ENGINEERING GEOLOGY

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.

REFERENCES: 1. Muthiayya, V.D. “ A Text of Geology”, Oxford IBH Publications, Calcutta, 1969 2. Blyth F.G.H. and de Freitas M.H., Geology for Engineers, Edward Arnold, London, 2010. 3. Bell .F.G.. "Fundamentals of Engineering Geology", B.S. Publications.

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 ENGINERRING

- 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, geochemistery, 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		Allied Branches
Physical geology		Engineering
geology Mineralogy		Mining
geology		Petrology
Geophysics	Structural	geology
Geohydrology		Stratigraphy
Geochemistry Paleontology		
Economic geology		

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 ands 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 earths 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 earths 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 from 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 sedimementary 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, concenteration, properties, uses from 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 ion 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 resitivity 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 $C0_2$, 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:

1) $2CaCO_3 + H_2O + CO_2$ ------------------ 2 Ca $(HCO_3)_2$
2) $CaSO_4 + 2H_2O$ -------------------- CaSO42.H2O

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 earths 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 30^0 to 33^0 to the horizontal.

The gently sloping side lies on the windward side, and makes an angle of about 10 to 15^0
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 minimized.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 form 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 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 acquiclude is an impermeable formation which may contain water but incapable of transmitting significant water quantities. An aquifuge is an impermeable formation neither containing not 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 he geologic formation and are found in sedimentary and igneous rocks. Secondary interstices developed after the rock was formed. Capilary interstices are sufficiently small so that surface tension fo4ces 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) 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 rocks 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 it 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 avalance.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 ferel. 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.

CHAPTER 2

MINERALOGY

2.1 PRE REQUISTE 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 GROPUS:

MINERAL GROU	**EXAMPLES**
Oxides	Quartz, magnetite, haematite, etc
Silicates	Feldspar, mica, hornblende, augite, olivine.et
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.

Iridescene: Some minerals show rainbow colors either in their interior 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 Structur es

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 kindney 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.ie 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 area 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:

Conchodal fracture	-	The broken surfaces shows 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 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 from 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) Orthopyrmaid
iii) Clinopyramid

Form:

The internal atomic arrangement of a mineral is manifested outwardly by development if 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.
iiiCrystalline	-	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 magnetic, whereas few others may be feebly magnetic like spinals 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 efractory 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,crystotallite,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) $CaAl_2Si_2O_8$

VARITIES OF POTASH

FELSPAR: Orthoclase

Sanidine

Microcline

SODA LIME FELSPAR:

Albite

Oligoclase

Andecine

Amarthitie

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

ORTHOPYROXENE: Enstatite ($MgSiO_3$)
Hyperthene [$(Mg,Fe)SiO_3$]

CLINOPYROXENE:

Augite [$(Ca, Na) (Mg, Fe, Al) (Al, Si)_2O_6$] Diopside [$CaMgSi_2O_6$]
Hedenbergite[$CaFeSi_2O_6$]

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

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

TRANSPARENCY: Translucent/opaque

2.7 AMIPHOBLE 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 HORNBLENDE: (COMPOUND-COMPLEX SILICATE)

CRYSTAL SYSTEM: Monoc;inic

HABIT: crystalline
CLEAVAGE:
good(prismatic)
FRACTURE: conchoidal
COLOUR: dark green, dark brown black

LUSTRE: vitreous

HARDNESS: 5 to 6

SPECIFIC GRRAVITY: 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 spilt 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.

S.No	*Mineral*	(%)	*S.No*	*Mineral*	(%)
(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.

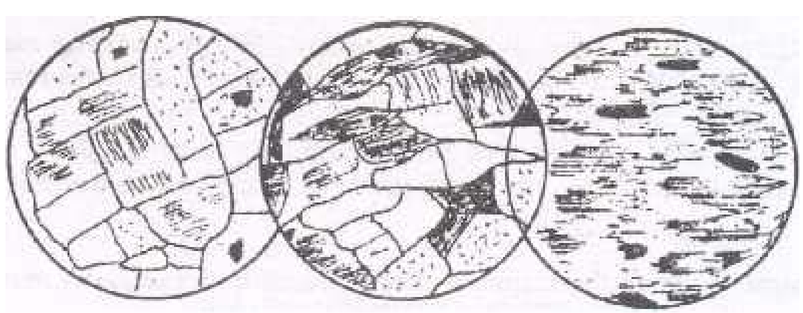
- Ø The term merocrystalline is commonly used to express the intermediate type, *i.e.* when some minerals are crystallized and others are of glassy character in the same rock.
- Ø Rocks with holocrystalline texture are also termed as phaneric and the holohyaline rocks are referred as aphinitic. The term microcrystalline is used for the textures in which the minerals are perceivably 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 ail 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

- Ø All those textures in which majority of constituent crystals of a rock are broadly equal in size are described as equigranular textures.
- Ø In igneous rocks, these textures are shown by granites and felsites and hence are also often named as granitic and felsitic textures
- Ø In the granitic texture, the constituents are either all coarse grained or all medium grained and the crystals show euhedral to subhedral outlines.

- Ø In the felsitic texture, the rock is micro granular, the grains being mostly microscopic crystals but these invariably show perfect outlines.
- Ø Thus felsitic textures may be described as equigranular and panidiomrphic.
- Ø 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 micregranular.

