ideal as aquifers.

When encountered during tunnelling unexpectedly, these could create uncontrollable situations.

The shattered axial regions being full of secondary joint systems are highly permeable.

As such very effective drainage measure are often required to be in readiness when excavations are to pass through folded zones.

Faulting

Similarly, fault zones and shear zones are highly permeable zones, likely to form easy avenues for ground water passage.

Inclined fault planes and shear zones over the roof and along the sides introduce additional complications in computation of rock pressure on the one hand and of rock strengths on the other.

This discussion leads to a general conclusion: wherever tunnel is intersected by fault planes or shear zones, it is to be considered as passing through most unsafe situations and hence designed accordingly by providing maximum support and drainage facilities.

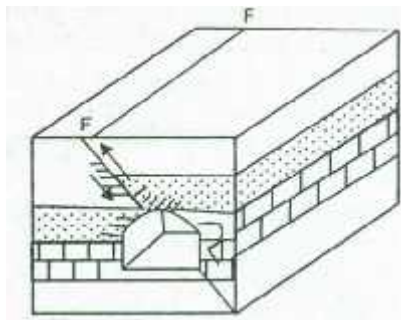
Joint Systems

Joints are cracks or fractures developed in rocks due to a variety of causes. although all types of joints tend to close with depth (due to load of overburden), their presence and orientation, has to be investigated.

Joints are planes of weakness and must always be suspected when the rocks are folded and faulted.

Even originally closed joints may become reactive and open up in the immediate vicinity of tunnel excavation.

Jointed rocks cannot be considered as self-supporting although these might belong to massive



Ground Water Conditions

Determination of ground water conditions in the region of tunnel project is not to

be under-estimated at any cost.

In fact ground water level vis-à-vis tunnel axis is a major factor governing computations of overhead loads on tunnels and also in the choice of method of tunnelling.

Groundwater conditions effect the tunnel rocks in two ways

Firstly, through its physico-chemical action, it erodes and corrodes (dissolves) the susceptible constituents from among the rocks and thereby alters their original properties constantly with the passage of time.

It might have already done much of this type of job when the tunnel is excavated through such water-rich rocks.

Secondly, it effects the rock strength parameters by its static and dynamic water heads.

Such an action may become highly pronounced when an artesian aquifer is actually intercepted by tunnel excavation.

3. BRIEFLY EXPLAIN ABOUT ROADS AND HIGHWAYS ?

Their planning, designing, construction and maintenance are among the major duties of civil engineers the world over.

geological investigations play important role in the design, stability and economical construction and maintenance of the roads.

Such investigations are aimed at providing full details regarding topography of the area, lithological characters of the rocks or soil and the ground water conditions.

Topography

Topography or the landform of a region is single most important factor that controls the selection of alignment of a road project.

Topographic maps would reveal the existence of various land features like valleys and the inflowing streams, the hills and their undulations, the plateaus and the plains with all their varying configuration from place to place.

Obviously, knowledge of all such features is not only important but very essential for a right alignment.

Preliminary surveys, including aerial surveys followed by detailed surveys are often necessary to obtain desired topographical

Lithological Character

Broadly speaking, ground may be divided into two types: consolidated, massive hard rock type and soft, unconsolidated type.

The Massive groups of rocks include all varieties of igneous, sedimentary and metamorphic rocks which can stand even with vertical slopes.

For making roads through them, however, these rocks require extensive blasting operations.

They cannot be simply cut out or dug out, Once cut, especially if they are free from joints and fractures and un favorably inclined bedding planes, these rocks stand erect for year without much maintenance.

The Unconsolidated group presents the engineer many complicated problems. Thorough soil investigations regarding their mode of origin, texture, structures,

porosity, permeability, degree of compaction, consolidation characteristics or compressibility, etc all are required to be known within broad limits to design safe and stable roads over them.

Residual soils are generally homogeneous and properties evaluated from selective bore hole samples might prove sufficient.

Geological Structures

The structural features of rocks, especially in those of sedimentary and metamorphic origin, have very important bearing upon the design of cuts as well as on the stability of the road as a whole.

A given rock might be quite hard and otherwise sound for a cut as road foundation.

But, if in the same rock some planes of weakness (such as bedding planes, joints, foliation, cleavage) are present in such a way that these are inclined towards the free side of the valley, the rock could likely fail along these planes.

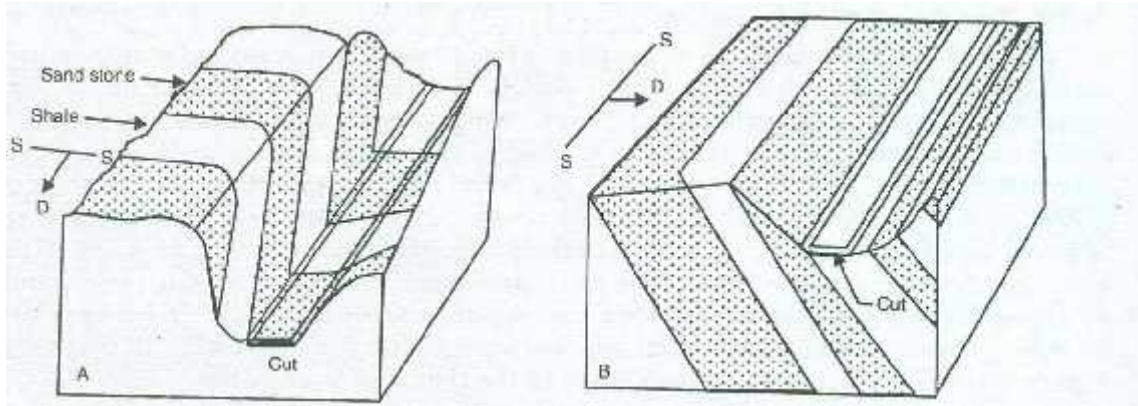
Such structural features include dip and strike, joints, fault planes and shear zones.