(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.
- Abrupt and discontinuous changes in these textures may result in the formation of the crystals of unequal dimensions.
- Thus, magma crystallizing at great depths may produce well-defined, large sized crystals.
- When the same magma (carrying with it these large crystals) moves upward, the pressure and temperature acting on it are greatly reduced.
- 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

- 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
- And the soluble constituents make up the ground mass crystallizing towards the end.

(3) Directive Textures

- 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 felspar 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 felspar 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.

- Ø 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

- Ø The igneous intrusions that have been injected along or between the bedding planes or sedimentary sequence are known as sills.
- Ø 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.
- Ø The upper and lower margins of sills commo11ly 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;

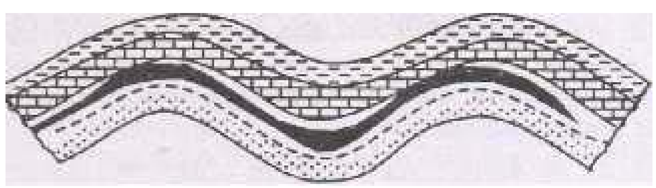
(c) Composite Sills: which result from two or more injections of different types of magma;

(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 arecordant, 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



Lacocothis

- 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 metes 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

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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.
- 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.

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 (Si02) 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 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.

Andesite

Definition.

- 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.

- 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

- 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 alkalifelspars (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 felspars of syenites are orthoclase and albite; microcline, oligoclase and anorthite are also present in them in subordinate amounts.
- In some syenites, the felspathoids (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 felspars (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 felspars 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 felspar,. the second zone is of quartz and felspar, third zone of microcline and fourth of quartz. The central zone is ploymineralic 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 factions 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, felspars 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 Panidiomrphic (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, felspars and olivine.

Types.

- Ø Many types of lamprophyres are distinguished on the basis of the type of felspar and the dark minerals occurring in them.
- Ø Thus, Minette is, a lamprophyre containing felspar orthoclase and the black mica, biotite; Vogesite is another variety having felspar 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)Si04.

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.

Orgin

- 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.

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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 anhydite.

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

- Ø The sediments making the rocks may be of various shapes: rounded, sub rounded, angular and sub angular.
- Ø They may show spherecity to various degrees.
- Ø Roundness and spherecity are the indications of varying degree of transport and abrasion suffered during that process.
- Ø Thus, Breccias are made up mostly of rough and angular fragments indicating least transport and abrasion.
- Ø 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.

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

(v) Fabric of Grains

- Ø A given sedimentary rock may contain many elongate particles.
- Ø Their orientation is studied and described in terms of orientation of their longer axes.
- Ø 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

- Ø In sedimentary rocks of chemical origin, the texture is generally defined by the degree and nature of crystallized grains.
- Ø 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

- Ø It is a mechanically formed sedimentary rock classed as Rudite.
- Ø It consists of angular fragments of heterogeneous composition embedded in a fine matrix of clayey material.
- Ø The fragments making breccia are greater than 2mm average diameter but some times these may be quite big in dimensions.
- Ø 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.
- 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 (gravels> 256mm) Cobble-Conglomerate (gravels: 64-256 mm) Pebble-Conglomerate (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 (SiO_2) 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 felspars, 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-l/2* mm	1/2 mm-1/4 mm	1/4 *mm-l/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 (Si02) 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

  respe
  ctivel
  y.
- 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 O	3%
2	Si02	15%	6	K2 0	3%
3	Al20 3	6%	7		1%
4		2%	8	Na20	5%

Types

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

Residual Shales:

These are formed from decay and decomposition of pr-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 transportedover wide distances before final settlement in basins of deposition.

Hybird Shales

In such shales, materials derived both from clastic sources and non clasticespecially 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 felspars 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.

3.6 LIMESTONES .

Definition

- 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.
- They are formed both bio-chemically and mechanically.

Composition

- Pure limestone is invariably made up of mineral calcite (CaC03).
- 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.
- 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 textureCommon 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 factions 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.

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

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 CaMg(C03h.
- 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 CaC03 and enriching it with MgC03.
- The CaMg(C03h 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.
- 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 CaS04.2H2O.
- 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, CaS04' 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

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

11. Flint and Chert
    - Flint is a dark coloured sedimentary rock of siliceous composition consisting chiefly of halcedony and extremely fine-grained quartz.
    - It occurs commonly as concretions or nodules in chalk (limestone) deposits.
    - Chert is also a sedimentary rock composed of cryptocrystalline silica showing great variety of colours.
    - 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.

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

(b) Replacement.

- 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
    - It is a sedimentary rock of glacial origin.
    - It is characterised by a structure less matrix that has fragments of various sizes, shapes and composition embedded in it.
    - Most of these embedded fragments bear striations and other evidence of their transport by glaciers before their deposition and compaction.
    - The name is derived from the fact the rock is merely a compacted and consolidated form of the glacial debris called till.
    - 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

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

METAMORHISM

METAMORHISM 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 crystalloblastic 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.

3.7.1 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 mineralogicaJ 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, felspar, 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 state 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 felspars 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 sta1'rolite-schists are common examples.

Origin

- Ø Slates and Schists are generally the product of dynamothennal 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 metamophorphic 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 felspars, 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 Felspar 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 pands 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 original 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, felspars, 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 granulose texture but the grain size shows considerable variation in different varieties;
- Ø It varies from finely sachhroidal 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.