Dip and Strike.

There may be three possibilities for making a cut in the inclined beds: it can be made parallel, at right angles or inclined to the dip direction.

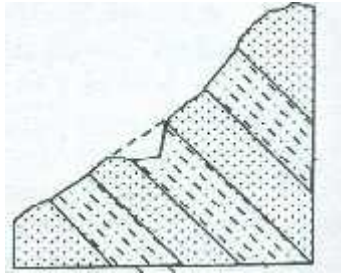
The relative merits of the cut vis-a-vis its stability would be as follows assuming other things are favourable:

Cut is parallel to the dip direction: In such a case, the layers offer a uniform behaviour on either side of the cut and as such the risk of failure is minimal on this account.



Cut is made parallel to the strike, that is, at right angles to the dip direction.

In some cases where the layers dip into the hill rather than in the road, the cut is considered quite stable



Road cut

Cutting Inclined to Dip and Strike:

In such cases also, the parallel to strike.

Beds strata will dip across the cutting and the slope of cutting dip into the hill
Safe. will be unequal on both sides.

Hence such a condition would give rise to similar difficulties as encountered in cuts parallel to strike.

When there is no alternative to cuts either parallel to or inclined to strike (other than at right angles), special measure might become necessary to ensure stability of slopes.

Such measures would include Enlarging of the section of the cutting, particularly on the hillside face, to stable Provision of strong, adequately high retaining walls; Very efficient drainage system to effectively remove water from the affected slopes.

Joints

These influence the stability of the cuts in the same way as the bedding planes When present in great abundance, joints reduce even the hardest rock to a mass of loosely held up blocks on the side of a cut which could tumble down on slight vibrations.

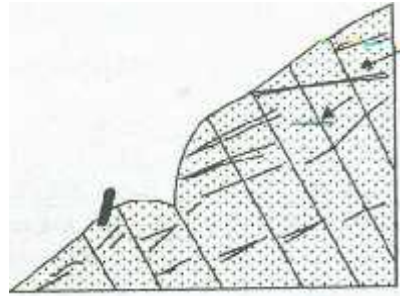
Further, even if the joints are few, but are continuous and inclined towards the free side of the cut, these and inclined towards the free side of the cut, these offer potential surfaces for slips during the presence of moisture.

In major road construction programmes, therefore, jointed rocks have to be provided artificial support by breastwalls and retaining walls for ensuring stability.

Faulting generally leads to the crushing of the rock along the fault planes and shear zones.

Faults Such a condition is, of course, very unfavourable for a cut when it happens to form upper or lower slope or even base of the cut.

It should not be left untreated in any case. These are the worst type of planes of potential failure.

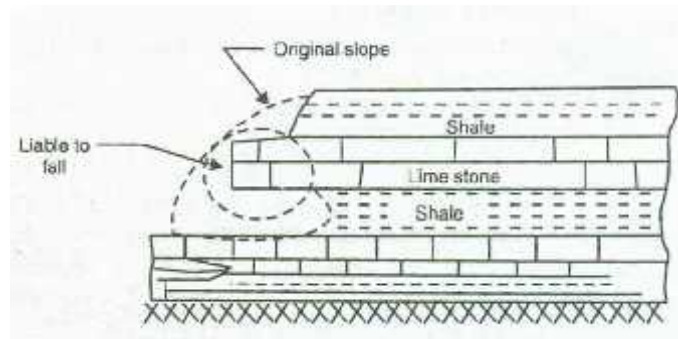


4. Briefly Explain about Weathering ?

In some cases, when the strata along or under a cut is composed of layers of rocks of different hardness, the softer layers get weathered at a faster rate than the overlying or underlying harder rocks.

This generally results in undermining which might cause slips or falls of the whole face.

Sometimes, when the top layers are weathered too heavily, the slope might experience a persistent rock fall or experience debris-fall type of situation from above.



Ground Water Conditions

It is always- necessary to investigate thoroughly the position of water table of the area.

It is quite likely that a water bearing zone (aquifer) might be intersecting the base or slopes of an alignment.

Specific care and design would be required for these natural water conduits.

These are always to be taken as weak and hazardous zones in the road.

It is also known that water exerts important influence on the bearing capacity of the rocks and soil.

Hence when the ground is rich with moisture it would not bear the design loads, unless these properties of ground have also been determined in moist conditions. sometimes there is a condition of free flow of ground-water through the soil.

This is quite dangerous for the stability of the road surface laid above such soil.